



# The North American Mosaic

An Overview of Key Environmental Issues

June 2008



[cec.org](http://cec.org)

This report addresses the state of the environment in the territories of the Parties to the North American Agreement on Environmental Cooperation by providing an overview of key environmental issues. It provides an objective appraisal of environmental trends and conditions to inform the Council's deliberations on strategic planning and future cooperative activities.

This publication was prepared by the Secretariat of the Commission for Environmental Cooperation. The design and implementation of this report benefited from the participation of the State of the Environment Advisory Group, which is composed of environmental reporting experts from the Parties. The views contained herein do not necessarily reflect the views of the governments of Canada, Mexico or the United States of America.

In general, this report does not address the wide variety of responses to the environmental issues described herein. Likewise, an evaluation of the efficacy of these responses is beyond its scope.

More information, including detailed references for the findings in this report, is available on the CEC website: <<http://www.cec.org/soe>>.

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## Preface

The North American Agreement on Environmental Cooperation obliges the Secretariat of the Commission for Environmental Cooperation to “periodically address the state of the environment in the territories of the Parties.” To meet this obligation, the Secretariat has developed this report—*The North American Mosaic: An Overview of Key Environmental Issues*—with the support of environmental reporting experts from the governments of Canada, Mexico and the United States.

This report describes a wide variety of environmental trends and conditions across North America. The breadth and diversity of the subject are astounding: from tiny invasive zebra mussels to global greenhouse gases measured by the teragram; from the last remaining vaquita porpoises to vast expanses of boreal forests and marine ecosystems; from invisible molecules of toxic chemicals to the all-too-visible smog and haze that blanket our cities from time to time.

That said, as the title indicates, this report is an overview. It is not a comprehensive treatment of environmental issues, many of which have been described elsewhere in much greater detail. The assemblage of environmental indicators in this report is far from complete; many measurements are not available at the national level, let alone in comparable forms across North America.

And yet there is value in this depiction of the North American environment. As a mosaic of existing information, this report prompts us to consider the following questions:

- What are the central environmental challenges confronting North America?
- What are the greatest priorities for cooperative action among our three countries to address these environmental challenges?
- How can we measure our progress and create effective feedback mechanisms?
- How can we enhance the relevance of trilateral cooperation through the Commission for Environmental Cooperation?

Over the next year, we will use this report along with other important information to engage the public, subject matter experts and the Parties in a careful evaluation of our progress to date and future opportunities for cooperation. The information assembled in this report is a starting point for discussion.

In some cases, the news is good. As described here and in our annual *Taking Stock* report, releases of many criteria air contaminants and toxic chemicals have declined over time. In other instances, North America

still faces challenges. In the area of climate change, emissions of greenhouse gases continue to increase above 1990 levels here and in the rest of the world as energy use and population expand. Likewise, the cumulative impact of human activities continues to have important repercussions for biodiversity and ecosystem services.

The challenges may seem daunting, but we can meet them with innovation and effective international cooperation. Consider reductions in chemicals responsible for the depletion of the stratospheric ozone layer. In just 15 years, North America reduced the production and use of these harmful substances by almost 97 percent as part of a larger global agreement to shift to substitutes. Recovery of the ozone layer is now expected by the middle of this century based on international cooperation prompted by the 1987 Montreal Protocol and its amendments.

As we begin to craft the Commission’s strategic plan for 2010–2015, our challenge is to identify those environmental issues where sustained environmental cooperation through the Commission can achieve real and important results. Such an effort will benefit the citizens of our three countries and demonstrate North America’s environmental leadership in the world. It is an effort that will repay us with rich dividends.

**Felipe Adrián Vázquez-Gálvez**

*Executive Director*

Secretariat of the Commission  
for Environmental Cooperation





# Climate Change

## Key Findings

- During the last few decades, the earth's climate has been disrupted by the rising temperature of the earth's surface. This global warming very likely stems from increases in atmospheric greenhouse gas (GHG) concentrations produced by human activities.
- In North America, the largest source of GHG emissions is energy-related activities, including electric power generation, transportation and industrial fuel use. Some of these emissions are offset by factors such as forest and agricultural carbon sinks.
- North America is responsible for about a quarter of global GHG emissions.
- Since 1990, North American GHG emissions have increased by almost 18 percent, or at roughly the same rate as total energy use.

*Climate change* refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be caused by natural internal processes or external forcings, or by persistent anthropogenic changes in the composition of the atmosphere or in land use.

## What Is the Environmental Issue?

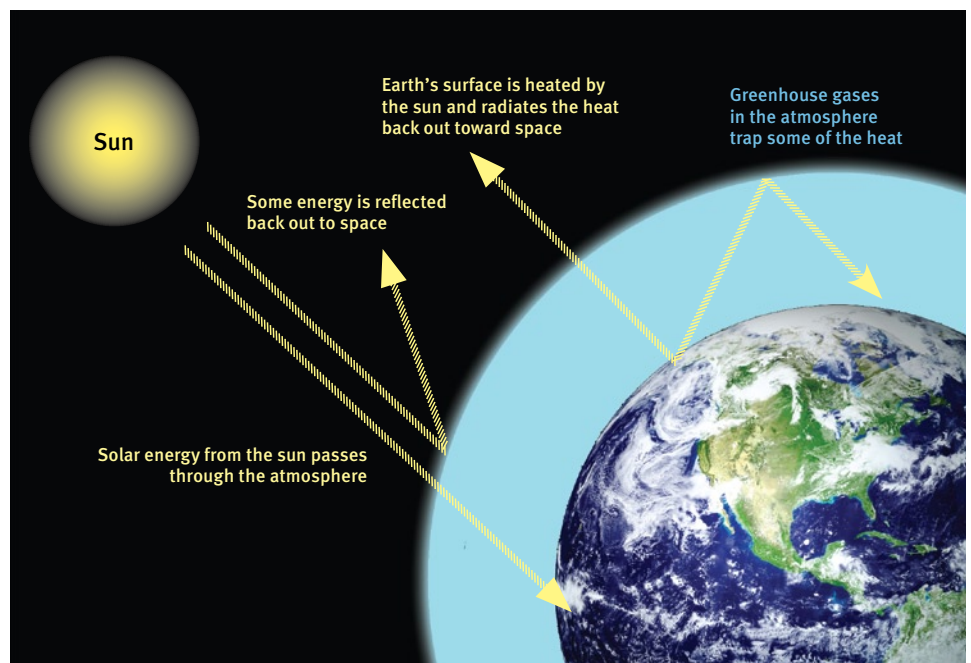
Climate change is any change in climate properties that can be measured statistically (such as mean temperature, precipitation or wind) caused by natural internal processes, external forcings or human activities and lasting decades or longer. The global climate has experienced substantial variability over the history of the planet, but during the last few decades the climate has been disrupted in an unprecedented fashion. This disruption consists of an exceptionally rapid increase in the global average temperatures of the earth's near-surface air and oceans. Unless current

policies and practices change, this warming trend and a variety of associated climate impacts are projected to continue.

## The Greenhouse Effect

Energy from the sun, which arrives mainly in the form of visible light, drives global climate and is the basis for life on earth. About 30 percent of the sun's energy arriving at earth is scattered back into space by the outer atmosphere, but the rest reaches the surface, where it is reflected back in the form of infrared radiation. The eventual escape of this infrared radiation into space is delayed by greenhouse gases such as water vapor, carbon dioxide,

## The Greenhouse Effect



ozone and methane. These gases make up only about 1 percent of the atmosphere, but they act like the glass roof of a greenhouse, trapping heat and keeping the planet warmer than it would be otherwise. Without the natural greenhouse effect, the average temperature at earth's surface would be below the freezing point of water. The natural greenhouse effect is therefore a prerequisite for life on earth.

Human activities are, however, very likely intensifying the natural greenhouse effect. Natural levels of greenhouse gases are being supplemented by emissions of carbon dioxide from the burning of fossil fuels, by the additional methane and nitrous oxide produced by farming activities and changes in land use, and by releases of long-lived industrial gases that do not occur naturally. As a result, global greenhouse gas emissions have grown since preindustrial times—70 percent between 1970 and 2004 alone.

Because of these emissions, global atmospheric concentrations of greenhouse gases have increased markedly and now far exceed preindustrial values. The concentration of carbon dioxide in the atmosphere has reached a record high relative to the last half-million years, and it has done so at an exceptionally fast rate.

### Global Climate Change

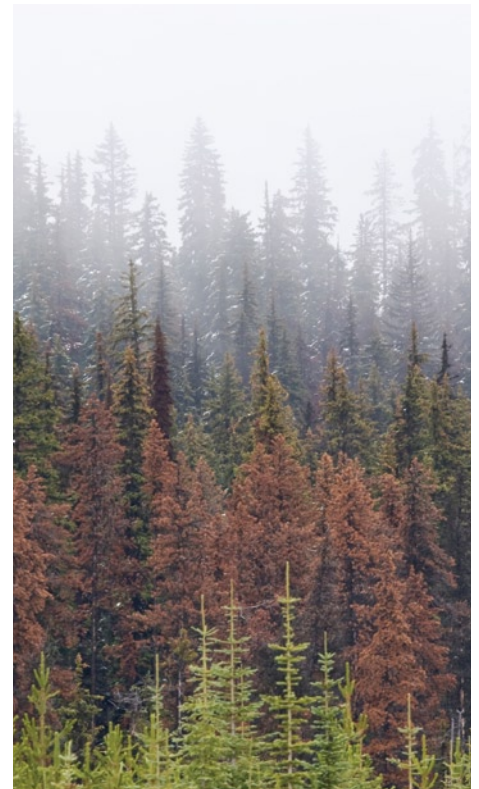
The impact of additional greenhouse gases on global climate is evident in increases in the average global air and ocean temperatures (especially at the higher latitudes), the widespread melting of snow and ice, and the rising average sea level globally. Eleven of the

last twelve years (1995–2006) are among the twelve warmest years since 1850. Over the last 30 years, the Arctic ice pack has shrunk on average each year by an area equivalent to Texas and Arizona combined, and the melting trend is accelerating.

Most of the observed increase in the globally averaged temperatures of the last 50 years is very likely attributable to the observed increase in concentrations of anthropogenic greenhouse gases. Indeed, the human impact on climate greatly exceeds that of known changes in natural processes, such as solar changes and volcanic eruptions. The current global temperatures are warmer than those of at least the past five centuries, perhaps those of more than a millennium. If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms.

### Why Is This Issue Important to North America?

North America is already experiencing locally severe economic damage and substantial ecosystem, social and cultural disruption from weather-related events, including hurricanes, other severe storms, floods, droughts, heat waves and larger and more frequent wildfires. Although climate change does not account for all weather extremes, it exacerbates the risk from these events by affecting the frequency, intensity and duration of extreme climate events and associated natural disasters. The economic damage from the severe weather is grow-



Trees ravaged by insect infestation.

ing dramatically, largely because of the rising value of the infrastructure at risk. The annual costs to North America have now reached tens of billions of dollars in property damage and lost economic productivity, as well as lives disrupted and lost. These patterns of climate change will continue unless the greenhouse gas emissions and the related greenhouse gas concentrations in the atmosphere that are causing global warming are substantially reduced.

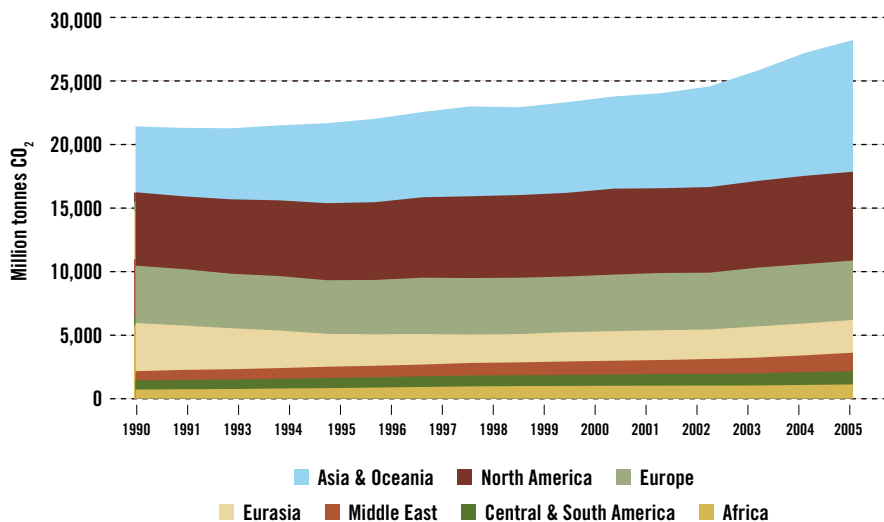
### Greenhouse Gas Emissions in North America

Home to some 7 percent of the world's population, North America is responsible for 25 percent of the total emissions of the most important greenhouse gas, carbon dioxide (see graph). Per person, North America emits twice as much carbon dioxide as Europe, over five times as much as Asia, and over 13 times as much as Africa. Per capita emissions are several times higher in Canada and the United States than in Mexico. These high rates are a result of higher per capita levels of economic activity, which drive greenhouse gas emissions, especially those related to energy consumption.

### Sources of Emissions

Since 1990, North American greenhouse gas emissions have increased by almost 18 percent (see graph)—or at roughly the same rate as total energy use, but more slower than the

Worldwide carbon dioxide emissions



Worldwide carbon dioxide emissions, 1990–2005. Source: US Energy Information Administration.

overall gross domestic product. Without significant advances in energy efficiency and productivity over this period, this rate would have been even higher.

Similar to the global picture, carbon dioxide constitutes over 80 percent of total greenhouse gas emissions in North America. The largest source of that gas, and of overall greenhouse gas emissions, is energy-related activities, including electric power generation, transportation and industrial fuel use.

The conversion of fossil fuels to energy (primarily electricity) is the single largest contributor to North American emissions of carbon dioxide. More than half of the electricity produced in North America is consumed in buildings, making that single use one of the largest factors in North American emissions. As of 2003, the carbon dioxide emissions from US buildings alone were greater than the total carbon dioxide emissions of any country, except China.

The transportation sector is the second-largest contributor to emissions of carbon dioxide in North America. This sector and its associated carbon dioxide emissions have grown steadily during the past 40 years. Growth has been the most rapid in Mexico, the country most dependent on road transport.

Important contributors to the remaining 20 percent of greenhouse gas emissions are releases of methane from natural gas systems, landfills and agricultural sources; nitrous oxide from nitrogen fertilization and fuel combustion; and certain fluorinated industrial gases.

The fluorinated industrial gases—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF<sub>6</sub>)—are potent greenhouse gases with long atmospheric lifetimes. Although they add only about 2 percent to the overall North American total greenhouse gas contribution, releases of these gases have increased sharply, up 72 percent between 1990 and 2005. Some industrial releases have fallen, but this achievement has been more than offset by the rapid switch to HFCs and PFCs as substitutes for chlorofluorocarbons and other ozone-depleting substances, in particular the introduction of HFC-134a as a chlorofluorocarbon (CFC) substitute in refrigeration and air-conditioning applications.

#### Recapture of Carbon

Land management activities can remove some portion of industrial greenhouse gas emissions. Forests and other vegetation act as a natural sink through carbon sequestration, but

their net impact varies across North America. In 2005 land use, land use change and forestry activities captured more than 11 percent of US

has established a direct link between higher temperatures and an increase in the incidence of dengue fever since 1995.

## More than half of the electricity produced in North America is consumed in buildings, making that single use one of the largest factors in North American emissions.

greenhouse gas emissions. Net carbon sequestration—primarily through a higher rate of net carbon accumulation in growing forests—was 16 percent greater than in 1990. In Canada, the contribution of land management activities is highly variable: over 20 percent net carbon accumulation in 1990, but only 2 percent in 2005. This fluctuation is attributable to the large and variable impact of emissions from wildfires. In Mexico, land management activities *added* to total greenhouse gas emissions because of deforestation and land clearing. In 2002 land use, land use change and forestry activities accounted for 14 percent of Mexico's total greenhouse gas emissions.

### What Are the Linkages to Other North American Environmental Issues?

As climate change continues, North America is expected to face additional challenges, some of which are described in the *Fourth Assessment Report* of the Intergovernmental Panel on Climate Change.

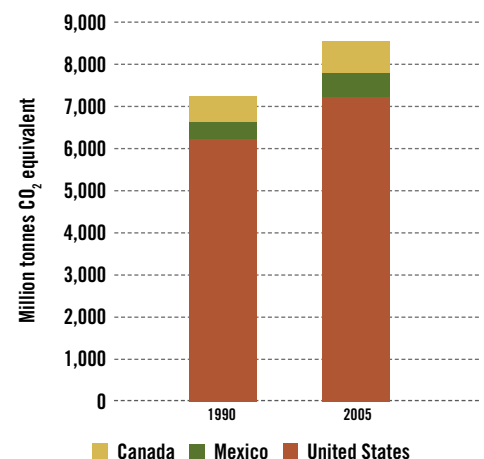
#### Human Health

By the end of the twenty-first century, climate change, with its higher temperatures and extreme weather in the form of longer and more intense heat waves, will have pronounced effects on human health, especially that of the elderly. Warming and climate extremes, including added exposure to pollen and ozone, are likely to lead to more respiratory illnesses. Periods of extreme weather and intense rainfall may spark as well an increase in water-borne diseases and degrade water quality. Climate change is also likely to hasten the spread of vector-borne infectious diseases, including Lyme disease and West Nile virus. In Mexico, the *Instituto Nacional de Ecología*

#### Water Quantity and Quality

In making their projections, scientists are less certain about future precipitation patterns than about future temperatures. They do, however, project that warming in western mountains will reduce the snow pack, increase evaporation, produce more winter flooding and reduce summer flows, exacerbating the competition among agricultural, municipal, industrial and ecological uses of water in the west. In the Great Lakes and major river systems, lower water levels are likely to spur adaptation challenges related to water quality, navigation, recreation, hydropower generation, water transfers and binational relationships. Some studies project widespread increases in extreme precipitation with greater risks of not only flooding, but also drought. In Mexico, studies indicate that almost 97 percent of the

North American greenhouse gas emissions



Greenhouse gas emissions in North America, excluding land management, 1990 and 2005 (latest data from Mexico from 2002, not 2005). Source: United Nations Framework Convention on Climate Change.

country is susceptible to a moderate or high degree of desertification and reduction in precipitation as a result of climate change.

#### Oceans, Coasts and Fisheries

Coastal communities and habitats are especially vulnerable to climate change. Sea levels are rising along much of the coast, and the rate of change will accelerate in the future, worsening the impacts of progressive inundation, storm surge flooding and shoreline erosion. The destruction inflicted by storms is likely to grow, especially along the Gulf and Atlantic coasts. As for wildlife, coastal habitats and dependent species are threatened by rising sea levels, changes in vegetation and a built environment that blocks landward migration.

#### Habitat Change and Disturbances

Climate change is a factor in the growing number of climate-related disturbances in North America such as wildfire and insect outbreaks, which are only likely to intensify with the drier soils and longer growing seasons that appear to lie ahead. Although in some areas vegetation growth may respond positively to recent climate trends, a rising incidence of disturbances is likely to limit carbon storage, enable the proliferation of invasive species and disrupt ecosystem services. As summers grow warmer, the window of high fire risk is expected to widen (see case study).

Over time, species will respond to climate pressures by moving north and to higher elevations in search of more suitable habitats, thereby rearranging North American ecosystems. The structure, function and services of ecosystems will change in response to the various capacities of species to shift ranges and from the constraints imposed by development, habitat fragmentation, invasive species and other pressures. This ecosystem alteration will be enhanced where high disturbance rates leave large areas open to recolonization by vegetation. In Mexico, half of the national vegetative cover may suffer alterations, including the disappearance of some zones and changes in others. In central and southern Mexico, climate change and land use patterns are projected to replace tropical forests with savannas, and the semiarid vegetation in most of central and northern Mexico with arid vegetation. Change in habitat distribution is expected to affect the species that inhabit these ecosystems. In tropical areas of Mexico, some species may become extinct altogether. 🦋

### Case Study – Accelerating Forest Ecosystem Disturbances

North American forests are indirectly influenced by climate through effects on natural disturbances such as wildfire, insects, and disease.

#### Wildfires

The area consumed by wildfires in the United States and Canada has increased dramatically over the last three decades. The intensity of wildfires is closely related to the availability of the dry, dead biomass they use as fuel. A warming climate produces longer summer periods that dry fuels, thereby promoting the easier ignition and faster spread of wildfires. Since 1980, US wildfires have consumed an average of 22,000 square kilometers (km<sup>2</sup>) a year, or almost twice the 1920–1980 average of 13,000 km<sup>2</sup> a year. From 1987 to 2003 in the western United States, the forested area burned was 6.7 times that burned from 1970 to 1986. In Canada, the burned area has exceeded 60,000 km<sup>2</sup> a year three times since 1990, or twice the long-term average. The wildfire-burned area in the North American boreal region increased from 6,500 km<sup>2</sup> a year in the 1960s to 29,700 km<sup>2</sup> a year in the 1990s. The human vulnerability to wildfires has also increased with rising population and housing development in forested areas.

#### Insects and disease

Insects and disease are a natural part of ecosystems. In forests, periodic insect epidemics kill trees over large areas. Recent epidemics have been related to the climate-sensitive stages in insect life cycles. Many northern insects have a two-year life cycle, and warmer winter temperatures allow a larger fraction of overwintering larvae to survive. Recently, spruce budworm in Alaska completed its life cycle in one year rather than the normal two. The mountain pine beetle has expanded its range in British Columbia into areas previously too cold. The susceptibility of trees to insects is increased when multiyear droughts degrade the ability of trees to generate defensive chemicals. The recent dieback of aspen stands in Alberta was caused by light snowpacks and drought in the 1980s, which triggered defoliation by tent caterpillars, followed by wood-boring insects and fungal pathogens. Extensive areas of dead, standing dry trees exacerbate the risk of large wildfires.



California wildfire.

## Ground-level Ozone

### Key Findings

- Ground-level ozone—unlike ozone in the stratosphere—damages human health, vegetation and materials. Ozone and its precursor chemicals travel across both North American and continental boundaries.
- Humans contribute to the formation of ground-level ozone primarily through burning fossil fuels in the transportation, industrial and electricity generation sectors. Evaporation of liquid fuels and solvents also adds to ozone formation.
- In certain areas of North America, levels of ground-level ozone exceed national standards for the protection of human health.
- Since 1990, total emissions of ozone precursor chemicals have declined in North America, but the trend in human exposure across the three countries is mixed, reflecting differences in location conditions and reporting methods.

**Ground-level ozone** is a colorless, highly irritating gas created by photochemical reactions between nitrogen oxides and volatile organic compounds produced largely by fuel combustion, gasoline vapors and chemical solvents.

### What Is the Environmental Issue?

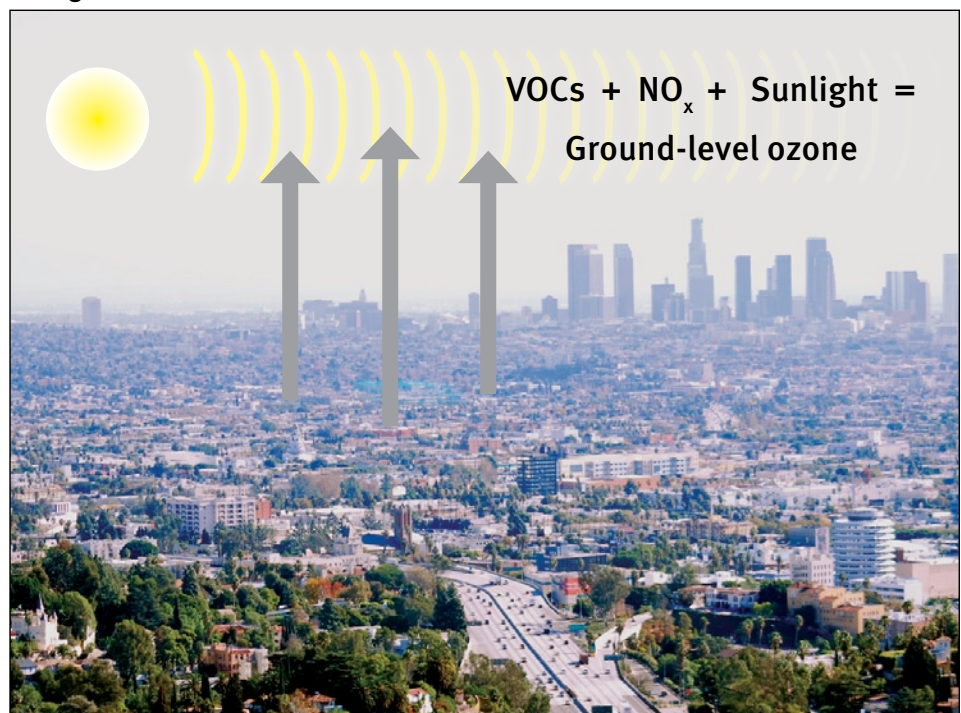
Ozone ( $O_3$ ) is a gas found in different parts of the atmosphere. Ozone in the upper atmosphere, or stratosphere, is an essential gas that helps to protect the earth from the sun's harmful ultraviolet rays. By contrast, the ozone found near the ground in the troposphere harms both human health and the environment. For this reason, ozone is often described as being “good up high and bad nearby.”

Ground-level ozone is produced when nitrogen oxides ( $NO_x$ ) and volatile organic compounds (VOCs) react through photochemical processes in sunlight (see figure). Power plants, motor vehicle exhaust, industrial facilities, gaso-

line vapors, and chemical solvents are the major sources of these emissions.

Ozone is also formed at ground level from natural emissions of VOCs,  $NO_x$  and carbon monoxide, as well as stratospheric ozone that occasionally migrates down to the earth's surface. Natural sources of ozone precursors include emissions from plants and soils, forest fires, and lightning. High ozone concentrations are observed at many remote mid-latitude sites in late winter and spring, especially at high elevations. However, long-range transport and the winter buildup of  $O_3$  precursors also contribute to these springtime levels, so it is not possible to attribute these high levels solely to natural sources.

### How ground-level ozone is formed





### Why Is This Issue Important to North America?

Ground-level ozone has deleterious effects on human and animal health and the environment. Despite reduction efforts by the three countries, it still exceeds national air quality standards in some areas of North America.

#### Effects of Ground-level Ozone

Ground-level ozone, a key component of smog, is considered a “nonthreshold” problem because even very small amounts in the air have deleterious effects on human health, especially the cardiovascular and respiratory systems. Exposure to ozone has been linked to premature mortality and a range of morbidity outcomes that include hospital admissions and asthma symptoms. After analyzing the air pollution and mortality data of eight major Canadian cities, Health Canada estimated that in these cities almost 6,000 deaths a year could be attributed to air pollution of which ground-level ozone is a major component. According to the Ontario Medical Association, air pollution costs Ontario citizens more than C\$1 billion a year in hospital admissions, emergency room visits and absenteeism. In the United States, studies of 95 major urban areas by researchers at Yale and Johns Hopkins revealed that an increase in daily ozone levels was associated with more than 3,700 deaths each year from cardiovascular and respiratory illnesses.

Vegetation, crop productivity, flowers, shrubs and forests are also damaged by ground-level ozone. Moreover, it can deteriorate cotton

Levels of ground-level ozone are often higher during hot summer days or downwind of the heavily populated areas that are emitting the necessary precursors. In the Northern Hemisphere, ozone levels are typically highest during the afternoon hours of the months in which temperatures are warm and the influence of direct sunlight is the greatest.

and synthetic materials, produce cracks in rubber and accelerate the fading of dyes, paints and coatings.

#### Reducing Emissions

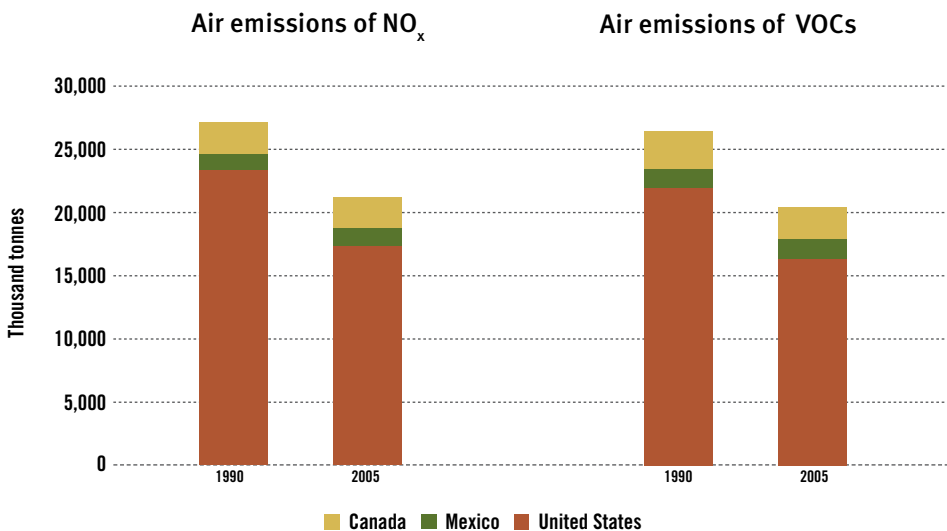
The 1970s saw the beginning of attempts to mitigate ground-level ozone concentrations across North America through directed reductions in precursor emissions. In response, both NO<sub>x</sub> and VOC emissions in the United States fell substantially, despite significant economic growth. In Canada, VOC emissions have decreased, but the trend in NO<sub>x</sub> emissions has been almost flat since 1990. Mexico has experienced reductions in emissions from vehicles, but increases in those from fixed or stationary sources for both NO<sub>x</sub> and VOCs. Overall, air emissions of ground-level ozone precursors in North America have declined since 1990, with releases of both NO<sub>x</sub> and VOCs falling over 20 percent (see graphs).

In all three countries, fuel combustion by mobile sources is a major source of both NO<sub>x</sub> and VOC emissions, with fossil fuel-fired power plants adding significantly to NO<sub>x</sub> emissions in the United States and Mexico. In Canada, upstream oil and gas production is the largest industrial contributor of NO<sub>x</sub>. In addition to fuels in the transportation sector, solvents are a major source of emissions of VOCs in all three countries, but oil and gas production is also a large contributor in Canada.

#### Monitoring Ozone Trends

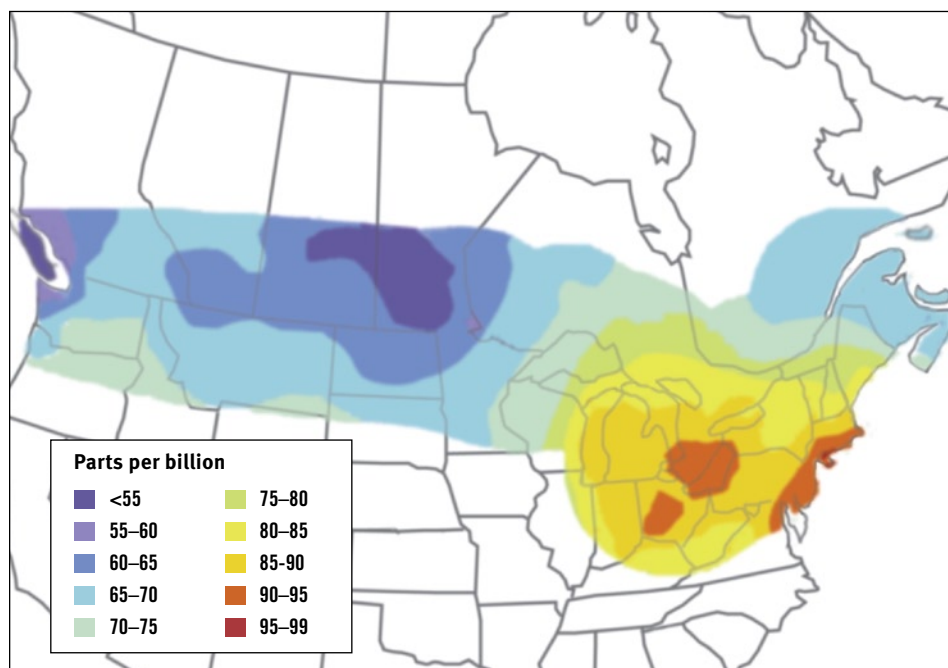
At present, considerable ozone data for North America are available from various networks. Characterization of North American trends and patterns is limited, however, by the lack of consistency in these data sets and by the inconsistent methods for preparing and reporting results. It is also difficult to derive meaningful North American trends because conditions vary greatly on a regional basis. Nevertheless, existing monitoring reveals that ambient levels of ozone exceed national standards in certain areas of all three countries.

In Canada, trends for ambient ozone based on the Canada-wide Standard (CWS) remained largely unchanged over the 15 years ending in 2005. However, the Canadian indicator for human exposure to ozone rose by an average of 0.8 percent a year, for a total increase of 12 percent between 1990 and 2005. The national ozone exposure indicator for Canada, which is weighted by population, is driven primarily by the ozone concentrations and populations in Ontario and southern



Sources: Environment Canada, Instituto Nacional de Ecología (latest data from Mexico from 2002, not 2005), US Environmental Protection Agency.

## Ozone concentrations along the Canada-US border (2002–2004)



Source: Bilateral Air Quality Committee.

Quebec. In 2005, communities in these areas recorded the highest ground-level ozone concentrations for both the CWS and seasonal averages. Many stations in Alberta also reported high seasonal average concentrations. In 2005, at least 40 percent of Canadians lived in communities with ozone concentrations above the ambient CWS target.

In Mexico, the frequency of days on which ground-level ozone concentrations exceed the standard has remained constant over time in most monitored cities. However, in Mexico City and Guadalajara, ground-level ozone remains a serious air quality problem. In 2005 at least 27.7 percent of Mexicans lived in municipalities in which ozone concentrations were above the national standard at least one day a year.

In the United States, national ozone concentrations averaged over one hour and eight hours fell by 12 percent and 8 percent, respectively, in the period between 1990 and 2005. Despite the decrease, in 2005, more than 10 percent of Americans lived in counties with air quality concentrations above the ozone one-hour National Ambient Air Quality Standard, and at least 33 percent lived in counties with concentrations above the eight-hour standard.

### Transboundary Flows

Both field studies and computer models confirm that the ozone problem in various regions of North America is a result of

the complex interactions between meteorological processes on various scales and precursor emissions and their chemistry. At times, ozone levels are predominantly the result of local emissions, with only minor contributions from upwind sources. And at other times, local ozone levels are dominated by the transport of ozone and its precursors from upwind sources.

## Analyses of ozone levels within 500 kilometers of the Canada-US border found higher ozone levels in the lower Great Lakes–Ohio Valley region and along the US East Coast.

Analyses of ozone levels within 500 kilometers of the Canada-US border found higher ozone levels in the lower Great Lakes–Ohio Valley region and along the US East Coast (see map). The lowest ozone values are largely found in the west and in Atlantic Canada. Levels are generally higher downwind of urban areas, such as in the western portions of lower Michigan. The locally higher levels in the complex terrain of the Georgia Basin–Puget Sound area of British Columbia–Washington

State are not well resolved in the map shown, although they are lower than in the east. Between 1995 and 2004, there was a decrease in annual ozone levels within this border region, with trend lines on either side of the border tracking similarly.

Ozone concentrations in the US-Mexico border region remain a concern in some areas. Although in the Rio Grande Valley no days in 2005 exceeded the binational eight-hour ozone standard, other monitoring locations in border sister-city pairs demonstrated exceedances, including Ambos Nogales (1 day), Ciudad Juárez/El Paso (6 days), Tijuana/San Diego (11 days), and Mexicali/Imperial Valley (24 days). Although overall compliance with the ozone standard is generally improving, Mexicali/Imperial Valley and Tijuana/San Diego consistently remained above the applicable standard from 2001 to 2005.

Transport of ozone and precursor emissions extends beyond North America's borders. North America is a source of ground-level ozone for Europe just as Asia is for North America. More widely, ground-level ozone levels are rising across the planet and have created "background" ozone concentrations, even in remote areas that are not directly affected by human influence. Retrospective analysis of eighteenth-century data from Europe suggests that ozone concentrations in the Northern Hemisphere may have doubled over the past century in response to the massive

industrialization that has taken place. Current "background" ozone concentrations in North America are about 30–40 parts per billion.

### What Are the Linkages to Other North American Environmental Issues?

Ozone and its precursor pollutants are linked to particulate matter (PM), another component of smog, and to acidification, eutrophication and climate change.

### Particulate Matter

When nitrate, an oxidation product of nitrogen dioxide ( $\text{NO}_2$ ), is combined with other compounds in the atmosphere, such as ammonia, it becomes an important contributor to the secondary formation of fine particulate matter ( $\text{PM}_{2.5}$ ). VOCs are also a precursor pollutant to the secondary formation of  $\text{PM}_{2.5}$ . Ozone and PM have some common precursor gases, and reductions in any one of these precursors can have complex, and at times negative, results for concentrations of ozone or PM. Efforts to address and reduce concentrations of ozone and PM are often integrated in air quality management programs to avoid negative air quality results.

### Acidification

Nitrogen oxides are formed primarily from the nitrogen liberated during combustion processes. Nitrogen oxide emitted during combustion quickly oxidizes to  $\text{NO}_2$  in the atmosphere. The  $\text{NO}_2$  then dissolves in water vapor in the air to form nitric acid ( $\text{HNO}_3$ ), and interacts with other gases and particles in the air to form particles known as nitrates and other products that may be harmful to people and their environment. Both  $\text{NO}_2$  in its untransformed state and the acid and transformation products of  $\text{NO}_2$  can have adverse effects on human health and the environment, harming vegetation, buildings and materials, and contributing to the acidification of aquatic and terrestrial ecosystems.

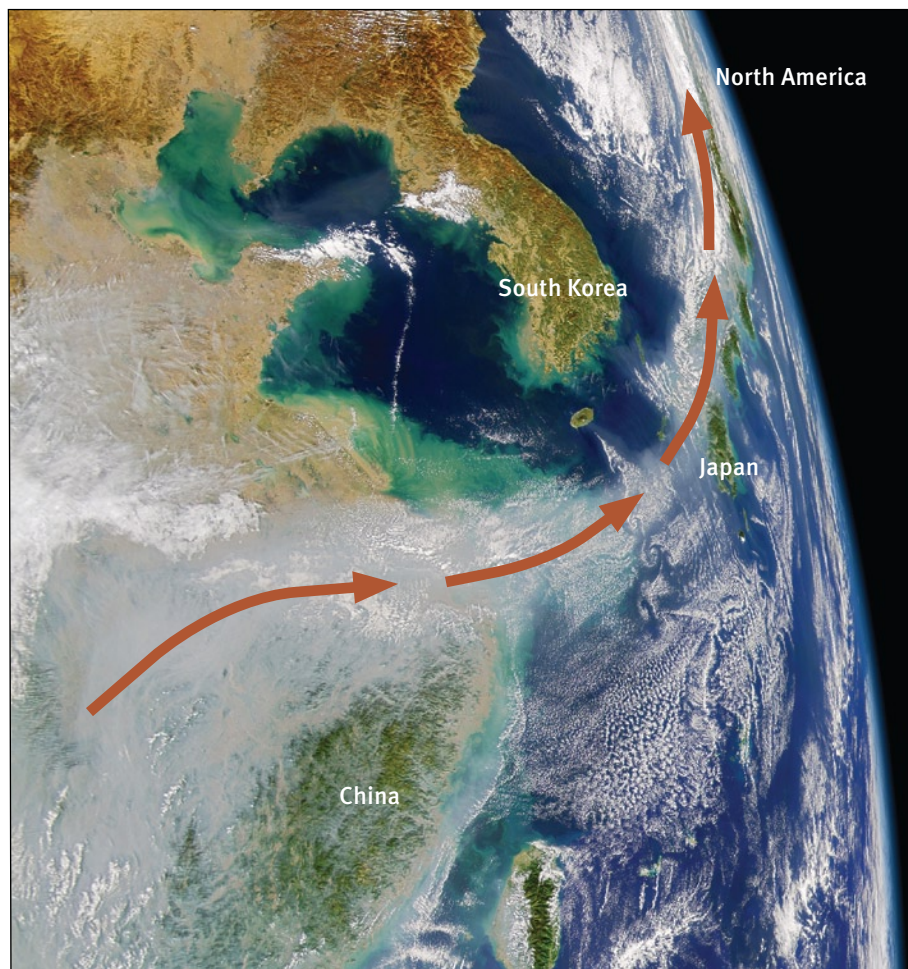
### Eutrophication

Nitrogen releases not only contribute to the formation of acid depositions, but also can act as a nutrient in ecosystems, resulting in eutrophication or overenrichment of soils and waters.

### Climate Change

When present in the upper troposphere, ozone is a very effective greenhouse gas. Strategies that reduce ozone concentrations on urban and regional scales probably help to limit the contribution of ground-level ozone to the greenhouse effect and global warming. 🦋

## Case Study – Transporting Asian Pollution to North America



Source: NASA

A recent study suggests that the transpacific transport of pollution from Asia influences North America's air quality during the spring and summer. Even small quantities of Asian emissions over North America during the summer can have significant implications for air quality management.

In the summertime, emissions from Asia and Europe contribute 4–7 parts per billion by volume (ppbv) to afternoon ozone concentrations in the surface air over the United States, instigating violations of the air quality standard. If Asian anthropogenic emissions triple from 1985 to 2010 as expected, surface ozone in the United States could increase by 1–5 ppbv during the summer.

The long-range transport of Asian pollution across the Pacific reaches a maximum in the spring because of the active cyclonic activity and strong westerly winds. The strongest Asian outflow occurs in the middle troposphere; it can be transported across the Pacific in 5–10 days. During the summer, the export of Asian pollution by convection competes with the export of mid-latitude cyclones. Transpacific transport occurs primarily in the middle and upper troposphere, with an average transpacific transport time of 6–10 days.

According to the analysis, the Asian air masses contained elevated levels of carbon monoxide, ozone, particulate matter, and other chemicals consistent with the dominant influence of combustion emissions over East Asia. High levels of methanol and acetone indicated that natural emissions were combining with the polluted outflow.



# Particulate Matter

## Key Findings

- Airborne particulate matter (PM) is an underlying cause of some serious human health problems, including cardiac and respiratory diseases. PM also adversely affects vegetation and building materials and contributes to regional haze and poor visibility. PM and its precursor chemicals are carried through the air across state, provincial, national and continental boundaries.
- PM has many natural and anthropogenic sources, among them direct releases to air from heavy equipment, fires, burning waste and dust from unpaved roads, stone crushing and construction sites. PM is also formed from precursor chemicals emitted by vehicles, power plants and industrial facilities.
- In certain areas of North America, levels of PM exceed national standards for the protection of human health.
- Since 1990, total emissions of PM and its precursor chemicals have declined in North America, but the trend in human exposure across the three countries is mixed, reflecting differences in local conditions and reporting methods.

*Particulate matter* is a mixture of solid particles and liquid droplets found in the air.

Its components include sulfates, nitrates, ammonium, organic carbon, black carbon, metals and soil dust.

## What Is the Environmental Issue?

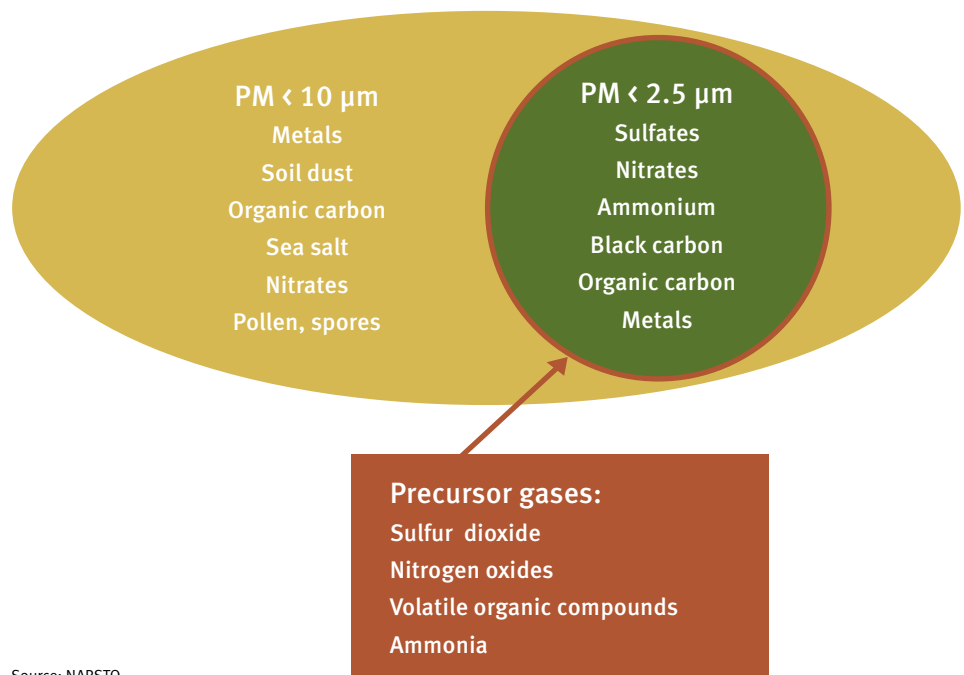
Particulate matter (PM), made up of solid particles and liquid droplets in the air, can be both large enough to appear as dirt and much smaller than the diameter of a human hair. Ambient PM mass is a complex mixture that is strongly dependent on source characteristics.

Particles are commonly tracked within two size ranges: PM<sub>2.5</sub> or “fine” PM, which has aerodynamic diameters less than or equal to 2.5 micrometers (µm) and PM<sub>10</sub>, which includes fine PM as well as larger “coarse” particles up to 10 µm (about one-seventh the diameter of a human hair)—see figure. Particles of different sizes behave differently

in the atmosphere. Smaller particles can remain airborne for long periods and travel hundreds of kilometers. Larger particles do not remain airborne as long because they tend to deposit closer to their point of origin.

In general, the coarse fraction of PM<sub>10</sub> is composed largely of primary particles released directly into the atmosphere by both natural events (e.g., forest fires and volcanoes) and human activities (e.g., agriculture, construction activities, dust from unpaved roads, residential wood burning and industrial activities). Conversely, PM<sub>2.5</sub> tends to be composed of more secondary particles. These secondary particles are formed in the atmosphere from chemical reactions involving

## Representative composition of particulate matter



Source: NARSTO.

## Diesel Emissions in the US-Mexico Border Region



Diesel emissions are a source of particulate and hazardous air pollution. The trucking, shipping and rail industries are responsible for a significant share of diesel emissions within the US-Mexico border region. Other important sources of on-road diesel emissions are school buses, garbage trucks and municipal buses. Of non-road diesel engines, construction vehicles and agricultural equipment are the largest mobile sources of  $PM_{10}$  and  $PM_{2.5}$ .

As the US-Mexico border opens more widely under terms of the North American Free Trade Agreement, cross-border truck transportation is expected to increase. Diesel emissions will become worse if the majority of Mexican diesel truck fleets continue to consist of vehicles built before 1993—the year engine manufacturers began to incorporate technology to reduce emissions and improve performance and fuel economy.

Because diesel emissions contribute so significantly to pollutants, retrofits and collaboration to reduce these emissions are under way. In January 2006, Mexico modified its fuel standard for gasoline and diesel fuels. An accelerated calendar was included for the border region, with the goal of providing the region with ultra-low sulfur diesel by January 2007.

Meanwhile, the San Diego Air Pollution Control District is retrofitting 60 heavy-duty diesel trucks from Tijuana with diesel oxidation catalysts. These devices reduce  $PM_{10}$  by 25 percent. In addition, the Laredo (Texas) Independent School District is modifying 50 school buses to burn ultra-low sulfur diesel fuel, and the Rio Rico, Arizona, school district is implementing a similar project. These two projects will reduce the exposure of schoolchildren to fine PM and serve as a demonstration project for other school districts on both sides of the border.

the precursor emissions of nitrogen oxides ( $NO_x$ ), sulfur dioxide ( $SO_2$ ), volatile organic compounds (VOCs) and ammonia ( $NH_3$ ).

### Why Is This Issue Important to North America?

Particulate matter has harmful effects on human health and the environment. Despite the efforts of all three North American countries to reduce PM, it still exceeds national air quality standards in some areas.

#### Effects of Particulate Matter

Research indicates that exposure to PM air pollution is linked to thousands of excess deaths and widespread health problems. Numerous studies have linked PM to aggravated cardiac and respiratory diseases such as asthma, bronchitis and emphysema and to various forms of heart disease. Fine PM has greater effects on human health than coarse PM because the smallest particles can travel deepest into the human lung, causing the greatest harm. Sensitive groups that appear to be at the greatest risk of such PM effects include older adults, individuals with cardiopulmonary disease, such as asthma or congestive heart disease, and children.

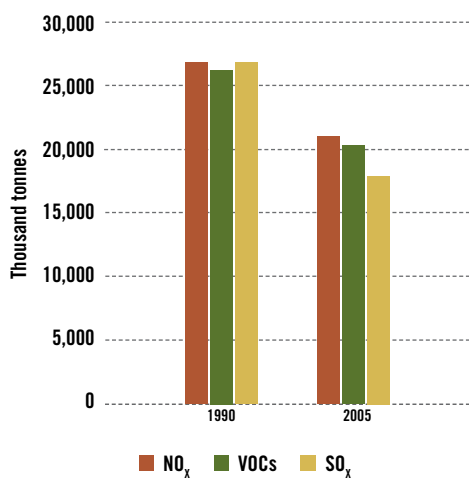
PM deposition also affects the environment by altering nutrient and chemical cycles in soils and surface water. For example, the deposition of particles containing nitrogen and sulfur may change the nutrient balance and acidity of aquatic environments, thereby altering species composition and buffering capacity. Some particles can corrode leaf surfaces or interfere with plant metabolism. PM also soils and erodes materials and buildings, including monuments, statues and other objects of cultural importance.

In addition to its effects on human health and the environment, fine PM is a main contributor to reduced visibility. This kind of haze is often noticeable in parks and wilderness areas, where periods of poor visibility result in lost tourist revenues.

#### Reducing Emissions

Between 1990 and 2005, direct fine PM air emissions in Canada and the United States declined by about a third (see graph). Important sources of direct fine particle emissions are diesel engines, burning activities and industrial sources. Only the Canadian and US  $PM_{2.5}$  emissions can be displayed over this time period because  $PM_{2.5}$  emission estimates for Mexico are available only for 1999. As of that year,

### Air emissions of PM precursor chemicals in North America

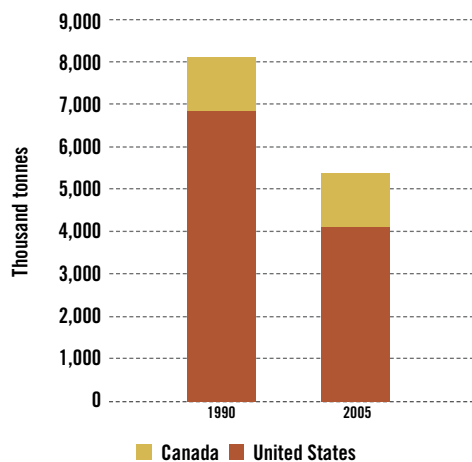


Sources: Environment Canada, *Instituto Nacional de Ecología* (latest data for Mexico from 2002, not 2005), US Environmental Protection Agency.

Mexico's contribution to North America's total PM<sub>2.5</sub> emissions was about 7 percent.

Because PM is also formed in the atmosphere by precursor emissions, it is important to understand which human activities contribute to precursor emission inventories. For NO<sub>x</sub> emissions, fossil fuel-fired power plants are important sources in the United States and Mexico, and all three countries count the transportation sector as a key contributor. For SO<sub>2</sub> emissions, coal-fired power plants in the United States and Mexico and smelters in Canada are large sources. Volatile organic compounds are produced by similar sources in all three countries—fuels,

### Air emissions of PM<sub>2.5</sub> in Canada and United States



Sources: Environment Canada, US Environmental Protection Agency.

solvents and oil and gas development—but in Canada residential wood burning also makes a large contribution. For ammonia, agriculture is a common source throughout North America. Across the continent, air emissions of PM precursors have declined since 1990 (see graph).

#### Monitoring PM Trends

At present, considerable PM data for North America are available from various networks using a number of different measurement techniques. Characterization of North American trends and patterns is limited, however, by the inconsistency of these data sets, lack of monitoring stations and suitable measurement technology in certain areas, as well as by differing methods for preparing and reporting results. It is also difficult to derive meaningful North American trends because conditions vary greatly on regional basis. In all three North American countries, however, the existing monitoring reveals that ambient levels of PM exceed national standards in certain areas.

## Despite the efforts of all three North American countries to reduce PM, it still exceeds national air quality standards in some areas.

In Canada, there was no statistically significant increasing or decreasing trend in PM<sub>2.5</sub> exposure either nationally or regionally during the years 2000–2005. Between 2003 and 2005, at least 30 percent of Canadians lived in communities with PM<sub>2.5</sub> levels above the Canada-wide Standard target. The communities affected were located in southern Ontario, southern Quebec and British Columbia.

Data on the levels of concentrations of PM<sub>2.5</sub> are not available for most Mexican cities. However, PM<sub>10</sub> measurements are available in various metropolitan areas. In 2005 the standard for PM<sub>10</sub> was exceeded on 173 days in Toluca, 163 days in Monterrey, 51 days in Guadalajara, 34 days in Mexico City and 11 days in Puebla. Over the past decade, most monitored cities have experienced a tendency toward fewer days of exceeding the standard, with the exception of Monterrey and Toluca. In 2005 at least 27 percent of Mexicans lived in municipalities where PM<sub>10</sub> concentrations were above the national standard at least 11 days a year.

Although concentrations of PM in the United States have generally fallen nationwide, they still exceed national standards in dozens of metropolitan areas. In 2006 some 14.7 million people were living in counties with PM<sub>10</sub> levels above the national air quality standard, and 66.9 million people were living in counties that exceeded both the annual and daily standards for PM<sub>2.5</sub>.

#### Transboundary Flows

Efforts to reduce PM to meet air quality standards in North America are confounded by the fact that PM levels are affected by local pollution, as well as pollution transported across state, provincial and national borders. PM can remain in the atmosphere for days to a few weeks, depending on the size and rate at which it is removed from the atmosphere through, for example, precipitation. Therefore, particles in any given area may originate locally or from sources hundreds to thousands of kilometers away. Regional contributions from sources distant to eastern North Ameri-

can urban areas can account for 50–75 percent of the total observed PM<sub>2.5</sub> mass concentration within a specific urban area.

Transboundary flows are important in the border region shared by Canada and United States. In 2005 the concentrations at stations in southern Ontario were influenced by significant contributions flowing from the United States, and in southern Quebec levels were affected by pollution from both the United States and Ontario. At the same time, PM<sub>2.5</sub> and its precursor emissions from Canada led to elevated concentrations of PM<sub>2.5</sub> in the eastern United States.

Along the US-Mexico border, the Rio Grande Valley remained consistently below the annual US standard for PM<sub>10</sub> from 2001 to 2005, but four other monitoring areas exceeded the standard (Ambos Nogales, Tijuana/San Diego, Ciudad Juarez/El Paso, and Mexicali/Imperial Valley). During this period, the Mexicali/Imperial Valley area consistently experienced annual PM<sub>10</sub> concentrations more than four times the US standard.



Fires in the Yucatán Peninsula and southern Mexico, 2003. Photo: National Aeronautics and Space Administration.

On a periodic basis, fires in one country can contribute to high PM concentrations in a neighboring country. For example, during April and May 2003 air quality in Texas, Oklahoma and other states suffered from large amounts of aerosol PM carried as smoke from fires in the Yucatán Peninsula and southern Mexico (see photo). The smoke plumes, which significantly degraded visibility and air quality in coastal regions along the Gulf of Mexico, were large enough to create circulation patterns in the atmosphere that trapped smoke aerosols and other PM in the lower atmosphere, further worsening air quality.

Particle pollution can also cross into North America from outside the region. Intercontinental transport of PM in the form of dust and desert sand has been tracked from Africa and Asia to North America. Although this transport of dust from both Asia and Africa does not contribute significantly to annual average concentrations in North America, it may occasionally contribute significantly to daily concentrations. For example, in the summer of 1997 a plume from North Africa contributed

to PM<sub>10</sub> concentrations at sites in the Houston, Texas, area by as much as 15–20 micrograms per cubic meter over two days.

### What Are the Linkages to Other North American Environmental Issues?

Particulate matter plays a role in various environmental issues, especially ground-level ozone, climate change and water quality.

#### Ground-level Ozone

PM<sub>2.5</sub> and ground-level ozone are closely related through common precursors, sources and meteorological processes. Because of this close relationship, changes in the emissions of one pollutant can lead to changes in the concentrations of PM or ground-level ozone. This finding is particularly important because certain regions, such as the eastern United States and southeastern Canada, experience high PM and ozone concentrations during the same season, whereas other regions, such as the San Joaquin Valley in California, have high PM and ozone levels in opposite seasons.

#### Climate Change

All particles affect climate change by scattering incoming and, to a lesser degree, outgoing radiation. Black carbon and other dark particles absorb radiative energy. Coarse particles and cloud droplets formed by the condensation of water vapor on particles also have radiative effects, which can have local and global impacts on climate change.

#### Water Quality

Particles and their precursors—particularly sulfur dioxide, nitrogen oxides and ammonia—can be carried long distances by the wind and eventually be deposited on the ground or in water. Their deposition makes lakes and streams acidic, changes the nutrient balance in coastal waters and large river basins and encourages eutrophication, depletes the nutrients in soil, damages sensitive forests and farm crops, and affects the diversity of ecosystems. Particles also carry toxic components such as mercury, which can degrade water quality and aquatic ecosystems. 🦋

# Stratospheric Ozone

## Key Findings

- Stratospheric ozone protects the earth's surface from excessive solar radiation, but this protective layer has become thinner, allowing penetration of harmful levels of ultraviolet radiation. Excess levels of ultraviolet radiation are harmful to human health and the environment.
- In response, countries have sought to control production, consumption and trade of ozone-depleting substances (ODS) through an international agreement. By the end of 2005, the parties to the Montreal Protocol had together phased out production and consumption of over 95 percent of ODS—which are used as refrigerants, aerosol propellants and for other purposes.
- Currently the earth's protective ozone layer remains thinner than historical averages; the ozone hole over Antarctica was at its largest and deepest ever observed in 2006.
- Canada, Mexico and the United States have substantially reduced emissions of ODS over the last 20 years, but these substances are still released from various sources in North America and globally. Recovery of the ozone layer is expected by the mid-twenty-first century based on compliance with the international agreement now in place. Reduction in ODS has delivered substantial climate benefits, because some ODS also act as greenhouse gases.

Ozone is a gas present throughout the earth's atmosphere. *Stratospheric ozone* protects life on earth by absorbing harmful rays from the sun as they pass through the upper atmosphere (the stratosphere). Because the ozone present at the earth's surface is detrimental, ozone is often described as being “good up high and bad nearby.”

## What Is the Environmental Issue?

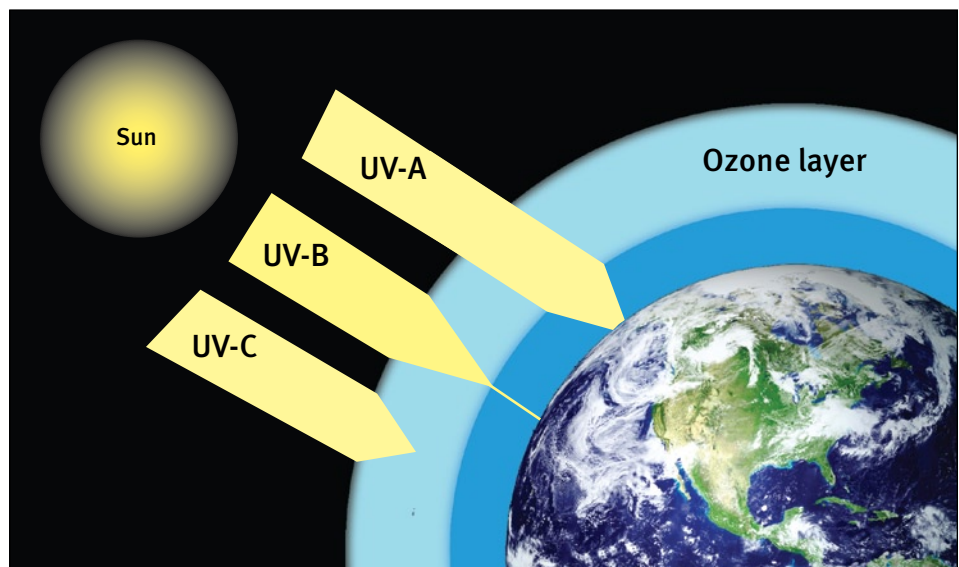
Stratospheric ozone protects the earth's surface by absorbing ultraviolet (UV) radiation from the sun (see illustration). It is naturally formed by chemical reactions involving ultraviolet sunlight and oxygen. Approximately 90 percent of ozone is in the stratosphere, the layer of the atmosphere that begins 10–15 kilometers above the earth's surface at the midlatitudes. The ozone in the stratosphere is referred to as the ozone layer.

### Thinning of the ozone layer

The stratospheric ozone layer is now thinner than it has been historically because of certain ozone-depleting substances, such as refrigerants and aerosol propellants. These substances were first produced commercially during the

twentieth century and some continue to be produced and used. When released, these chemicals make their way to the upper atmosphere and gradually convert to more reactive gases that destroy ozone. Overall thinning of the ozone layer has been recognized since the 1970s, and the total loss is currently estimated to average 3 percent over the globe, with more thinning occurring toward the polar regions and less near the equator. Above Antarctica, an ozone hole now forms each September. During September 2006, the average area of the ozone hole, at 27.5 million square kilometers, was the largest ever observed (see photo). A little over a week later, instruments recorded the lowest concentrations of ozone ever observed over Antarctica, revealing that the ozone hole was the deepest it had ever been.

## UV protection by the ozone layer



Source: United Nations Environment Programme.

Because the ozone layer absorbs some of the biologically harmful ultraviolet radiation from the sun, reductions in stratospheric ozone levels allow more UV radiation to reach the earth's surface, where it affects human health, disrupts biological processes and damages materials.

**Ozone-depleting Substances**

The substances most responsible for the destruction of the ozone layer are listed in the following table along with their uses in everyday life. Alternatives to these substances include hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). HCFCs, a transitional CFC replacement, are used as refrigerants, solvents and fire extinguishers. HFCs and PFCs are used as refrigerants, aerosol propellants and solvents.

**Why Is This Issue Important to North America?**

Ozone depletion has significant health and economic consequences for North America. It is generally worse at latitudes approaching the poles, specifically the northern and Arctic regions in the North American context.

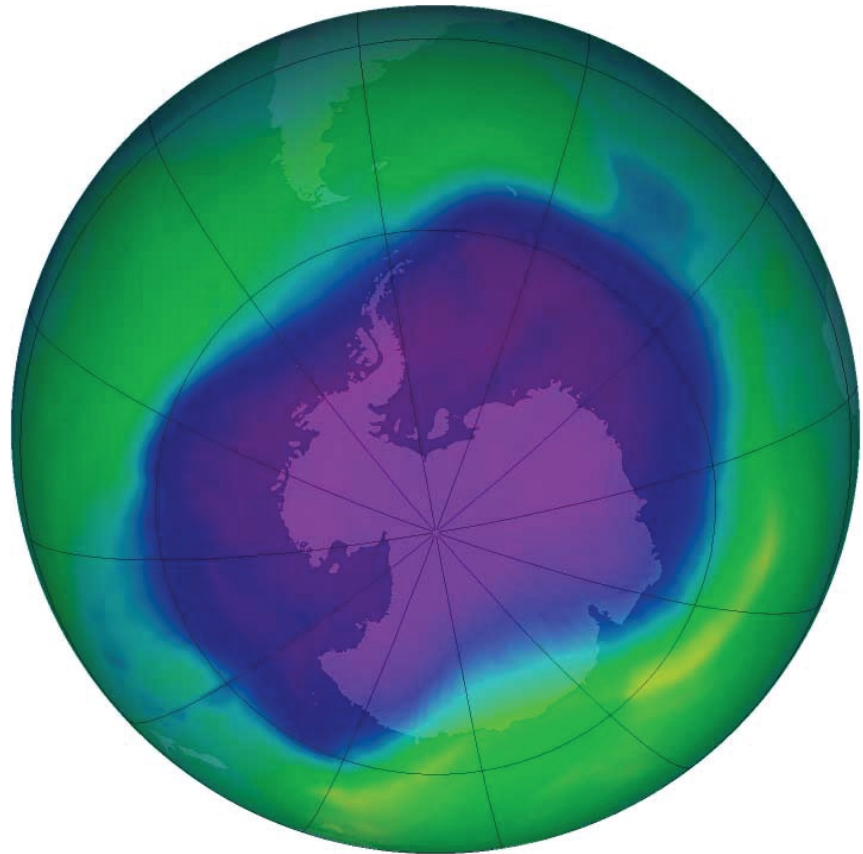
**Effects of UV-B Radiation**

Overexposure to UV-B radiation, the most damaging type of ultraviolet radiation, can cause a range of health effects, including skin cancers and premature aging, eye damage (such as cataracts) and suppression of the immune system. The physiological and developmental processes of plants are also affected by UV-B radiation, which can damage sensitive crops such as soybeans and rice and reduce crop yields.

**Common ODS and Their Uses**

Substance	Uses
Chlorofluorocarbons (CFCs)	Refrigerants, cleaning solvents, aerosol propellants and blowing agents for plastic foam manufacture
Hydrochlorofluorocarbons (HCFCs)	Refrigerants, cleaning solvents, aerosol propellants and blowing agents for plastic foam manufacture
Halons	Fire extinguishers/fire suppression systems
Carbon tetrachloride	Production of CFC (feedstock), solvents
Methyl chloroform	Industrial solvents for cleaning, inks, etc.
Methyl bromide	Fumigant used to control soil-borne pests and diseases in crops prior to planting

The Antarctic ozone hole (21–30 September 2006)



Source: National Aeronautics and Space Administration.

Marine phytoplankton, which serves as the base for the ocean's aquatic food chain, is under stress from UV-B radiation as well. Studies have also found that solar UV-B radiation damages fish, amphibians and other animals in their early developmental stages.

More broadly, increases in solar UV radiation could affect terrestrial and aquatic biogeochemical cycles, thereby altering both sources and sinks of greenhouse and chemically important trace gases.

Finally, synthetic polymers, naturally occurring biopolymers and other commercially useful materials are adversely affected by solar UV radiation. Increases in solar UV-B levels accelerate their breakdown outdoors.

**Reducing Emissions**

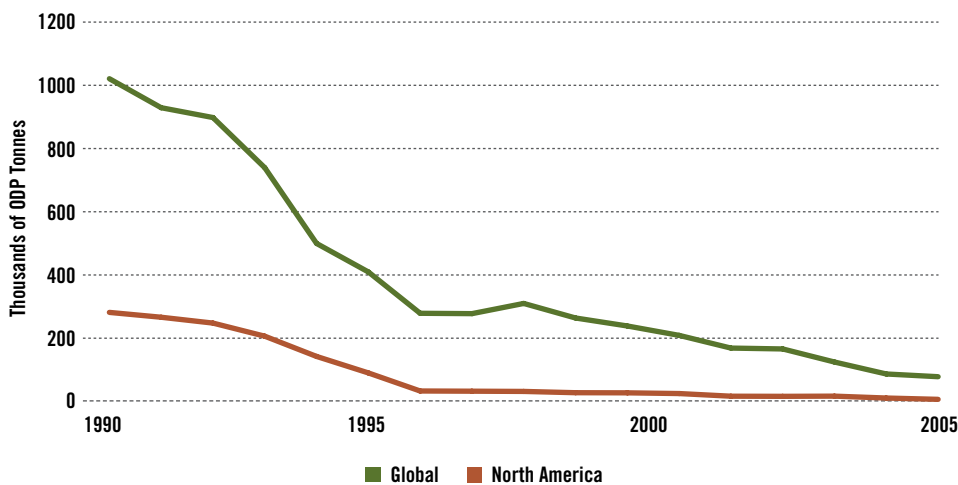
Canada, Mexico and the United States are addressing the destruction of the ozone layer by eliminating the production and consumption of ozone-depleting substances on a schedule determined by the Montreal Protocol on Substances that Deplete the Ozone Layer. This agreement has led to a phase-out of the production and consumption of CFCs and other ODS. Currently, 191 countries and the European Community are parties to the Protocol and are implementing its requirements.

By the end of 2005, the parties had together phased out over 95 percent of ODS, reducing production levels from a 1990 level of over 1 million Ozone Depletion Potential (ODP) tonnes a year to about 93,000 ODP tonnes a year in 2005. North American production and consumption declined from about one-third to under one-fifth of the global total (see graph).

Also through 2005, the production and consumption of ozone-depleting substances in North America fell by almost 97 percent (see

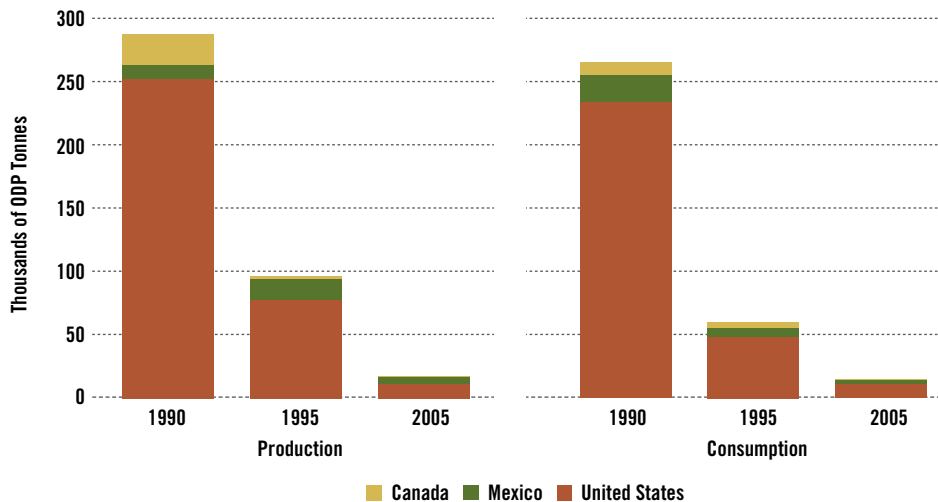
graph). Because of the long time that it takes for ODS to move from ground level to the stratosphere, the impact of their elimination will not be felt for many years. It is estimated that the ozone layer could recover by about 2050, provided that all ozone-depleting substances of anthropogenic origin are eliminated. However, long-term predictions are uncertain because not all of the processes of ozone depletion are understood. The role of very short-lived ODS is still being studied, along with the impact of climate change on the stratosphere and ozone depletion.

**Total reported production of ozone-depleting substances globally and in North America**



ODP = Ozone Depletion Potential. Source: United Nations Environment Programme.

**North American reductions in ozone-depleting substances**



ODP = Ozone Depletion Potential. Source: United Nations Environment Programme.

### Monitoring Stratospheric Ozone Trends

Over North America, total stratospheric ozone levels began falling in 1965, reaching their lowest levels in 1993. The ozone layer has since begun to recover, but as of 1998–2001 average overall levels were still 3 percent lower than those observed 20 years earlier. Since 1993, ozone levels over North America have been trending upward as result of reduced ODS emissions and reformation of stratospheric ozone.

### Illegal Trade in ODS

Somewhat complicating this picture of progress is the illegal trade in significant amounts of ODS on a global basis. Although all new CFCs are now banned in industrialized countries, millions of refrigerators, automobile air conditioners and other equipment that use CFCs are still in service. Servicing this equipment with CFC replacements is possible, but often more expensive. In addition, used CFC-based equipment is exported to developing countries by countries that have phased out CFCs. These factors create incentives for the illegal trade in ODS, which has been estimated at 10–20 percent of the legitimate global trade. Issues related to the legal trade of equipment and illegal trade of ODS may complicate progress toward the ultimate elimination of ODS on a worldwide basis.

### What Are the Linkages to Other North American Environmental Issues?

Stratospheric ozone depletion has major linkages to other key North American environmental issues—principally climate change and the health of terrestrial and aquatic ecosystems.

### Climate Change

The depletion of the ozone layer and climate change were originally understood to be separate threats. Recently, however, both the Environmental Assessment Panel for the Montreal Protocol and the Intergovernmental Panel on Climate Change stated that there is conclusive scientific evidence that ozone depletion and climate change are linked.

Some ozone-depleting chemicals (CFCs, HCFCs and Halon 1301) and their replacements (HFCs and PFCs) are powerful greenhouse gases. The accumulation of greenhouse gases, including ODS, increases warming of the lower atmosphere, which leads, in turn, to the cooling of the stratosphere. Stratospheric cooling hampers the formation of ozone and favors

the development of polar ozone holes. Studies indicate that within two decades climate change may exceed CFCs as the principal cause of overall ozone loss.

Global efforts to phase out ozone-depleting substances have benefited the earth's climate in two ways. First, the net global decline in emissions of ODS has resulted in a drop in greenhouse gas emissions equivalent to several billion tonnes of carbon dioxide. Second, the reductions needed to meet international obligations have frequently required equipment upgrades and more efficient energy practices that reduce greenhouse gas emissions.

### Health of Terrestrial and Aquatic Ecosystems

The linkages between terrestrial ecosystems and the higher levels of UV-B radiation resulting from ozone depletion are complex. The responses of plants and other organisms to increased UV-B radiation are influenced by a variety of environmental factors such as carbon dioxide, water availability, mineral nutrient availability, heavy metals and temperature. Many of these factors are also changing as the global climate is altered.

Higher levels of UV-B radiation damage terrestrial organisms, including plants and microbes. They change patterns of gene activity and affect life cycle timing, as well as change plant shape and the production of plant chemicals not directly involved in primary metabolism. Plant chemicals not only are important in protecting plants from pathogens and insect attacks, but also affect food quality for humans and grazing animals.

The effects of ozone depletion and increased UV radiation on aquatic ecosystems are complex as well. Higher levels of solar radiation have negative impacts on the growth, photosynthesis, protein and pigment content and reproduction of phytoplankton and on the sea grasses that are important biomass producers in aquatic ecosystems.

Zooplankton and other aquatic organisms, including sea urchins, corals and amphibians, are also sensitive to UV-B radiation. Polar marine ecosystems, where the increases in ozone-related UV-B radiation are the greatest, are likely to be the oceanic ecosystems most influenced by ozone depletion.

The linkage between UV-B radiation, aquatic ecosystems and global warming is also important. When these ecosystems are exposed to higher levels of UV-B radiation, their ability to act as a sink for atmospheric carbon dioxide is reduced. 🦋

## Case Study – Phasing Out Methyl Bromide in North America

Methyl bromide (MeBr), a highly toxic, odorless, colorless gas, has been used as an agricultural soil and structural fumigant to control a wide variety of pests. However, because MeBr depletes the stratospheric ozone layer, Canada, Mexico and the United States agreed under the Montreal Protocol to phase out methyl bromide as a crop pesticide by 2005 in the United States and Canada and by 2015 in Mexico. The phase-out allows an exemption for quarantine applications and preshipment applications to eliminate quarantine pests as well as a Critical Use Exemption designed for agricultural users with no technically or economically feasible alternatives.

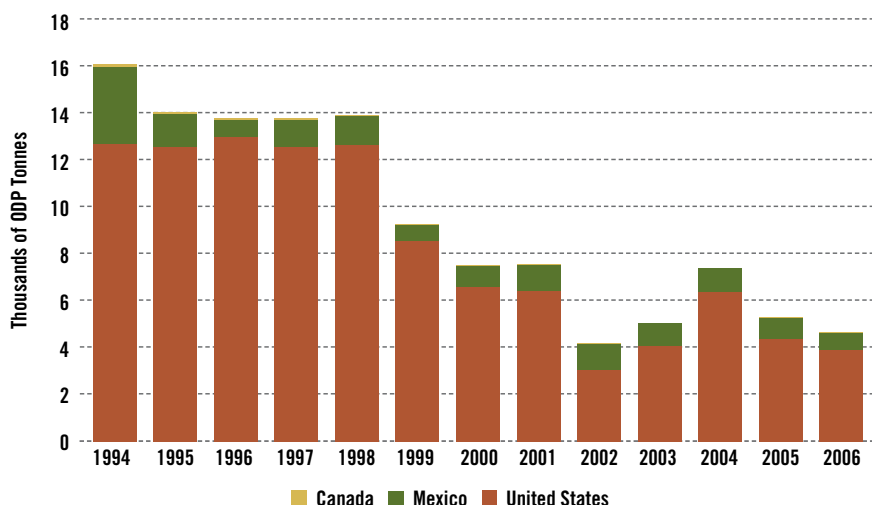
The United States manufactures MeBr and exports it to both Canada and Mexico, because neither country produces MeBr. In all three countries, MeBr is used in growing crops such as strawberry, tobacco, asparagus, flowers, potatoes, tomatoes, peppers and cucumbers. Competition among agricultural producers in the face of different phase-out schedules in the three countries has influenced the ways in which Canada, Mexico and the United States are phasing out MeBr (see graph for these countries' consumption levels of MeBr over the period 1994–2006).

Canada's consumption of MeBr (25 ODP tonnes in 2006) accounts for less than 1 percent of global methyl bromide consumption. The MeBr ban in effect is accompanied by the promotion of alternative technologies emphasizing integrated pest management. Canada has requested a small number of Critical Use Exemptions for the production of strawberry plantlets and fumigation of flour and pasta mills.

With consumption of about 7 percent of the global total, Mexico has the right to a flexible approach as a developing country under the Montreal Protocol. Mexican consumption peaked in 1994 at 3,253 ODP tonnes, falling to 723 ODP tonnes by 2006. Mexico is reducing its MeBr consumption in a stepwise fashion.

The United States remains a significant producer and consumer of MeBr, requesting exemptions for MeBr beyond the original phase-out date in 2005 (see graph). In 2006 the United States produced 6,502 ODP tones of MeBr—55 percent of the global total. That same year, the United States consumed 3,885 ODP tonnes of MeBr—almost 40 percent of the global total. Despite its exemption requests, the United States still reduced MeBr production by over 60 percent and consumption by 75 percent between 1991 and 2006.

North American consumption of methyl bromide



ODP = Ozone Depletion Potential. Source: United Nations Environment Programme.





## Land Use

### Key Findings

- Human land use affects ecosystem function, biological diversity, water quality and quantity and climate. Humans have extensively altered natural land cover in ways that affect the provision of vital ecosystem services.
- The most important human alterations of the natural land cover include widespread changes that have reduced and disturbed forested areas, native grasslands and wetlands to allow farming, ranching, resource extraction and human settlements.
- About 16 percent of North America is designated as “protected” by national governments to preserve valued species, natural spaces and environmental services. Some of these protected areas are affected by encroaching human activities, while other, more remote areas are less directly influenced.
- Compared with overall landscape modification since European colonization, current annual changes are small. However, rates of deforestation and urbanization in certain areas are affecting local ecological systems and global climate.

**Land use** refers to the purposes to which humans commit land cover such as forests and grasslands. Some land uses—particularly those that are less intensive or involve less alteration of natural systems—cause less disruption to ecosystem services such as water purification, recharging of groundwater, nutrient recycling, decomposition of wastes, regulation of the climate and maintenance of biodiversity.

### What Is the Environmental Issue?

Land use is one of the most striking manifestations of humans’ presence and physical impact on the planet. More fundamentally, humans have altered the global patterns and prevalence of species and ecosystems. Several recent studies confirm that human-dominated ecosystems now cover more of earth’s land surface than do natural or “wild” ecosystems. According to one estimate, more than 75 percent of the earth’s ice-free land shows evidence of alteration from human residence and activity, with less than a quarter remaining as wildland. Together, croplands and pastures have become one of the largest land use categories; they occupy about 40 percent of the earth’s land surface.

Intact landscapes with little or no visible signs of influence from human activities such as agriculture, tree felling, mining, highways, pipelines or power lines are increasingly rare. One approach to measuring the extent of intact landscapes is the human influence index, which uses data on population density, settlement patterns, land use and infrastructure to measure the direct human impact on terrestrial ecosystems (see map). The direct human influence is highest in coastal regions and row crop farming areas, along transportation corridors and near population centers.

Although the amount of land in North America is constant, how land is used changes continually. The relationship between land use and land cover is complex because a particular kind of land cover may correspond with a variety of land uses. For example, forested land may be used for timber production, habitat, recreation or watershed protection. Likewise, some

land uses such as agriculture may require maintaining several distinct land covers over time, such as cultivated crops, fallow land, woodlots or even burnt area. Despite this complexity, attempts to categorize land use and land cover can be useful for analyzing humans’ impact on natural ecosystems. Changes in land use can affect the distribution and type of land cover (such as forests, cropland and urbanized areas), the ability of ecosystems to provide valuable services that support life, and even elevation and terrain.

### Why Is This Issue Important to North America?

Human activities have modified the original vegetation cover and landscape of North America in ways that have important implications for the environment. Land use and land cover affect many aspects of environmental quality and the services provided by ecosystems.

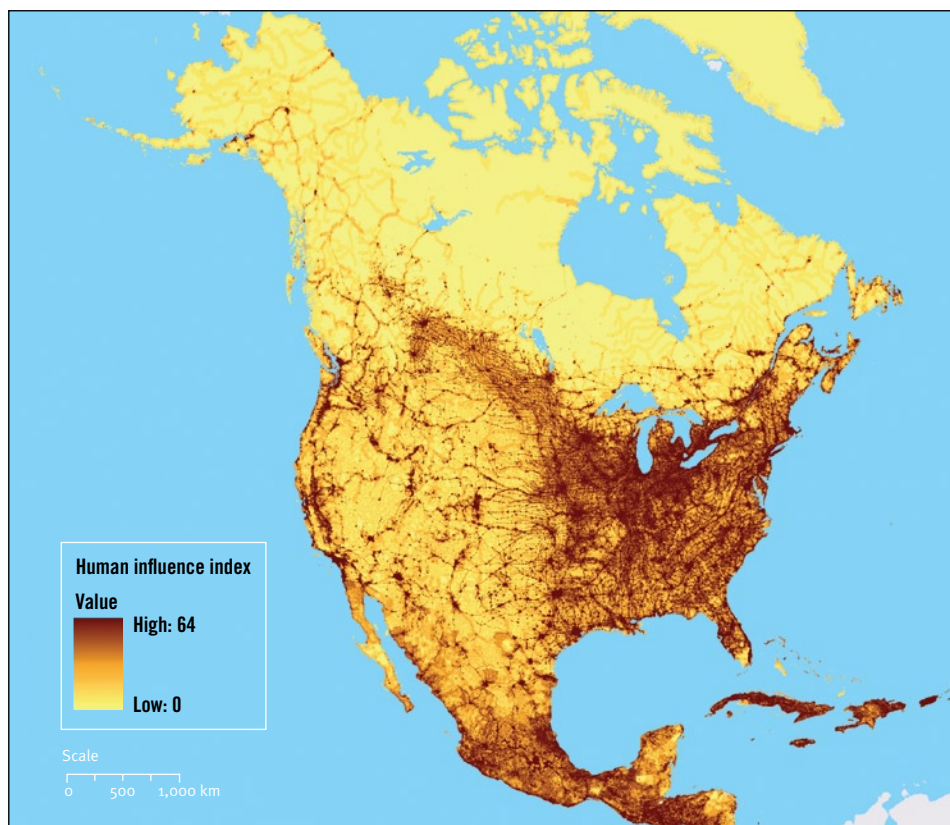
#### Forests

Forests, both managed and unmanaged, cover about a third of North America’s land area. Within this forested area is a great diversity of forest types of which some 45 percent is classified as boreal, mostly in Canada and Alaska. Temperate and tropical forests make up the remainder of the forested area. North America has almost 20 percent of the world’s forests and over a third of its boreal forests.

The extent of forested land is relatively stable in Canada, increasing slightly in the United States and declining in Mexico. Since 1990, Canada has experienced a net increase in forested area of less than 1 percent, whereas



## Human influence index for North America (2000)



Source: Center for International Earth Science Information Network and Wildlife Conservation, Last of the Wild Data Version 2, 2005 (LWP-2): Global Human Influence Index.

forest cover in the United States has grown by about 1.5 percent. In Mexico, between 3.5 and 5 million hectares of temperate and tropical forests have been lost over the last decade. The estimated annual deforestation rates in Mexico range from 0.5 percent to 1.14 percent from the early 1990s to 2000.

Changes in the structure of forest ecosystems introduced by human pressures can make forests more susceptible to damage by fires, drought, insect infestations and air pollution. For example, in Canada, clear-cutting has led to the proliferation of the balsam fir, which is vulnerable to the spruce budworm. In the conterminous United States, almost half of all forests are considered highly fragmented—that is, much of the forested area is in close proximity to a forest edge. Although the United States has many large regions of forest, fragmentation is so pervasive that edge effects disrupt ecological processes and suitability for wildlife habitat on most forested lands. In Mexico, the structure and composition of the remaining woodlands have been altered by the selective extraction of certain preferred tree species and by the extensive conversion of forests to pasture.

### Agriculture

In all, almost a third of North America's surface is devoted to agricultural uses. Although it accounts for only 12 percent of the world's agricultural area, North America produces almost 20 percent of the world's cereals and an equal percentage of the world's meat.

Since 1990, the overall amount of land dedicated to agricultural uses in North America has declined by about 1.5 percent. In Mexico, the most significant opening of land for farming and cattle occurred from 1940 to 1965, with annual growth rates of up to 10 percent a year. Although this trend has slowed, Mexico's agricultural land uses continued to expand by 3.5 percent a year after 1990 and remain a major driver of land transformation. In Canada and the United States, the amount of land devoted to crops has declined since the 1950s. However, even with declines in overall agricultural area, the environmental effects of agricultural practices are still significant. Recent research has revealed that excessive nutrient loading from agriculture has created a considerable hypoxic zone of low dissolved oxygen in the northern Gulf of Mexico, which is causing ecological stress and the death of bottom-dwelling aquatic organisms.

The agricultural area devoted to permanent pasture in North America has remained relatively steady since 1990. However, based on historical land use changes for farming and ranching, temperate North American grasslands have undergone significant changes that have transformed the ecosystem and led to significant losses of biodiversity, especially species such as grassland birds, bison, prairie dogs and the black-footed ferret. Grasslands are one of the continent's most endangered ecosystems (see case study). In 2001 about 55 grassland wildlife species in the United States were either threatened or endangered. In Mexico, overgrazing is reducing the productivity of grasslands and threatening biodiversity.

### Wetlands

Wetlands cover over 10 percent of North America. At 2.5 million square kilometers, this area represents some 40 percent of the global wetland area. Historically, wetlands, which include swamps, bogs and marshes, were undervalued as wasteland to be dredged for ports and marinas or drained for farms, housing and other development. In recent years, scientists have cataloged the many important ecological contributions of wetlands—as breeding grounds for waterfowl, fish and crustaceans; as areas to capture and filter sediments and organic matter; for water retention and flood mitigation; and as protective barriers against storms in coastal areas, among others. As of 2004, North America had almost 200,000 square kilometers of "Ramsar" wetlands, denoted as having international importance.

In the conterminous United States, almost half of all wetlands have been drained since European settlement. In Canada, only 14 percent of wetlands have been lost over this period, primarily in southern Canada. In both countries, agricultural uses have accounted for about 85 percent of the historical loss. But agricultural conversion has slowed in recent years, and urban and suburban development has become a more important driver of wetland loss. Mexico's wetland area is estimated at 36,000 square kilometers, and the historical loss is estimated to be 16,000 square kilometers. Much of Mexico's wetlands are found in coastal areas, where they are pressured by oil infrastructure, urban and tourist development, livestock production and aquaculture.

### Urban Areas

Human settlements such as cities, towns and suburbs vary widely in density, form and dis-



tribution. Urban settlements, as they have been defined by the census bureaus of Canada, Mexico and the United States, contain 75–80 percent of the population of the continent. Determining the extent of human settlements across North America presents a challenge because definitions of such settlements vary greatly, particularly among nations. However, one estimate, based on satellite imagery of nighttime lights, puts North America’s human settlement area at almost 5 percent of the total continental land area. With settlement and urbanization, there has been an increase in the construction of impervious surfaces, which reduce the absorption of water on-site and groundwater recharge and increase storm water diversion, flows and impacts on surface water systems.

Because both the majority of North America’s population and its best agricultural land generally occupy the same regions, urbanization and sprawl have also led to the loss of agricultural land. Over the last 30 years, about half of the area transformed to urban uses in Canada was once agricultural land. In the United States, of the more than 36,400 square kilometers of land developed between 1997 and 2001, 20 percent came from cropland, 46 percent from forestland and 16 percent from pastureland. In recent years, the extent of developed land (urban and industrial) in the United States has increased rapidly. More specifically, from 1982 to 2002 the area of developed land grew

at a rate of 47 percent, almost twice the rate of population growth. In Mexico, 995 square kilometers were converted to urban uses between 1993 and 2000.

The expansion of low-density suburban and rural developments are associated not only with the loss of prime agricultural land, but also with the fragmentation and loss of

### Biodiversity

Habitat loss is the single greatest threat to biodiversity. When habitat is lost or fragmented, species that depend on this habitat experience a variety of pressures that ultimately lead to reduced species populations. During the last 200 years, North America has experienced dramatic transformations of ecological systems

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## Decisions about land use can have significant effects on the contribution of human activities to the emissions of greenhouse gases associated with climate change.

forests, wetlands, grasslands and other wildlife habitats and the associated loss of biodiversity. Development in rural areas has also increased the risk of “interface” fires, which are associated with the intermingling of settlements with flammable forests and grasslands.

### What Are the Linkages to Other North American Environmental Issues?

Changes to land cover threaten biological diversity, contribute to climate change and alter the functioning and provision of ecosystem services.

and significant changes in the abundance of species. As nations have sought to find solutions to transportation, housing, energy and other material needs, the natural environment has been subjected to pressures arising from land cover conversion, habitat fragmentation and pollution. At the same time, protected areas have been established in an attempt to preserve valued species and natural spaces.

Currently, 16 percent of North America is covered by nationally designated protected areas. In some areas, this legal protection status has reduced the extent of human impacts in populated regions. Elsewhere, remoteness,

Protected areas of North America (left) and areas of least human influence (right)



Source: Commission for Environmental Cooperation and Center for International Earth Science Information Network and Wildlife Conservation, Last of the Wild Data Version 2, 2005 (LWP-2): Global Last of the Wild.



terrain and climate have provided large expanses of territory with *de facto* protection from direct human influence (see maps). However, as the climate changes the impacts of human activity will be felt directly and indirectly in even the most remote areas.

### Climate Change

Decisions about land use can have significant effects on the contribution of human activities to the emissions of greenhouse gases associated with climate change. For example, decisions about the extent and patterns of human settlement have had important and long-lasting implications for transportation and its associated greenhouse gas emissions. Likewise, decisions affecting the protection of North American forests affect, in turn, the service provided by those forests as a carbon sink—they have drawn in some 269 million metric tonnes of carbon per year over the last decade or so. Indeed, North American forests contain more than 170 billion tonnes of carbon, of which 28 percent is in live biomass and 72 percent in dead organic matter. Most of the current net removal of carbon from the atmosphere and its storage in vegetation and soil is not a product of deliberate management practices, but instead can be attributed to a combination of past management and the response of terrestrial ecosystems to environmental changes. The substantial carbon removals by the forests of Canada and the United States result largely from the abandonment of agricultural land and subsequent regrowth of shrubs and trees.

### Water Quality and Quantity

Land use activities often affect water quality and hydrology. For example, deforestation may lead to greater susceptibility to flash flooding and sediment loading in nearby streams. Urban development creates large volumes of excess storm water runoff, which can cause flooding, add pollution, create groundwater recharge deficits and alter stream ecology. Development of rural areas also has impacts on stream flows, altering aquatic ecosystems and their ability to maintain habitat and sediment balance. Some of the common impacts of changes in land use on water quality include increased organic matter and biological oxygen demand, changes in stream temperature and sediment load, salinization, changes in water flow and loadings of toxic chemicals, including pesticides and fertilizers. 🐛

## Case Study – North American Grasslands



Source: Commission for Environmental Cooperation.

The natural prairie of central North America is a transboundary ecological region shared by Canada, Mexico and the United States. The prairie grasslands are an immense, contiguous geographic region (see map) with a wide variety of species, land uses and cultural and social practices, as well as economic conditions and political-administrative regimes. The North American prairie is one of the planet's largest biomes.

The northern grasslands are North America's most productive breeding grounds for aquatic birds, featuring species characteristic of both the eastern and western regions of the continent. The prairies maintain resident bird populations, in addition to providing nesting sites and stopover sites for migratory species. More than half the nesting ducks and many other grassland-dependent wildlife species in the United States depend on this crucial habitat. This region is also home to the largest known populations of certain species of hummingbirds, orioles, buntings, warblers, quail and thrashers. The southern grasslands are known for their varied mosaic of species, including 23 percent of the more than 1,500 cactus species found worldwide.

Unfortunately, this ecosystem has suffered extensive deterioration over the last 150 years. In the United States, less than 10 percent of the native Tallgrass prairie remains as grassland; 71 percent has been converted to cropland and 19 percent to urban areas. The main causes of the extensive loss of grassland habitats are changes in land use, such as the historical conversion to farmland or pasture, chemical pollution from farming, overuse of aquifers and unsustainable ranching practices. Extensive cattle raising in such a fragile region often has a negative impact on vegetation and soil properties and characteristics, and thus on the survival of multiple plant and animal species. The diminished grassland coverage also increases the area's vulnerability to wind erosion, which reduces its suitability as a wildlife habitat. Soil compaction impedes natural recovery and leads to desertification. Other major threats include gas and oil drilling; urbanization with the associated highway networks, population density and groundwater overutilization; the growing presence of invasive species; and the increasing aridity arising from climate change.



## Oceans and Coasts

### Key Findings

- Oceans and coastal regions are critical to the social and economic well-being of North America. The continent's coastal and offshore marine ecosystems are home to a remarkable diversity of species, including marine mammals, fish, invertebrates and plants. Coastal regions also lay claim to some of the continent's highest population densities and rates of population growth.
- North America's oceans and coastal regions provide a wide range of goods and services, such as fisheries, trade routes, recreation and tourism, and oil and gas production. Direct human uses, coupled with the impacts of climate change, affect the condition of these ecosystems and their biodiversity.
- The diversity of coastal ecosystems and the variability of human activity affecting them complicate efforts to summarize overall conditions. In general, coastal ecosystems are subject to substantial cumulative impacts from human activities, particularly from development and land use change. Offshore, the productivity of certain fisheries has been greatly reduced by harvesting pressures.
- Despite progress using ecosystem approaches to management and the precautionary approach, trends in North America show continuing overfishing in some areas and ongoing challenges related to land use change, habitat damage and bycatch. Climate change is expected to impose additional stress on marine and coastal ecosystems, with particularly profound effects in the Arctic Ocean from both environmental changes (such as a shrinking sea ice cover) and the associated increase in economic activity.

**Oceans**—the continuous saltwater bodies that cover more than 70 percent of the earth's surface—shape its climate, provide a means of transport and are home to an important part of the planet's biodiversity. **Oceans and coasts**—where land meets the sea—provide a wide range of valued goods and services, including fisheries, trade routes, recreation and tourism, oil and gas production and ecological diversity.

### What Is the Environmental Issue?

Coastal and marine ecosystems support some of the most productive and valuable habitats in the world, including estuaries, coastal wetlands, beaches, mangrove forests, seagrass meadows, coral reefs, sea mounts and upwelling areas. In the three North American countries, these ecosystems extend up to 100 kilometers inland and fully across their marine jurisdictions. The health of these habitats depends on the quality of the ecosystems' physical and chemical processes and associated biological communities. Their degradation and loss affect the viability and productivity of invaluable natural resources.

Globally, coastal areas produce disproportionately more ecosystem services than

most other geographic areas, even those with a larger total geographic extent. At the same time, these ecosystems are experiencing the most rapid environmental change. During the last few decades over a third of mangroves have been lost or converted in countries that monitor these areas. Similarly, approximately 20 percent of coral reefs have been destroyed and an additional 20 percent or more degraded globally. In some countries, the decline of coastal wetlands is reaching 20 percent a year. In the Arctic Ocean, the effects of climate change on marine and coastal areas are already evident or are expected. These effects include loss of sea ice cover, shoreline erosion, flooding caused by rising sea levels and melting permafrost.



Miami, Florida, USA.



Atlantic salmon smolts. Photo: US Fish and Wildlife Service.

A recent global analysis of the cumulative effects of human activities on the oceans found that ecosystems with the highest predicted cumulative impact scores are the hard and soft continental shelves and rocky reefs. Almost half of all coral reefs were categorized as experiencing medium-high to very high impacts. Shallow soft-bottom and pelagic deepwater ecosystems experienced the lowest impact because of the lower vulnerability of these ecosystems to most anthropogenic drivers. Overall, the results highlight the greater cumulative impact of human activities on coastal ecosystems (see map). This analysis does not, however, fully account for the emerging pressures in Arctic coastal ecosystems from the effects of climate change.

### Why Is This Issue Important to North America?

Marine resources and coastal areas are important contributors to North America's social and economic well-being. Indeed, the continent's coastal areas are characterized by some of its highest population densities and rates of population growth. As of 2000, 36 percent of the total North American population lived within 100 kilometers of the coast.

#### Fisheries

Fisheries play a critical role in North America's coastal economies, but ongoing improvements are needed in the management of these resources to ensure their long-term sustainability.

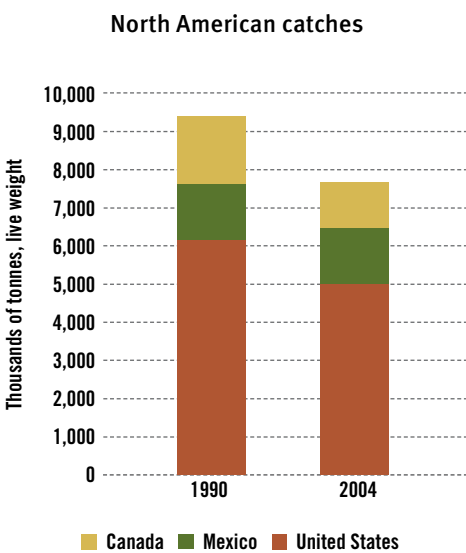
Canada harvests more than 100 commercially valuable species of fish. In 2004 it ranked as the sixth-largest exporter of fish and fishery products in the world, generating revenues of over C\$2 billion. The major marine finfish species in Canada are hake, redfish, cod, herring, salmon and capelin; shellfish products include shrimp, scallop, lobster and snow crab. However, fisheries in Canada are not without problems. Many of the groundfish fisheries off the Atlantic coast and Pacific salmon stocks have declined precipitously. To ensure sustainability and manage the impacts of fishing on sensitive areas, Canada is adopting a precautionary and ecosystem-based management approach to fisheries. In 2004 Canada announced a vision for a renewed fishery sector that aims to improve the economic and biological performance of Canadian fisheries based on these principles.

Mexico is one of the top 20 seafood producers in the world, contributing 1.5 percent of total world fisheries production by weight. Mexico's marine ecosystems also offer other economic benefits that are even more valuable—the coral reefs, clear tropical waters and white sand beaches that serve as a draw for Mexico's lucrative tourism industry. And yet industrial and coastal development, agriculture and tourism have all strained Mexico's ecosystems, and it has not been able to maintain the nearly exponential growth in fisheries that occurred in the final decades of the last century, in part because of the collapse of the anchovy fishery. Stagnant or declining catches, overexploitation of socially important species for artisanal fisheries, and a scarcity of rural development alternatives have created challenges, especially in places where fisheries have great local importance such as Sinaloa and Sonora.

The United States is the third-largest seafood producer country in world behind China and Peru, based on the value of marine and inland capture fisheries. As of 2004, the United States was the fourth-largest exporter and second-largest importer of fish and fishery products by value. Overall, the status of some US fishery stocks have improved, and others have declined. The number of stocks considered "overfished" increased from 43 in 2005 to 47 in 2006. Stocks that are overfished have biomass levels below biological thresholds specified in their fishery management plans. The number of stocks "subject to overfishing" increased from 45 to 48. A stock that is subject to overfishing has a fishing harvest rate above the level that provides for the maximum sustainable yield. The majority of the 530 assessed stocks in the United States are either not overfished (75 percent) or subject to overfishing (80 percent). In the United States, legislation signed in 2007 contains significant new provisions to end overfishing, promote market-based approaches to fisheries management, improve fisheries science, enhance international cooperation and address illegal, unreported and unregulated fishing, as well as bycatch of protected species.

Over time, the significant fishing industries in all three North American countries have experienced declining production. In 2004 North American commercial landings were over 7.6 million tonnes, a reduction of almost 20 percent since 1990 (see graph).

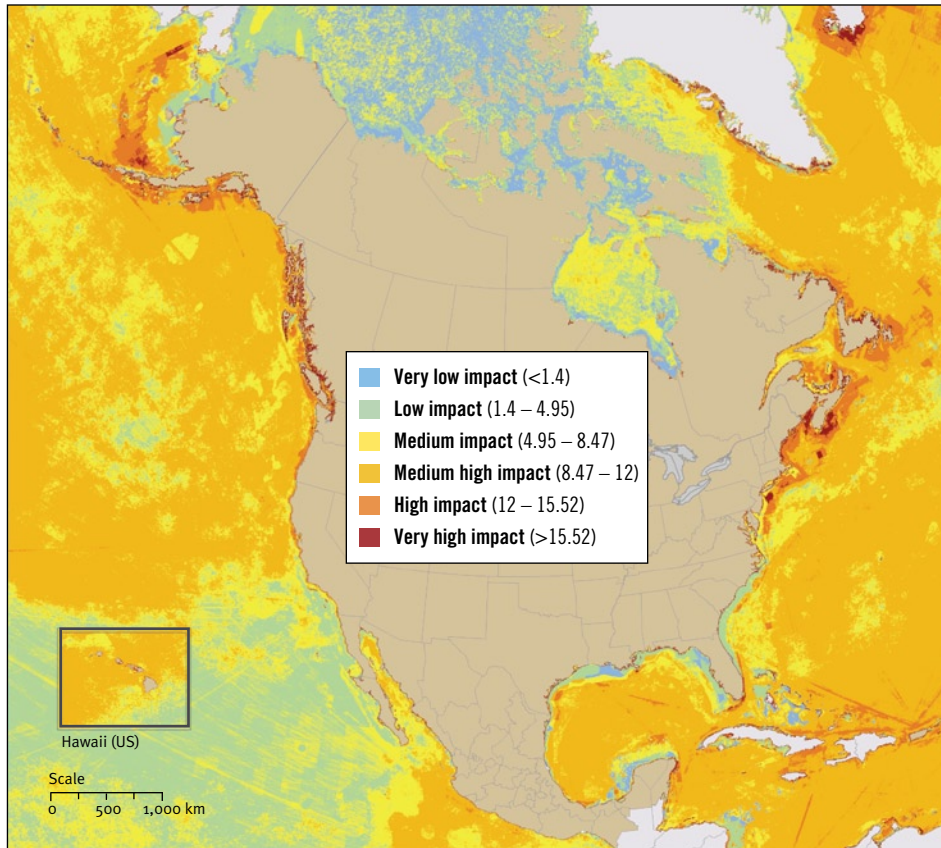
In North America, fishing pressures have been particularly acute in the north-



Source: Fisheries and Oceans Canada.



## Impacts of human activities on North America's marine ecosystems



Source: Adapted from Benjamin S. Halpern, "A Global Map of Human Impact on Marine Ecosystems," *Science* 15 February 2008, 948–952.

The continent's coastal areas are characterized by some of its highest population densities and rates of population growth. As of 2000, 36 percent of the total North American population lived within 100 kilometers of the coast.

eastern regions, but these pressures have also been felt in the Gulf of Mexico and Caribbean, in the Gulf of California and on the West Coast. Affected species include Atlantic cod, Atlantic salmon, haddock, yellowfin tuna, flounder, grouper, red snapper and others. Overfishing affects not only target stocks, but also a wide array of species in the food web, and can cause cascading ecological effects that change the nature of marine ecosystems, sometimes permanently.

### Habitat Damage and Bycatch

Overfishing is not the only problem. The unintended harmful effects of human activities in the oceans, including fishing impacts on habitats and fishing incidental take are also a concern. Habitat damage includes that to living seafloor structures as well as alterations to the geologic structures that serve as nursery areas, refuges and homes for fish and organisms living in, on or near the seafloor. This damage reduces the ability of marine ecosystems to sustain fish-

eries. Bottom gears such as dredges and bottom trawls are associated with high levels of impact on certain types of habitat.

Bycatch refers to the incidental take of fish, other vertebrates and invertebrates not targeted by fishing gear and that may be retained or discarded alive, injured or dead. Currently, almost one-quarter of what is caught by global fisheries is discarded at sea each year. Although nontarget species generally have little or no commercial value, they can become entangled or hooked accidentally during the capture of targeted species such as shrimp, swordfish or tuna. Fisheries bycatch has been implicated as an important factor in the decline of many populations of protected species, including loggerhead and leatherback sea turtles, albatrosses and petrels, sharks and marine mammals such as the vaquita porpoise (see case study). Like those associated with habitat damage, these losses can have cascading effects through marine ecosystems. Although no management strategy has yet succeeded in eliminating bycatch, effective mitigation approaches have been proposed and adopted in some cases. Examples are accounting for bycatch in fishing quotas and installing equipment such as turtle excluders, streamer lines to reduce the catch of seabirds and fine-mesh net aprons to avoid entangling dolphins. Canada, Mexico and the United States participate in domestic and international initiatives to address bycatch.

### What Are the Linkages to Other North American Environmental Issues?

Oceans and fisheries are not, as once thought, vast and inexhaustible resources immune to human activity. In fact, oceans and the coastal areas that border them are linked through important ecological processes.

### Land Use and Habitat

The ability of coastal systems to provide highly valued services is not limited to the marine area in question. Ocean health is intimately linked to that of adjacent marine, freshwater and terrestrial ecosystems, and vice versa. Port development, urbanization, resort development, urban sprawl, aquaculture and industrialization can destroy coastal forests, wetlands, coral reefs and other habitats. Dredging, reclamation and engineering works also account for widespread, usually irreversible destruction. Large segments of North America's coastal areas are at risk of development-related habitat conversion and decline.



The loss of wetlands, coastal sands and mudflats also has implications for fisheries, because many of these areas provide critical nursery habitat for valuable marine species. In the Arctic, the effects of climate change on coastal habitats are expected to be particularly pronounced.

#### Water Quality

Marine and coastal ecosystems play an important role in maintaining water balance and providing freshwater for human consumption. Freshwater is also the main link between land use and the provision of coastal ecosystem services. Land-based sources of pollutants are delivered via rivers, from runoff and through atmospheric deposition. Logging of forested areas contributes to erosion and sedimentation, leading to estuarine decline in coastal and marine ecosystems. This pressure reduces the available feeding and nursery habitats for many marine species. Agriculture introduces harmful fertilizers, nutrients and toxics into coastal ecosystems. Polluted waters entering the marine environment cause degradation, lead to loss of ecosystem services and often pose human health issues. The removal of buffers such as riparian and estuarine wetlands compounds the problem by reducing the natural waste management that these ecosystems provide. Diversion of freshwater from estuaries results in losses of water and sediment delivery to nursery areas and fishing grounds.

#### Climate Change

The condition of the oceans and climate change are inseparable—not only because marine and coastal systems suffer the effects of climate change, but also because oceans drive both climate and weather. Global climate change imposes additional stress on coastal and marine systems that have been degraded by chronic multiple impacts and may impede the resilience of marine and coastal ecosystems. Coastal systems are simultaneously vulnerable to rises in sea level, erosion and acute storm events.

Although all oceans are susceptible to the impacts of climate change, the relatively pristine Arctic Ocean is particularly vulnerable. Rising temperatures are already rapidly and profoundly affecting sea ice cover, ocean processes and coastal habitat integrity. When those effects are coupled with the associated increase in natural resource development and shipping activities, North Americans may find that the Arctic will require considerably more effort to protect the integrity of its marine ecosystems and the communities that depend on them. 🐞

### Case Study – The Vaquita

The vaquita (*Phocoena sinus*), a small porpoise endemic to the northern Gulf of California, Mexico, is the most critically endangered marine small cetacean in the world—it is estimated that the population numbers only about 150. The vaquita is threatened primarily by the fishing gill nets used to catch fish and shrimp. Although other risk factors are the trawling that affects vaquita behavior and the uncertain effects of dam construction on the Colorado River and the resultant loss of freshwater input to the upper Gulf, entanglement is the clearest and most immediate concern.



Photo: Omar Vidal.

Captive breeding is not feasible for vaquitas because of the difficulty in capturing these small, solitary elusive animals in relatively deep water and the complete lack of experience with this species in captivity.

In only a few years, the options for conserving the vaquita will be severely reduced. Although conservation groups, concerned scientists and government officials in Mexico have invested significant time and financial resources in vaquita conservation over the last 25 years, progress toward reducing entanglement has been slow, in spite of efforts to phase out gill nets in the vaquita's core range and provide compensation schemes for fishermen. Indeed, the Biosphere Reserve in the northern Gulf has fallen far short of its potential for vaquita conservation. On 29 December 2005, Mexico declared the area in which about 80 percent of verified vaquita sightings had been made a Vaquita Refuge. In the same decree, the state governments of Sonora and Baja California were offered \$1 million to compensate affected fishermen. The effectiveness of this major initiative remains to be seen.





# Invasive Species

## Key Findings

- Biological invasion and the diversity and abundance of species spreading beyond their natural ranges are at the highest rates ever recorded with serious consequences for the environment, economy and human health.
- A significant increase in the introduction of non-native species into and within North America has been an unintended consequence and cost of the growing scale of global trade, travel, and transport since the early 1900s.
- Individual invasive species have already had profound and quantifiable negative impacts on the environment, economy, industry, infrastructure, human health and ecological function in North America. Climate change is making northern ecosystems more receptive to invasive species because of milder winters creating the potential for a significant increase in the introduction of these species.
- The issue of invasive species is recognized and the spread of certain individual species is monitored on a regular basis but comprehensive trend indicators are not available for major biomes (i.e., terrestrial, freshwater, marine/estuarine) or North America as a whole.

**An *invasive species* is a plant, animal or microscopic pathogen that, once transported out of its native range, has established itself, spread and caused harm to the environment, economy or human health in its new habitat.**

## What Is the Environmental Issue?

Invasive species are a significant environmental challenge. At no time in history has the rate of biological invasion, and the diversity and volume of invaders, been so high and the consequences so great.

Today, goods, services and people are on the move worldwide. These international movements and transactions have brought social and economic benefits to many people in North America, but they also have brought new challenges. The growing rate and scale of global trade, travel and transport since the early 1900s have been accompanied by an exponential increase in the introduction of non-native species into and within North America. At times, non-native species are introduced intentionally for use in a broad range of industries such as agriculture, aquaculture, horticulture and the pet trade. But

they also may arrive as inadvertent “hitchhikers” via imported plants and livestock, travelers and their baggage, manufactured goods, packaging materials and conveyances such as airplanes and ships in their ballast water or on their hulls (see table, which presents some common pathways of biological invasion).

North America’s intracontinental transportation systems are vast. They include 7.5 million kilometers of roads, thousands of kilometers of navigable waterways and railroads, extensive coastal shipping routes and nearly half of the world’s airports. Once on the continent, invasive species can spread along roads and waterways and hitchhike on vehicles, in baggage and among cargo shipments, while marine/estuarine invaders can travel via intra-coastal shipping or be transported by currents. Because invasive species do not respect political boundaries, species that invade one country have the potential to spread within a

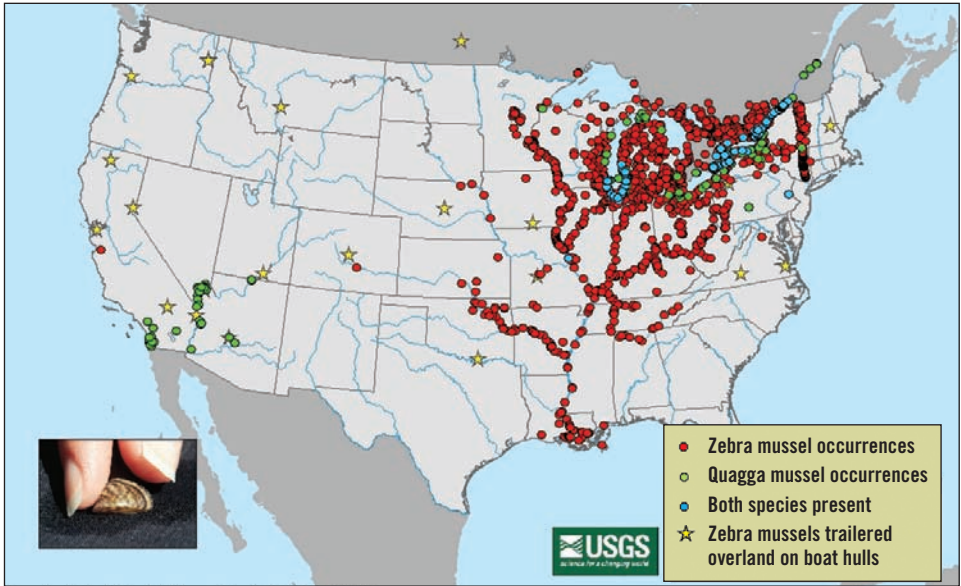
## Pathway categories

Transport mechanisms	Living commodities (biological species unintentionally introduced)	Living commodities (biological species intentionally introduced)
Via conveyances, packaging, equipment, and non-living commodities	Via living commodities that are not intended for release into the environment	Via living commodities that are intended for release into the environment
For example: Ship hulls Ballast water Solid wood packaging (pallets, dunnage) Military equipment Clay tiles	For example: Fruits and vegetables for consumption Pets Laboratory animals Animals for zoos and public aquaria displays	For example: Horticultural plants Crops Stocked fish Game animals

Source: Adapted from National Invasive Species Council



**Distribution of zebra and quagga mussel sightings in United States and Canada (March 2008)**



Source: US Geological Survey.

region. For example, both zebra mussels and quagga mussels were unintentionally introduced to North America through shipping. These invasive mussels were first discovered

in the Canadian waters of Lake St. Clair near Detroit in 1988. They have since spread throughout watersheds across the continent with negative impacts on aquatic environ-

ments and local economies (see map, which depicts sightings of these invasive mussels in the United States and Canada). Recreational boats are major vectors in freshwaters to redistribute these mussels and other freshwater invasive species once they have invaded North America. Ballast water and hull fouling are important transport mechanisms for the introduction and spread of marine and estuarine species, especially in the Great Lakes and coastal estuaries.

Once invasive species are introduced, ongoing changes in land use, climate and freshwater and marine ecosystems can facilitate biological invasion by making habitats more challenging for native species and more hospitable to invasive species. Because disturbed habitats often favor rapid colonizers, they are particularly vulnerable to the invasion of non-native species. From the perspective of the invasive species, it does not matter whether the environmental changes are natural or human-induced (see box).

**Why Is This Issue Important to North America?**

With its many linkages to the global economy, North America is extremely vulnerable to the introduction of invasive species from abroad. Likewise, species native to Canada, Mexico and the United States can be spread via the international movements of people and trade goods to other countries (within North America and beyond) where they can become invasive. As trade, transport and travel expands, so do many of the risks associated with biological invasion. The environmental and economic consequences of invasive species can be significant. Climate change is increasing the risk of introduction of harmful non-native species.

**Environmental Implications**

Permanent elimination of native species unique to North America is one of the issues at stake. In the United States, invasive species rank second to habitat modification as a cause of species endangerment, and they are the primary driver of extinctions in island ecosystems, as well as many freshwater systems worldwide. Extinction of native species can result from a single or multiple impacts from invasive species, including competition for food, space, or reproductive sites; increased predation; and/or parasites and diseases for which native species have no defense. Invasive species can also degrade eco-

**When Prevention Fails . . .**

Here are a few examples of invasive “hitchhikers” that have already had profound negative impacts on the environment, economy, industry, infrastructure and human and animal health in North America:

- Asian carp** (*Hypophthalmichthys nobilis*, *H. molitrix* and others): environment
- Asian longhorned beetle** (*Anoplophora glabripennis*): environment, industry
- Asian tiger mosquito** (*Aedes albopictus*): human and animal health
- Brown tree snake** (*Boiga irregularis*): environment, infrastructure, human health
- Chytrid fungus** (*Batrachomyxium dendrobatidis*): environment
- Dutch elm disease** (*Ophiostoma ulmi*): environment, industry
- Emerald ash borer** (*Agrilus planipennis*): environment, industry
- European green crab** (*Carcinus maenas*): environment, industry
- Giant African snail** (*Achatina fulica*): environment, industry, human health
- Gypsy moth** (*Lymantria dispar*): environment, industry
- Norway rat** (*Rattus norvegicus*): environment, infrastructure, human and animal health
- Red imported fire ant** (*Solenopsis invicta*): environment, human health

As of 2006, Mexico's *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* (Conabio) had identified at least 800 invasive species in Mexico, including 665 plants, 77 fish, 2 amphibians, 8 reptiles, 30 birds and 6 mammals. In Canada, invasive alien species include at least 27 percent of all vascular plants, 181 insects, 24 birds, 26 mammals, 2 reptiles, 4 amphibians, several fungi and mollusks, and 55 freshwater fish. Although extensive data on individual species are available, similar totals are not currently available for the United States.



system functions and the production of ecosystem services, from food production to aesthetic value. Even the most well-protected natural areas are not immune to biological invasion. Predicting ecological impacts is made all the more difficult in that the effects of invasive species may be evident immediately or observable only after many years.

**Economic**

Invasive species can take a heavy financial toll on governments, industries and private citizens. Economic losses can be a direct cost such as lost or reduced crop production, or an indirect loss of tourist dollars from reduced quality reefs or sport fisheries. Globally, the economic losses from invasive species have been estimated at US\$1.4 trillion a year. The cost to the United States is more than \$100 billion a year. In Canada, the damage to agricultural crops and forestry from harmful invasive plant pests has been estimated at C\$7.5 billion annually, and in the Canadian province of Manitoba

alone, the economic losses from Dutch elm disease have been estimated at \$30 million. Another type of direct economic impact is the cost to meet existing or proposed national and international regulations, such as the proposed requirement for ballast water treatment for all new ships under the International Maritime Organization ballast water treaty. The impact and management costs of a single species can carry a substantial price tag (see box for examples). If indirect costs such as loss of ecosystem services were also counted, these estimates would be substantially higher.

**Human Health**

The consequences of invasive species for human health can be direct from exposure to new diseases and parasites or indirect from higher and more frequent exposures to pesticides necessary to eradicate and control invasive species. Pathogens and parasites may themselves be invasive species or may be introduced by invasive vectors such as non-native mosquitoes. Cholera and some of the microorganisms that can cause harmful algal blooms are relocated and released in the ballast water carried by large ships. Other high-profile diseases

**The Costs of Control and Eradication**

The **Formosan termite** (*Coptotermes formosanus*), introduced into the south-eastern United States from East Asia, is an expensive visitor: an estimated US\$1 billion a year is spent on property damage, repairs and control measures.

The **European gypsy moth** (*Lymantria dispar*), introduced into North Carolina in 1993 and eradicated four years later, carried a \$19 million price tag.

The Great Lakes Fishery Commission—jointly administered by the Canadian and US federal governments—spends about \$22 million a year to control the **sea lamprey** (*Petromyzon marinus*).

Researchers estimate the **zebra mussel** (*Dreissena polymorpha*) cost the power industry alone US\$3.1 billion in the 1990s, with an impact on industries, businesses and communities of over \$5 billion. In Canada, Ontario Hydro has reported that the zebra mussel has cost each generating station \$376,000 a year.

The cost of eradicating one or more introduced mammals from 23 islands off the coast of northwest Mexico was about \$750,000.

**Case Study – The Cactus Moth**



Larvae of the invasive cactus moth.

The cactus moth (*Cactoblastis cactorum*) reproduces and feeds on cacti in the genus *Opuntia*, commonly known as prickly pears. Originally from South America, the cactus moth has been introduced around the world as a biocontrol agent for invasive cacti. In 1989 the moth was discovered in the Florida Keys, likely having arrived either by natural wind dispersal or on imported horticultural prickly pear cacti from the Caribbean. Since that time, the moth’s range has expanded northward along the Atlantic and Gulf coasts of Florida, despite active control efforts. This expansion has put North America’s native *Opuntia* at great risk.

Mexico is a hotspot of prickly pear diversity, with 38 endemic species covering 3 million hectares. The United States also has 31 species of prickly pear, nine of which are endemic, including Florida’s extremely rare *Opuntia corallicola*. Numerous species of birds, bats, mammals and insects depend on prickly pears for food and habitat, and the cacti provide erosion control for fragile desert soils.

Aside from its enormous consequences for North American biodiversity, the cactus moth threatens the agriculture, landscaping and ranching industries. In 2000 the value of ornamental prickly pear cacti used for xeriscaping, or dryland gardening, in Arizona amounted to US\$14 million a year. Prickly pear pads (nopales) and fruits (tuna) are the seventh-largest agricultural crop in Mexico, where they are frequently gathered from the wild to supplement dietary intake. A national symbol, the prickly pear is featured on the Mexican flag and currency.

In a display of international cooperation, the Mexican government has funded US Department of Agriculture efforts to halt the westward spread of the cactus moth. However, in 2006 the moth was discovered on the Mexican island of Isla Mujeres (9 kilometers from Cancún on the mainland), and the Mexican government is now attempting to eradicate it through an extensive trapping program.

Photo: Peggy Greb, <http://www.ars.usda.gov/is/graphics/photos/sep06/d588-2.htm>.



caused by invasive pathogens are malaria, dengue fever and the human immunodeficiency viruses that cause AIDS. Less well-known diseases can also be problematic. For example, the giant African snail, a potential food source as well as a pet, provides an intermediate host for rat lungworm, which can infect the human brain, causing headache, fever, paralysis, coma and even death.

### What Are the Linkages to Other North American Environmental Issues?

Invasive species are associated with a range of continent-wide environmental issues. Rapidly changing environmental conditions will tend to increase the diversity, spread and impacts of invasive species.

#### Climate Change

Climate change is likely to increase both the rate of new invasions into North America as well as promote the spread of invasive species already established. Stress on natural environments, such as that caused by climate change, may decrease their ability to resist biological invasion. Climate change is likely to increase the opportunities for invasive species to establish themselves after a storm or fire. Warmer temperatures or changes in rainfall patterns may enable certain species to expand their ranges and occupy new roles in ecological systems. Changes in the direction and strength of airflow could influence the spread and migration of airborne species, such as flying insects, while changes in near-shore currents could affect the distribution of marine/estuarine invaders.

#### Land Use

Because many invasive species are fast-growing, highly opportunistic ecological generalists, land use change generally favors biological invasion. For example, road building, edge maintenance for roads and power transmission corridors, and logging can open new areas to invasive species and facilitate their spread via equipment and workers. Agricultural activities can introduce invasive species into new areas through seed contamination and crop “escapes.” And abandoned agricultural areas may be invaded by invasive species before natural succession can restore the local plant community. In urban and suburban environments, gardeners introduce non-native species for gardening that may spread into natural environments by means of “green space” corridors.

#### Water

Invasive species can place significant limits on the availability of potable water, as well as surface water for use by wildlife. Certain species such as pines and eucalyptus can draw down water tables and negatively influence regional water cycles. By affecting nutrient cycling, aquatic invasive species can promote eutrophication or the growth of undesirable algae. Invasive aquatic plants can choke waterways and trap sediment, causing the aquatic system to stagnate and eventually fill in. Stagnation can also increase the risk of disease such as West Nile virus by fostering mosquito populations.

#### Energy

Governments around the world are investing in biofuel energy production. Many of the characteristics that make plants good biofuel candidates—such as rapid growth rates and tolerance of disturbed environments—are the same characteristics that make a plant an effective invader. In fact, several species of invasive plants have been proposed for biofuel production in North America. The risk then becomes the potential escape of non-native species used for biofuel into the natural environment. 🦋

### Case Study – Tree Pests

In the United States and Canada, the recent appearance of several invasive species that are threatening forests and forest product industries turned a spotlight on a neglected pathway: solid wood packaging materials, including the crates, pallets and dunnage used to transport various commodities. These materials can harbor the eggs, larvae and adult



Asian longhorned beetle. Photo: US Fish and Wildlife Service

forms of bark- and wood-boring insects. Recent examples of serious pests that may have been introduced through untreated packaging materials are the emerald ash borer (*Agrilus planipennis*) and the Asian longhorned beetle (*Anoplophora glabripennis*).

The emerald ash borer was first discovered in 2002 on infested ash trees in Detroit, Michigan, and neighboring Windsor, Ontario, but apparently it arrived undetected and became established over a decade earlier. Native to China and eastern Russia, the beetle feeds on ash trees, killing them in the process. Ash trees are an important part of North American forests, providing food for numerous species of wildlife, and are a popular street tree in many midwestern US and Canadian cities. The emerald ash borer has spread into Ohio, Indiana, Illinois and farther into Michigan and Ontario, killing over 15 million ash trees in southeastern Michigan alone. Hitchhiking on nursery shipments, lumber and firewood, it has repeatedly escaped the quarantine areas set up by federal, state and provincial governments. Unfortunately, the prospects for successfully eradicating the emerald ash borer are not good.

The Asian longhorned beetle was first discovered in New York in 1996, followed by detections in 1998 in Illinois, in 2002 in New Jersey and in 2003 in Ontario. The beetle attacks and kills many types of hardwood trees, including maples, and could drastically alter the region’s forests, as well as cost the forestry, landscaping, maple syrup and fall color tourism industries billions of dollars. This insect also could decimate 30 percent of urban street trees in the United States at a replacement cost of hundreds of billions of dollars. Since first detecting the insect, the US and Canadian governments have undertaken costly eradication efforts, requiring the removal of thousands of neighborhood, park and street trees. Although proceeding slowly, the eradication efforts have had promising results. Moreover, national, regional and international standards for fumigation and labeling are being developed to prevent invasive species from infesting packing materials.



## Species of Common Conservation Concern

### Key Findings

- North America's species of common conservation concern are a group of migratory, transboundary and endemic species that Canada, Mexico, and the United States have identified from among the continent's great wealth of wild flora and fauna as requiring cooperative attention for their effective conservation.
- North America is subject to pressures that affect the conservation of these species—among them, climate change, land use and habitat conversion, invasive species and pollution.
- Across North America, almost 1,600 species are critically endangered, endangered or vulnerable. The terrestrial and marine species of common conservation concern are a small but important sample of birds, mammals and reptiles selected for special conservation attention by the three countries.
- Some species have experienced population increases, while others are still declining in numbers. Although the status of individual species is assessed periodically, a North American trend indicator for this group as a whole is not available.

*Species of common conservation concern* are a group of North American migratory, transboundary and endemic species. As charismatic species, they were chosen for their ability to attract public attention and garner conservation resources. Conserving these species and their habitats requires regional cooperation. Successful conservation of these species will also have benefits for other species.

### What Is the Environmental Issue?

North America's species of common conservation concern are a group of species selected from among North America's great wealth of wild flora and fauna for special attention. Most of these species use or travel through a series of different habitats throughout North America, and thus can only be protected through the effective collaboration and action of multiple stakeholders.

Canada, Mexico and the United States share ecosystems that are home to species that move freely across their national borders. With that in mind, experts and representatives

of the three countries' federal wildlife services compiled a list of species whose conservation is of common concern and would require a regional approach. Priority was given to transboundary or migratory bird and mammal species that are endangered or threatened in one or more countries, extinct in at least one country, or warrant special concern, and to those likely to demonstrate the importance of trilateral or bilateral cooperation (see box for a list of the land species selected).

In the selection process for marine species, priority was given to transboundary or migratory species that are at high risk of extinction



Golden-cheeked warbler, breeding adult male. Photo: Gene Nieminen, USFWS-NCTC.



American black bear. Photo: Steve Maslowski.



Black-tailed prairie dog.

because of current status or trends, inherent natural vulnerability or susceptibility to anthropogenic threats; are ecologically significant; are officially listed as being of conservation concern by one of the three North American countries, by the World Conservation Union or by the Convention on International Trade in Endangered Species; are capable of recovery or management; and have a high potential for public engagement. The list finally developed by the country teams focused on three taxonomic groups: marine mammals, seabirds and sea turtles (see box).

Migratory and transboundary species use or travel through a series of habitats in

North America. Because of the large-scale migratory patterns and transboundary nature of these species, they depend on the continued availability of breeding and feeding habitats, as well as the important movement corridors and staging areas along the migratory routes linking the breeding and foraging grounds. The survival of many land and marine species of common conservation concern depends on the existence of ecosystems that are relatively intact. Changes to their status may point to deeper problems of biodiversity.

### Why Is This Issue Important to North America?

Addressing the needs of these species requires paying attention to the root causes of biodiversity loss, especially landscape change and habitat loss on land and incidental take and habitat damage in the marine environment. The recovery of species that are migratory or have transboundary ranges is difficult or impossible without cooperation among the affected countries. Even endemic species may be affected by pressures originating outside the host country.

#### Categories of Species of Concern

The North American species of common conservation concern are a small group when compared with the almost 1,600 species that are critically endangered, endangered or vulnerable in North America (see graph), but they are important nevertheless. They include ecologically important species, flagship species, umbrella

#### Terrestrial Species of Common Conservation Concern

##### Birds

- Burrowing owl** (*Athene cunicularia*)
- California condor** (*Gymnogyps californianus*)
- Ferruginous hawk** (*Buteo regalis*)
- Golden-cheeked warbler** (*Dendroica chrysoparia*)
- Loggerhead shrike** (*Lanius ludovicianus*)
- Mexican spotted owl** (*Strix occidentalis lucida*)
- Mountain plover** (*Charadrius montanus*)
- Northern spotted owl** (*Strix occidentalis caurina*)
- Peregrine falcon** (*Falco peregrinus*)
- Piping plover** (*Charadrius melodus*)
- Whooping crane** (*Grus americana*)

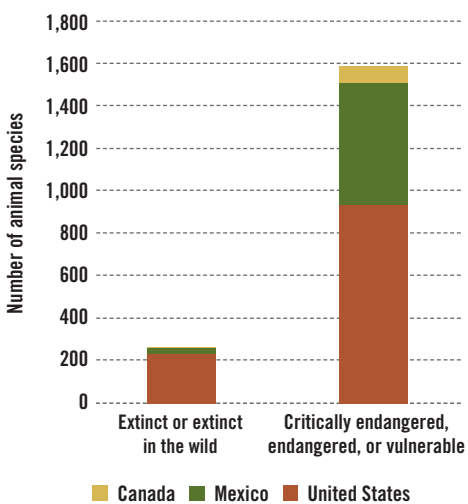
##### Mammals

- Black bear** (*Ursus americanus*)
- Black-tailed prairie dog** (*Cynomys ludovicianus*)
- Gray wolf** (*Canis lupus*)
- Lesser long-nosed bat** (*Leptonycteris curasoae yerbabuena*)
- Mexican long-nosed bat** (*Leptonycteris nivalis*)
- Sonoran pronghorn** (*Antilocapra americana sonoriensis*)

species, keystone species and indicator species, as well as species of taxonomic rarity and those having a high percentage of the global population located in North America.

*Flagship species* represent a wide range of taxa, different levels of risk and wide geographic spread. In essence, most are charismatic species—a trait that should help galvanize public attention and garner conservation resources. An example is the sea otter, one of the smallest marine mammals. Its captivating image appears on a variety of products from t-shirts to mouse pads and is well known to the general public. Another example is the vaquita, a small porpoise endemic to the northern Gulf of California, Mexico. The vaquita is threatened primarily by the fishing gill nets used to catch fish and shrimp that are consumed domestically and exported across North America.

### Species in jeopardy in North America



Source: 2007 IUCN Red List of Endangered Species.



## Marine Species of Common Conservation Concern

### Marine mammals

**Blue whale** (*Balaenoptera musculus*)

**Gray whale** (*Eschrichtius robustus*)

**Guadalupe fur seal**

(*Arctocephalus townsendi*)

**Humpback whale**

(*Megaptera novaeangliae*)

**Killer whale** (*Orcinus orca*)

**Right whale**

(*Eubalaena glacialis* and *Eubalaena japonica*)

**Sea otter** (*Enhydra lutris*)

**Vaquita** (*Phocoena sinus*)

### Seabirds

**Pink-footed shearwater**

(*Puffinus creatopus*)

**Short-tailed albatross** (*Phoebastria albatrus*)

**Xantus' murrelet**

(*Synthlibirampus hypoleucus*)

### Sea turtles

**East Pacific green turtle**

(*Chelonia mydas agassizii*)

**Hawksbill turtle** (*Eretmochelys imbricata*)

**Kemp's Ridley turtle** (*Lepidochelys kempii*)

**Leatherback turtle** (*Dermochelys coriacea*)

**Loggerhead turtle** (*Caretta caretta*)

*Umbrella species* are those whose effective conservation will result in the protection of many other species that share the same habitat. For highly migratory animals such as the leatherback turtle, hawksbill turtle, loggerhead turtle, right whale, gray whale, pink-footed shearwater, short-tailed albatross and whooping crane, protection of umbrella species means protecting a whole suite of linked habitats—and the myriad organisms they support.

*Keystone species* play a pivotal ecological role in maintaining the biological diversity and structure of the food web. For example, removal of the sea otter would cause cascading effects that ultimately would result in the loss of kelp forests and associated communities. The hawksbill turtle also plays a keystone role—preventing the domination of the reefs by fast-spreading sponges. For keystone species, the



Two Kemp's ridley hatchlings, Padre Island, Texas, USA. Photo: NPS, Padre Island National Seashore.



Pink-footed shearwater. Photo: Hadoram Shiraha.

## The survival of many land and marine species of common conservation concern depends on the existence of ecosystems that are relatively intact.

risk of extinction implies broader community-level consequences.

Species of common conservation concern may also act as *indicators* or biological barometers of how well or badly their host ecosystems are faring. Such is the case for the grasslands, a highly modified ecosystem under extreme duress, where a majority of the terrestrial species of concern make their home.

### What Are the Linkages to Other North American Environmental Issues?

North America is subject to natural and anthropogenic pressures that affect the conservation of these and other species.

### Human Use of Terrestrial and Marine Ecosystems

The detrimental effects of changes in land use and habitat fragmentation on animal populations are well known. The destruction of land habitat may stem from factors such as conversion of natural habitat to agricul-

tural or urban development, physical modification of rivers or water withdrawal from rivers. Habitat loss also occurs in coastal and marine systems. For example, trawling of the seabed can significantly reduce the diversity of marine habitats, and destructive fishing and coastal development can lead to losses of coral reefs. When habitat is lost, plant species and the associated community of animals whose habitat is largely determined by the composition of the native plant communities become extinct. Even more widespread than total habitat loss is habitat fragmentation. The smaller pieces of the original habitat are not large enough to maintain viable populations of some species.

### Invasive Species

After habitat destruction and fragmentation, the introduction of invasive species is regarded as the greatest threat to the continuity of biodiversity. Invasive species compete with native species primarily for space and food, and

the vulnerability of natural ecosystems to fire, flood and other natural phenomena is altered if the composition of native species is disturbed. Invasive species also propagate disease and disturb natural ecosystem processes. The diverse geography of North America allows invasive species from almost anywhere to find a hospitable place in some part of the region, with ecosystems ranging from Arctic tundra, tropical coral reefs and deserts to rain forests and freshwater rivers and lakes.

### Climate Change

Climate change is expected to intensify habitat disturbance in North America. A greater number of disturbances are likely to enable the proliferation of invasive species and disrupt ecosystem services. Over time, species will respond to the climatic pressures by moving north and to higher elevations in search of more acceptable habitats, thereby rearranging North American ecosystems. From the tropical jungles of Mexico to the Arctic regions of Canada and the United States, the structure, function and services of ecosystems will change in response to the various capacities of species to undertake such range shifts and from the constraints imposed by development, habitat fragmentation, invasive species and broken ecological connections.

### Pollution

Certain threats to biodiversity, especially those that undermine ecosystem integrity in ways not easily seen, are difficult to quantify. For example, it is known that pollution affects the hawksbill turtle. Pesticides, heavy metals and PCBs have been detected in turtles and eggs, and oil spills harm the animal's respiration, skin, blood chemistry and salt gland functions. Like other marine turtles, hawksbills eat a wide variety of debris, including plastic bags, packing peanuts, tar balls, balloons and plastic pellets. Even at low levels of ingestion, this debris can interfere with metabolism and block the digestive system. Toxic byproducts can also be absorbed. The exact impact of pollution on this and other species is difficult to measure because the effects of specific pollutants at varying levels on the health of exposed species are unknown. 🦋

## Case Study – Burrowing Owl



Burrowing owl.

The burrowing owl (*Athene cunicularia*) is a bird with resident and migrant populations alike in Canada, Mexico and the United States (see photo). Northern populations of the burrowing owl migrate south during winter, spending the season in Mexican territory and the southern United States (see map). The species prefers grasslands, desert zones and open areas. One distinctive characteristic of this bird is that it nests in burrows it digs itself, or in burrows dug by mammals such as prairie dogs, gophers and ground squirrels. These holes not only provide a place to nest, but also protect against wind, rain, sun and predators.

Burrowing owl populations have fallen throughout Canada and the United States; Mexico does not have sufficient data to determine that country's trends. In Canada, the situation of the burrowing owl is critical—it faces possible extinction.

Intensive land use—particularly conversion of grasslands to farming—is thought to be an important factor in the drop in the burrowing owl population. Prairie dog and

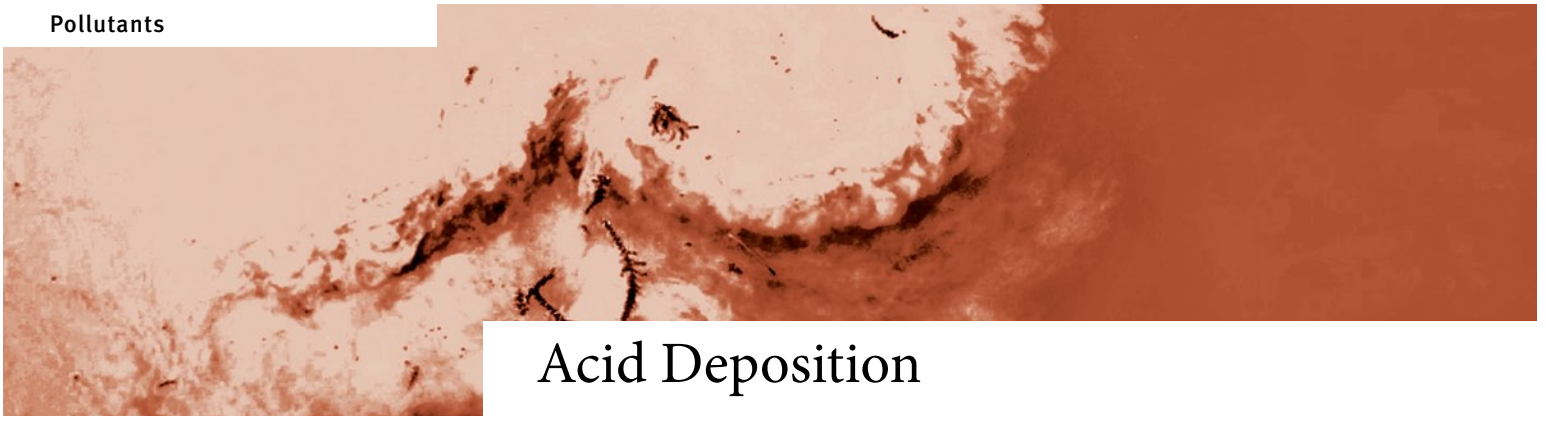
### Regions populated by the burrowing owl



Source: NatureServe.

rabbit eradication programs may be another. Intensified land use has led to the loss and overall fragmentation of nesting grounds. Fragmentation hinders the owl's ability to find a mate, and it appears to interfere with juvenile dispersal as well. Other factors underlying population decline include urban development, pesticide use and invasive grass species that change grassland physiognomy. In Canada, over 75 percent of the prairies have been cultivated, and much of the remaining grasslands have been altered by human activities. Problems along the burrowing owl's migration routes and in the wintering grounds may be contributing to higher species mortality as well.





## Acid Deposition

### Key Findings

- Acid deposition (commonly called acid rain) degrades the quality of forests, coastal ecosystems, lakes and soils; harms wildlife; and corrodes building materials. Acidifying emissions can cross national and provincial or state boundaries, affecting ecosystems hundreds of kilometers away.
- Sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) are acidifying emissions that contribute to acid deposition. These chemicals are emitted mainly by human activities such as metal smelting and fossil fuel combustion in electricity generation and transportation.
- Since 1990, emissions of SO<sub>2</sub> in North America are down by one-third and those of NO<sub>x</sub> have declined by just over one-fifth. Sulfate deposition in the eastern United States and Canada has decreased substantially over the last 15 years, whereas the reduction in nitrate deposition has been less dramatic.
- Despite the considerable progress made toward reducing emissions and the deposition of acidifying pollution, many sensitive ecosystems are still receiving levels of acid deposition above the threshold levels that cause long-term damage. Furthermore, some regions previously affected by high levels of acid deposition are not recovering as expected.

*Acid deposition* primarily results from the transformation of air pollutants such as sulfur dioxide and nitrogen oxides into secondary pollutants such as sulfuric acid, ammonium nitrate and nitric acid. Acidic particles and vapors can be deposited on the earth's surface as acid precipitation (wet deposition) or via particles such as fly ash, sulfates, nitrates, and gases (dry deposition).

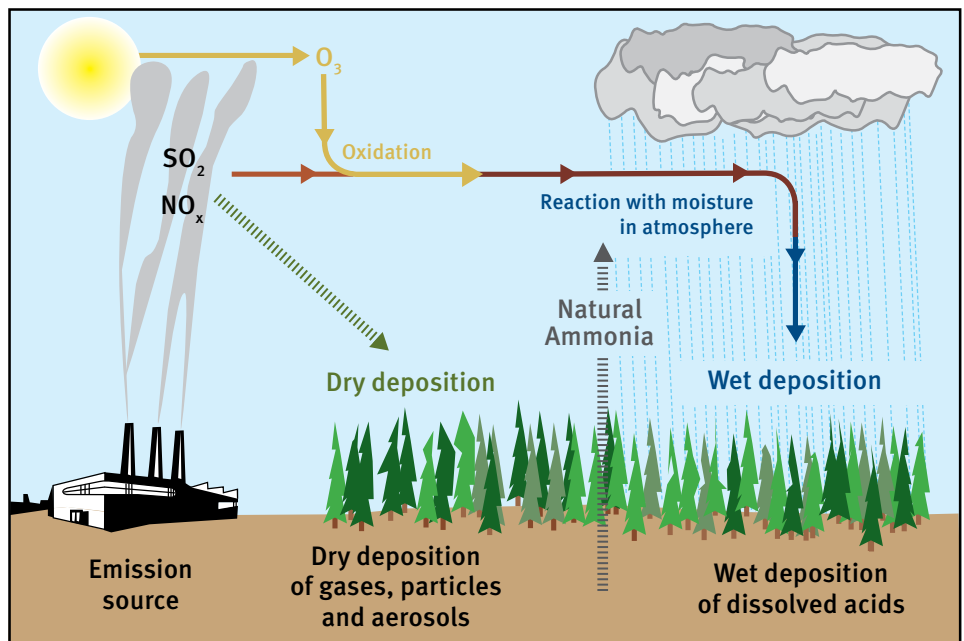
### What Is the Environmental Issue?

Acid deposition has already damaged North American forests, lakes, soils, buildings and historic monuments—in some cases, irretrievably. The air pollutants giving rise to acid deposition affect human health and air quality as well. But the problem is not just a North American one. Because acidic pollutants can travel great distances through the atmosphere to be deposited in ecosystems hundreds and even thousands of kilometers away, acid deposition is a global problem. Emissions from North America travel as far as Europe, and

pollution from Asia affects human health and the environment in North America.

Air pollutants, particularly emissions of oxides of sulfur and nitrogen, are the precursors of acid deposition. In North America, sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) are emitted by anthropogenic sources such as metal smelting and fossil fuel combustion in electricity generation and transportation, as well as by natural sources such as volcanoes, forest fires and lightning. However, the vast majority of SO<sub>2</sub> and NO<sub>x</sub> emissions that contribute to acid deposition are a product of human activities (see illustration of acid deposition process).

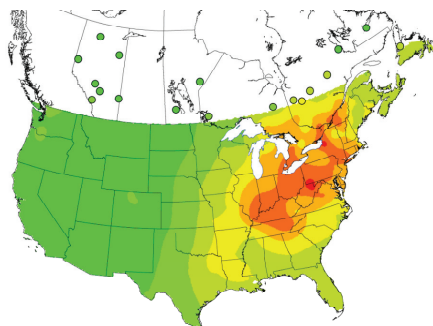
### The acid deposition process



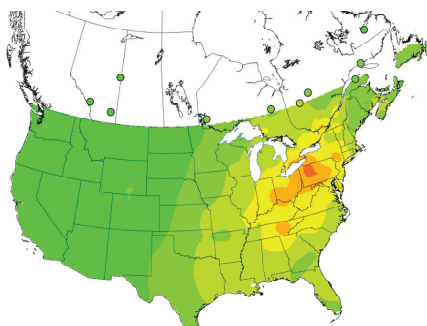
Adapted from: Michael Pidwirny, Physical Geography.net—Fundamentals of Physical Geography, <<http://www.physicalgeography.net/fundamentals/8h.html>>.

## Wet sulfate and wet nitrate deposition in the United States and Canada

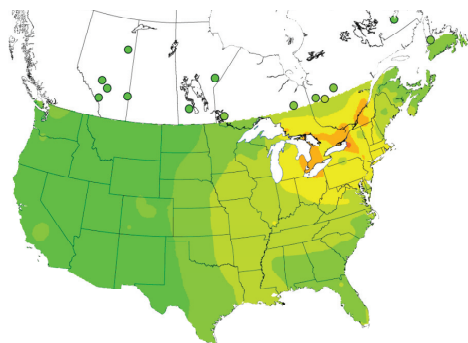
5-year (1990–1994)  
mean sulfate wet deposition



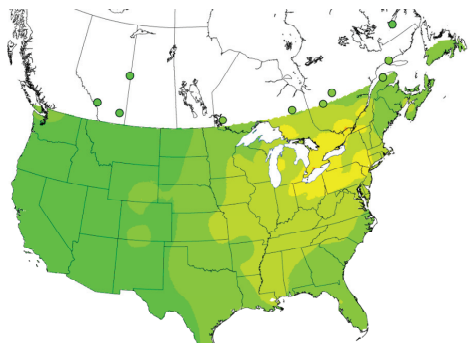
5-year (2000–2004)  
mean sulfate wet deposition



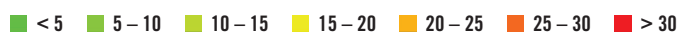
5-year (1990–1994)  
mean nitrate wet deposition



5-year (2000–2004)  
mean nitrate wet deposition



(kg/ha/yr)



Source: NATChem. Maps courtesy of Chul-Un Ro, Environment Canada.

Acidification of ecosystems occurs when the deposition of acidic compounds exceeds the neutralizing capacity of the receiving environment. Clean rainwater is slightly acidic, with a pH of about 5.6, because it contains dissolved carbon dioxide from the air. Acidic pollution has a pH lower than this, normally ranging between 4 and 5. A decrease in a single pH unit represents a ten-fold increase in acidity. Thus rainwater with a pH of 4.2 is about 25 times more acidic than clean rain. By making soil and water more acidic, acid deposition harms plants, animals and ecosystem integrity in affected areas. It also damages buildings, monuments and painted surfaces.

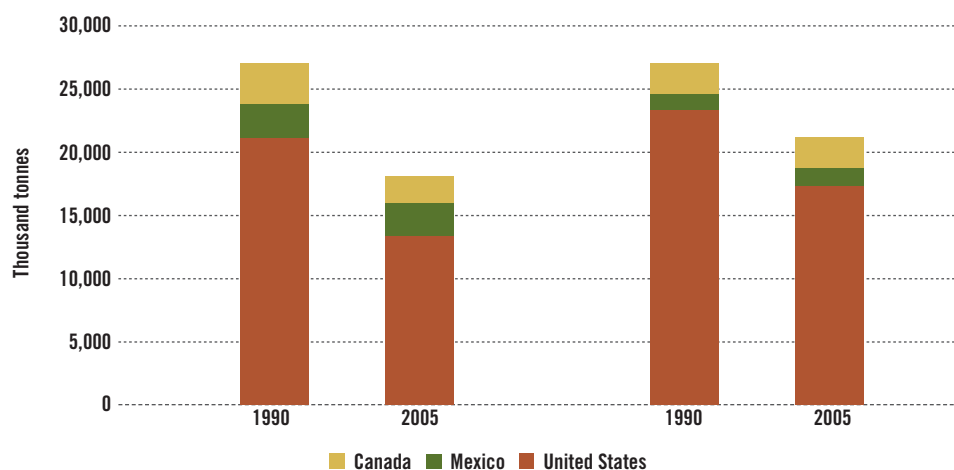
In a lake, acid deposition creates a cascade of effects that reduce fish populations and may even completely eliminate a fish species from a water body. As acid rain flows through soils in a watershed, metals such as aluminum are released into the lakes and streams in that watershed. Both low pH and increased aluminum levels are directly toxic to fish. In addition, they cause chronic stress that, although it may not kill individual fish, does lead to lower body weight and smaller size and makes fish less able to compete for food and habitat. Acidification of lakes and streams can also increase the amount of methyl mercury available in aquatic systems. In certain lakes in Canada and the United States that have a low pH, the common loon, a duck-like waterbird, has been found to have elevated blood mercury levels.

In forest soils, excess acid deposition increases the susceptibility of forests to stresses from pests, pathogens and climate change, resulting in poorer forest health, lower timber yields and eventual changes in the composition of forest species. Acid rain weakens trees by damaging their leaves, limiting the nutrients available to them or exposing them to toxic substances slowly released from the soil. Quite often, these effects of acid rain, in combination with one or more additional threats, injure or kill trees.

Finally, the pollutants that cause acid rain are harmful to human health. In the air, they join with other chemicals to produce smog, which can irritate the lungs and make breathing difficult, especially for people suffering from asthma, bronchitis or other respiratory conditions. Fine particulate matter, containing sulfate derived from  $\text{SO}_2$ , is thought to be especially damaging to the lungs.

Air emissions of  $\text{SO}_2$

Air emissions of  $\text{NO}_x$



Sources: Environment Canada, *Instituto Nacional de Ecología* (latest data from Mexico from 2002, not 2005), US Environmental Protection Agency.

## Why Is This Issue Important to North America?

The effects of acid deposition across North America can be addressed only in cooperation with the neighboring jurisdictions that contribute to acidifying emissions. The issue of acid rain first caught the public's attention in the late 1970s and early 1980s when its devastating impacts on ecosystems in eastern North America were publicized. In 1980 Canada and the United States began working together to address this trans-boundary issue. The two countries signed the Canada-US Air Quality Agreement in 1991 to promote scientific understanding and pollution reduction in both countries.

### Efforts to Reduce Emissions

Canada and the United States gave priority to SO<sub>2</sub> emissions because lowering these emissions was understood to be most important in lessening damage to sensitive ecosystems. Since 1990, SO<sub>2</sub> air emissions in North America have declined by almost one-third (see graph). At present, electric power generation accounts for the largest emissions of SO<sub>2</sub> in the United States, while in Canada the dominant emitting sector is base metal smelting.

Over the same period, air emissions of NO<sub>x</sub> have declined by just over one-fifth (see graph). Mobile sources such as cars and trucks are the most significant sources of NO<sub>x</sub> emissions in North America, with the remainder coming from power plants and other sources.

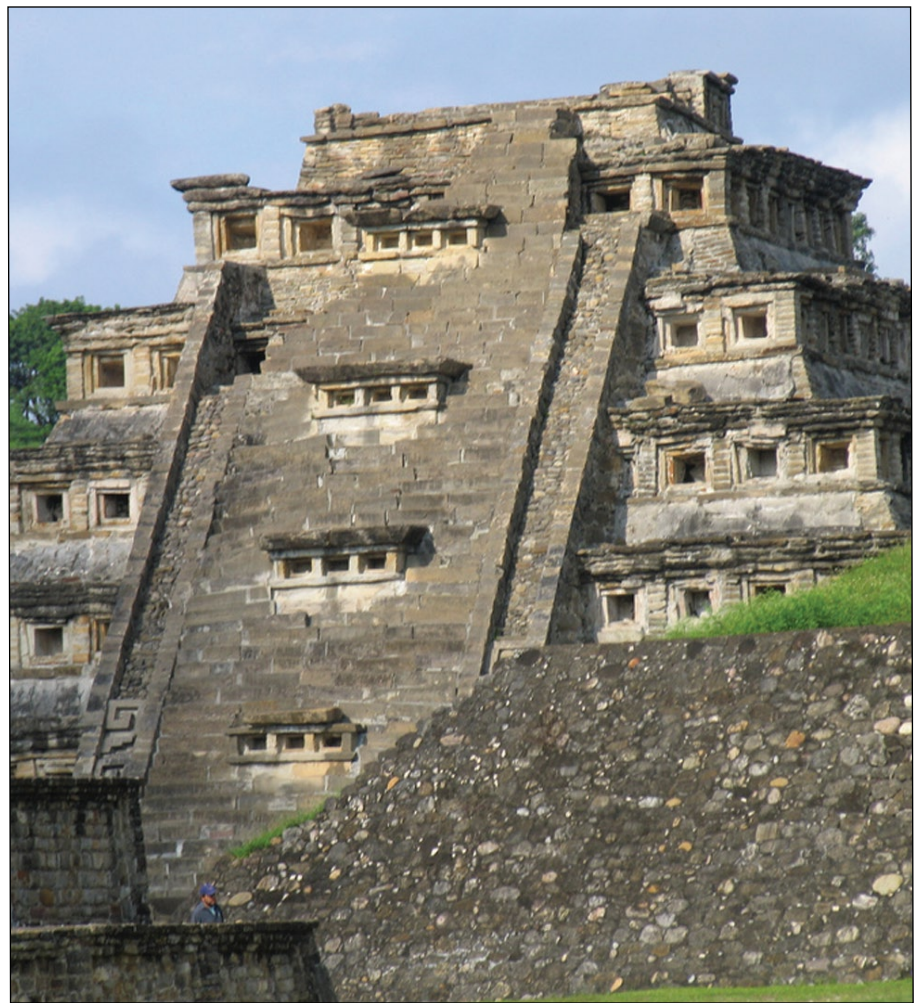
### Results

In response to emission reductions, levels of sulfate deposition in the eastern United States and Canada decreased substantially over the period 1990–2004, whereas changes in levels of nitrate deposition have been less dramatic (see maps).

### Affected Areas

Many of the water and soil systems in eastern North America cannot neutralize acid naturally. As a result, these areas are sensitive to acid deposition. To understand the capacity of ecosystems to absorb acid deposition, scientists have developed the concept of “critical load”—that is, an estimate of the amount of deposition that a particular ecosystem can receive below which no harmful effects occur. The critical load depends on the quantity of acid-neutralizing bases, such as calcium and magnesium salts, in a region's water and in the surrounding rocks and soils.

## Case Study – Acidification at El Tajín, Mexico



Pyramid of the Niches, El Tajín, Veracruz, Mexico. Source: Luiz Castro.

Located in the present-day municipality of Papantla de Olarte in Veracruz, Mexico, El Tajín was one of the most important cities in the Mesoamerican Gulf zone. Its archaeological zone contains constructions dating back to 100 A.D. From 600 to 1150 A.D., the city reached its maximum size and influence.

Humberto Bravo Álvarez and the section on environmental contamination at the *Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México*, are studying the effects of acid rain on archaeological and historical sites at El Tajín. From 18 August 2002 to 9 April 2003, they collected 40 rain samples at the El Tajín archaeological site and applied atmospheric trajectory analysis to each precipitation sample to determine air transport pathways corresponding to the precipitation events. Trajectory models are useful in identifying upwind regions likely to contribute to the pollutant burden at downwind receptors.

The analyses indicated that 85 percent of the precipitation events sampled at El Tajín were acidic (pH < 5.62). The back trajectory analysis of these acidic events showed a great variation, indicating there was no apparent directional preference for transport during these events and suggesting the importance of local sources. The El Tajín archaeological zone is surrounded by possible sources of acid rain precursors in the form of industries burning fuel oil with a high sulfur content (such as electric power plants and refineries). Thus both these sources and more distant ones may be important contributors to rainfall acidity at El Tajín.

Despite the progress in reducing acidifying emissions, some ecosystems are making a slower-than-expected recovery. In the United States, acidic surface waters are still found in the upper Midwest, Adirondack Mountains and northern Appalachian regions. In Canada, the areas receiving depositions higher than their critical loads are in provinces that are part of the Canadian Precambrian Shield. In Ontario, Quebec, New Brunswick and Nova Scotia, the susceptible hard rock (granite) areas lack the natural capacity to neutralize or buffer acid rain effectively. Historically, lower levels of industrialization combined with natural factors such as eastwardly moving weather patterns and soils with buffering capacity have largely protected western prairie ecosystems in Canada and the United States from the impacts of acid rain.

Although similar maps are not available for Mexico, the effects of acid deposition are evident in national parks near Mexico City where acid rain has damaged forests and soils, as well as in the damage to monuments and historic buildings in Mexico City and elsewhere (see case study, previous page).

### What Are the Linkages to Other North American Environmental Issues?

Scientists' initial concerns about the effects of acid deposition on forests and building materials have now expanded to include the relationship of acidifying pollution to biodiversity and sensitive coastal ecosystems.

#### Biodiversity

The various species that inhabit lakes, rivers and wetlands differ in their abilities to tolerate acidity. Acidification primarily reduces the variety of life inhabiting a lake and alters the balance among surviving populations. Changes in the mix of species inhabiting water bodies also affect birds and other species farther up the food chain, as some kinds of food resources become scarcer and others become more abundant. Scientists cannot say whether species that have disappeared from an acidified lake will ever return—even if pH levels return to normal.

#### Coastal Ecosystems

Linked to acid deposition is the effect of nitrogen deposition on coastal ecosystems, where nitrogen is often the limiting nutrient. Higher levels of nitrogen in coastal waters can cause significant changes to those ecosystems. Some

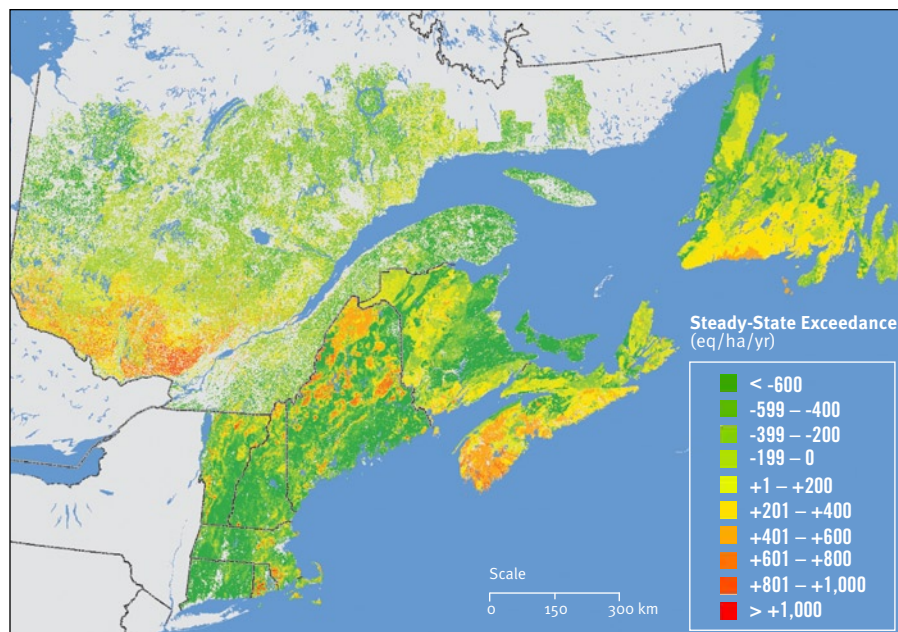
### Case Study – Forest Sensitivity to Sulfur and Nitrogen Deposition

Although sulfur emissions in the United States and Canada have fallen in response to control programs, the continued emissions of acidifying sulfur and nitrogen compounds present a serious long-term threat to forest health and productivity in parts of northeastern North America. This conclusion was reached by a study of the northeastern United States and eastern Canada conducted by the Conference of New England Governors and Eastern Canadian Premiers Forest Mapping Group.

According to the Forest Mapping Group's study, the atmospheric deposition of sulfur and nitrogen from 1999 to 2003 exceeded the critical load in more than one-third of the study area (see map). In the eastern Canadian provinces, the most sensitive forest areas occur in southern Quebec, especially in the Lower-Laurentides north of the St. Lawrence River, in southeastern Nova Scotia, and in southern Newfoundland. In New England, the most sensitive forest areas occur in the mountain ranges and coastal areas where soils are poor and weathering rates low, and where there is greater demand for nutrients due to more intensive harvesting.

Based on forest monitoring in Quebec and the known effects of acid deposition, the Forest Mapping Group's study concludes that high exceedances of critical loads lead directly or indirectly to reduced forest growth and health.

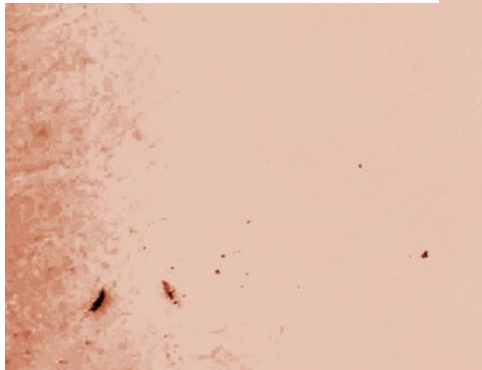
#### Forest areas sensitive to acid deposition in the New England states and eastern Canadian provinces



Source: Conference of New England Governors and Eastern Canadian Premiers Forest Mapping Group.

60 percent of estuaries in the United States suffer from overenrichment of nitrogen, a condition known as eutrophication. Symptoms of eutrophication include changes in the dominant species of plankton (the primary food source for many kinds of marine life), which can cause algal blooms, low levels of oxygen in the water column, fish and shellfish kills, and cascading population changes up the food chain. In addition, the higher levels of turbidity

in the water because of the large amounts of algae can kill off submerged aquatic vegetation, which is an important habitat for many estuarine fish and shellfish species. Although a large number of the most highly eutrophic estuaries are along the US Gulf and Mid-Atlantic coasts, overlapping many of the areas with the highest nitrogen deposition, eutrophic estuaries can be found in every region of the conterminous US coastline. 🐞



## Industrial Pollution and Waste

### Key Findings

- Industrial pollution and waste encompass the full range of materials generated by industrial activities that are unwanted by the producer. At times, they represent an unrealized opportunity to improve production efficiency and reduce disposal costs.
- Certain components of industrial pollution and waste are hazardous to human health and the environment. Related concerns include sensitive human populations such as children, the implications of low-level exposures to multiple pollutants, and contamination of ecosystems.
- Every year, industrial activity in North America generates substantial quantities of toxic chemicals, air contaminants, hazardous and nonhazardous waste, and radioactive materials that must be managed to protect human health and the environment.
- Some trends in waste management are encouraging, such as industries' adoption of pollution prevention methods and a sustained decline in releases of carcinogens and other toxins of concern, but progress has not been uniform.

*Industrial pollution and waste encompass the full range of unwanted substances and losses generated by industrial activities, including emissions to air or surface waters and the substances sent to sewage treatment plants, deposited in landfills, released or applied to the land, treated, injected underground, controlled through storage, recycled or burned for energy recovery.*

### What Is the Environmental Issue?

Industrial production contributes goods, services and jobs, but it is also a major source of pollution and waste. This pollution and waste can be classified into six categories: toxic chemicals, criteria air contaminants, greenhouse gases, hazardous wastes, nonhazardous wastes and radioactive wastes.

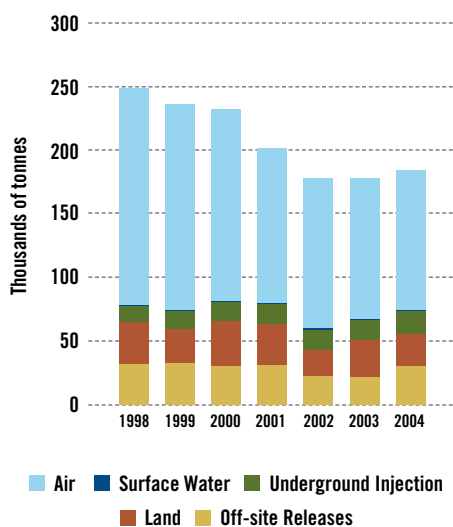
#### Toxic Chemicals

These substances are hazardous to human health and the environment. In 2004 North

American industrial facilities generated over 5 million tonnes of toxic chemicals as production-related pollutants and waste (see box). Despite this large amount, data for comparable industries and chemicals in Canada and the United States reveal encouraging trends. Over the period 1998–2004, total releases of carcinogens and developmental/reproductive toxicants declined by 26 percent in the United States and Canada (see graph), compared with a 15 percent reduction in all tracked chemicals. Mexican data are not available for this time period. Although releases to most media for these



## Releases of carcinogens and developmental/reproductive toxicants (Canadian and US data)



Source: Commission for Environmental Cooperation, *Taking Stock 2004*.

chemicals have declined over time, releases to underground injection have increased. This disposal method, in which fluids are released into subsurface wells, has increased by over 40 percent since 1998 for carcinogens and developmental/reproductive toxicants. Furthermore, even though facilities with the largest reported amounts have made progress in reducing toxic releases and transfers, the more numerous facilities reporting smaller pollution amounts are tending to move in the opposite direction.

### Criteria Air Contaminants

These substances, which include nitrogen oxides, sulfur oxides, carbon monoxide, particulate matter and volatile organic compounds, are associated with environmental effects such as smog, acid rain and regional haze, and health effects such as respiratory illness. These pollutants are emitted from a variety of sources, including residential fuel combustion, motor vehicles and agricultural activities. Industrial sources are also major contributors—among them, electric utilities, primary metal smelters and cement kilns. Although emissions of criteria air contaminants are trending downward, reductions from sources such as motor vehicles have been partially offset by increases from certain oil and gas industry subsectors attributed to expanded production.

### Greenhouse Gases

These gases, which include carbon dioxide (CO<sub>2</sub>), methane and nitrous oxide, are linked to global climate change. Industrial energy use is a major source of CO<sub>2</sub> emissions in North America, roughly on a par with the CO<sub>2</sub> emissions arising from energy use in the agricultural, commercial and residential sectors combined. Although CO<sub>2</sub> emissions from industrial energy use dropped by more than 30 percent from 1980 to 2005, emissions from transportation increased by about 50 percent and those from electricity generation and refineries by nearly 60 percent during the same time period. Total emissions of greenhouse gases in North America amounted to more than 8.5 billion tonnes of CO<sub>2</sub> equivalent in 2005.

### Hazardous Wastes

Hazardous wastes are industrial waste streams that may contain more than a single chemical or substance. They are typically defined by characteristics such as ignitability, reactivity, corrosivity and toxicity. Comparable North American data for hazardous waste generation and management are currently lacking, making it difficult to discern trends. Although the United States issues a biennial hazardous waste report, periodic nationwide data are lacking in Canada (except for cross-border shipments) and are at an early stage of development in Mexico.

The amounts of hazardous wastes being generated are significant. In the United States, nearly 34.8 million tonnes of hazardous waste were generated in 2005, mostly in the form of liquid waste. Government estimates put Canada's annual generation at about 6 million tonnes. In Mexico, data from over 35,000 facilities put the annual total at 6.17 million tonnes in 2004. Mexico's total generation of hazardous wastes is not known, but 8 million tonnes a year is frequently cited.

### Nonhazardous Wastes

Nonhazardous industrial wastes include coal ash, foundry sands, cement kiln dust, mining and mineral processing wastes, oil and gas production wastes, and other wastes that lack the characteristics of hazardous waste. Although these waste streams are not classified as hazardous, their management is not without risk and generally legal requirements are in place for their proper treatment and disposal. In Canada, disposal of wastes from nonresidential sources (industrial, commercial and institutional) increased from 14.6 to 15.5 million tonnes between 2002 and 2004. In the United States and Mexico, overall estimates of nonhazardous industrial waste are not readily available, although estimates for various individual sources may exist.

## North America's Pollutant Release and Transfer Registers

In North America, all three countries track certain industrial pollutants using Pollutant Release and Transfer Registers (PRTs). PRTs compile facility-reported annual data on releases of specific substances to air, water and land, as well as disposal and transfers off-site for treatment or recycling. In 2004 over 5 million tonnes of releases and transfers were reported.

Canada's **National Pollutant Release Inventory** (NPRI), established in 1992 based on recommendations of stakeholders from industry and environmental organizations, tracks more than 300 chemicals as well as criteria air contaminants.

Mexico's **Registro de Emisiones y Transferencia de Contaminantes** (RETC), which recently became mandatory, covers some 100 chemicals and forms part of the *Cédula de Operación Anual* (annual certificate of operations), which is also used to collect data on hazardous waste generation, energy use and other indices of environmental management.

The **US Toxics Release Inventory** (TRI), begun in 1987, now tracks data from facilities on more than 600 chemicals.

Enhancing the comparability of their PRTs is a shared priority for the three countries. In June 2002, the CEC Council signed Council Resolution 02-05: Action Plan to Enhance Comparability Among Pollutant Release and Transfer Registers in North America.

### Radioactive Wastes

Radioactive wastes are by-products of certain industrial activities, in particular electricity generation. In 2005 nuclear power generation produced 1,697 tonnes of spent fuel (expressed as amounts of heavy metal) in Canada, 21 tonnes in Mexico and 2,396 tonnes in the United States.

### Why Is This Issue Important to North America?

Industrial pollution and waste pose potential threats to human and ecological health if not properly managed. The concerns range from toxic effects on fetuses and children to the health implications of low-level exposures to multiple pollutants and the degradation of habitats and ecosystems. These concerns do not stop at the borders, because some pollutants can travel long distances and waste is shipped to recycling and disposal sites across political boundaries.

### Health and Environment

The pollution and waste tracked through PRTRs and regulated by environmental laws in North America are those the national governments have identified as raising concerns about human health or the environment. The effects of certain toxic chemicals on the health and development of children and other vulnerable groups are a special concern. Researchers describe “windows of vulnerability” during fetal and child development in which toxic exposures can have particularly devastating effects. Although the traditional focus has been on overt health effects such as cancer, scientists are increasingly worried about the more subtle effects of low-level toxic exposures, such as impairments in endocrine and neurological functions.

### Long-range Transport

Industrial pollution and waste are important in the North American context because pollutants travel through the air and water to cross national borders and because wastes are also shipped across borders for recycling, treatment and disposal. The deposition of persistent contaminants in the distant north, in locations far from industrial sources, attests to the ability of pollutants to travel far from their points of origin. The industrial pollution and waste released into rivers or water bodies that span political boundaries, such as the Great Lakes and the New River,



which runs from Baja California into California, is also a shared concern, especially the effects of persistent bioaccumulative toxic substances (PBTs).

### Waste Management

Decisions on how to manage wastes have environmental implications. Municipal waste incineration, medical waste incineration, burning of hazardous wastes in cement kilns and backyard waste burning were among the top sources of dioxins, according to US and Canadian inventories. Dioxins, like some other PBTs, can be dispersed long distances by air currents and other environmental pathways and tend to settle in colder regions.

are managed. Whatever the differences, it is true that North American companies ship hundreds of thousands of tonnes of hazardous waste each year between Canada, Mexico and the United States. When wastes are sent to other jurisdictions for recycling, treatment or disposal, the waste shipments must be transported along roads and railways and through populated areas before reaching their final destinations.

### Economic Costs

Apart from their potential effects on humans and the environment, wastes represent inefficiency in industrial production. Wastes impose costs on facilities; they must pay for

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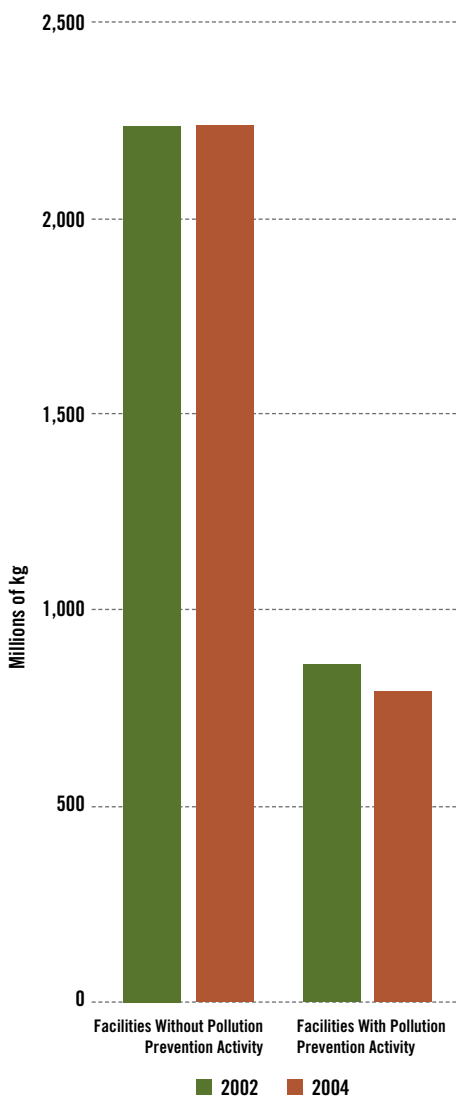
Industrial pollution and waste are important in the North American context because pollutants travel through the air and water to cross national borders and because wastes are also shipped across borders for recycling, treatment and disposal.

The regulatory requirements governing the management of hazardous wastes can influence the waste management decisions of industrial facilities. For example, such regulations may inhibit recycling by facilities because of concerns about higher compliance costs. Jurisdictional differences in regulatory requirements, in addition to differentials in waste management pricing, can also influence decisions about where and how wastes

waste management, regulatory compliance and underutilized material inputs. From a societal perspective, the economic costs include paying for cleaning up contaminated sites, regulating waste-generating industries and ensuring medical treatment for the adverse effects of environmental exposures. The nonmonetary costs include the depletion of nonrenewable resources, consumptive land use and degradation of ecosystems.

Companies and jurisdictions are increasingly striving to decouple waste generation from economic productivity. PRTR data demonstrate that facilities undertaking pollution prevention activities are able to reduce their wastes faster than those who do not (see graph). The graph also reveals that over three-quarters of waste is generated at facilities that have yet to pursue pollution prevention. Reducing waste does not require reducing economic activity. California has the largest subnational economy in North America, but ranks thirtieth among states and provinces in total releases of toxic chemicals.

**Total releases and transfers of PRTR substances for facilities with and without pollution prevention activities (Canadian and US data)**



Source: Commission for Environmental Cooperation, *Taking Stock 2004*.

### What Are the Linkages to Other North American Environmental Issues?

Land use planning and climate change are just two of the other important environmental issues linked to industrial pollution and waste.

#### Land Use

Waste poses challenges for local land use planning, ranging from the siting of new treatment, storage and disposal facilities to the question of how to manage “brownfield” sites. In the United States, as of 2008, 1,581 sites (final and deleted) were on the Superfund program’s National Priorities List and 3,746 facilities are expected to need cleanup under the Federal Resource Conservation and Recovery Act. Numerous other sites are under local or state jurisdiction, and so the full extent of contaminated land is unknown. In Canada, about one-quarter of the 17,866 contaminated sites under federal responsibility are on native reserves, placing an additional burden on populations already vulnerable to environmental threats because of socioeconomic factors or geography. In Mexico, the federal government has identified 300 contaminated sites covering 200,000 hectares. The location of polluting industries, landfills and other waste management sites also raises questions of environmental justice.

#### Natural Resource Depletion

Inefficient use of materials and energy affects the use of natural resources. Depletion of natural resources is mediated by the renewability of the inputs used and the degree of recycling undertaken within or among industrial sectors. Recycling and energy recovery of industrial wastes enable the wastes from one process to become the material inputs or energy source for another. More than a million tonnes of materials, mostly metals, were sent for recycling by PRTR-reporting facilities in 2004, and nearly 300,000 tonnes were sent for energy recovery. However, recycling and energy recovery can have their drawbacks. Recycling activities themselves can be sources of environmental contamination, and the air releases and residuals from energy recovery are a concern.

#### Climate Change

Industrial pollution and waste contribute to climate change as well. The anaerobic decomposition of wastes in landfills produces methane, a potent greenhouse gas, and waste incineration releases carbon dioxide. The transportation of wastes to recycling, treatment and disposal sites produces transportation-related carbon emissions. Finally, the materials disposed of as waste must be replaced by more raw materials, which implies further consumption of fossil fuels and additional carbon releases. 🦋





# Persistent Bioaccumulative Toxic Substances

## Key Findings

- Persistent bioaccumulative toxic substances (PBTs) are chemicals that break down slowly in the environment, accumulate in humans and other species and are toxic. Although only a limited number of PBTs are currently receiving attention, more may be identified through ongoing screening activities.
- PBTs may be released intentionally (such as pesticides) or unintentionally (such as combustion or manufacturing byproducts). Some PBTs are dispersed globally by air currents and other environmental pathways, resulting in contamination even in regions far from their points of origin.
- Comprehensive biomonitoring data are not available for all of North America, but local and country-specific studies have measured PBT levels in humans and wildlife. The implications of these findings are under investigation in all three countries.
- The levels of certain PBTs in the environment have been reduced by eliminating or reducing releases and adopting alternatives, but recovery times are slow because these chemicals do not break down to harmless byproducts easily or quickly.

*Persistent bioaccumulative toxic substances (PBTs) are chemicals that do not degrade easily in the environment. PBTs typically accumulate in fatty tissues and are slowly metabolized, often increasing in concentration within the food chain. Certain PBTs have been linked to adverse health effects in both humans and animals.*

## What Is the Environmental Issue?

There is substantial evidence that persistent bioaccumulative toxic substances (PBTs) cause long-term harm to human health and the environment. This evidence has provoked an international response to the problem (see box).

### PBTs and Human Health

In North America, humans are exposed to many different environmental contaminants, including certain PBTs. Studies have linked various PBTs to a range of adverse effects in humans, including nervous system disorders, reproductive and developmental problems, cancer and genetic impacts. Certain PBTs mimic hormones, possibly altering sexual characteristics and other hormonal functions.

### PBTs and Animal and Plant Health

Like humans, animals and plants are exposed to PBTs in the environment through air, water and food. The animals most likely to be exposed to toxic levels of PBTs are those higher up in the food chain, such as marine mammals, birds of prey and certain fish species. The fish consumption advisories issued by governments around the Great Lakes and elsewhere are designed to protect people from the risks of eating contaminated fish. Mercury, polychlorinated biphenyls (PCBs), chlordane, dioxins and DDT—the PBTs that commonly contaminate fish—accumulate in fish tissue at concentrations thousands of times higher than in the water. PBTs can stay in sediments for years, a source of contamination for bottom-dwelling creatures that are then eaten by predators (see illustration of bioaccumulation and biomagnification).

## An International Response to PBTs

With 151 other nations, Canada, Mexico and the United States are all signatories to the Stockholm Convention on Persistent Organic Pollutants (May 2001). Canada and Mexico have ratified this treaty, but the United States has not.

The Convention identifies 12 organic PBTs for control. These chemicals fall into three categories:

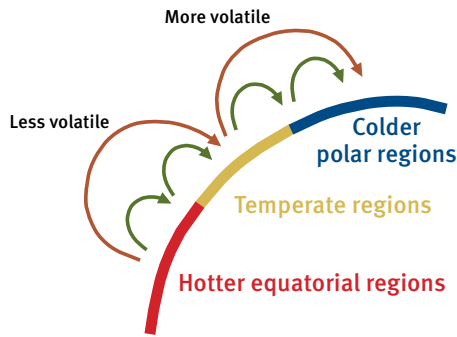
**Pesticides**—aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene

**Industrial chemicals and unintended byproducts**—HCBs and PCBs

**Unintended byproducts**—dioxins and furans.

Many of the 12 chemicals covered by the Stockholm Convention are no longer produced, and yet they persist in the environment. Even though only a limited number of PBTs are currently receiving attention, more may be identified through ongoing screening activities.

## The grasshopper effect and global distillation



Source: Environment Canada.

The persistence of these substances in the environment is considerable. Chlordane was banned in the United States in 1988, but 105 fish consumption advisories were still issued for this substance in 2006. Likewise, DDT has been banned since 1975, but 84 DDT-related fish consumption advisories were still issued in 2006 in the United States.

### Why Is This Issue Important to North America?

PBTs are intentionally and unintentionally released into the environment. Once in the environment, some PBTs can readily disperse throughout specific regions and across international boundaries, both within North America and globally. PBTs are of particular concern to North America because they are found in environmentally sensitive areas, such as the Arctic (see illustration of pathways into the Arctic), the Great Lakes and the Gulf of Mexico.

#### Sources of PBTs

Worldwide, all industrial sectors use chemicals, but certain sectors are more likely to emit PBTs. These emissions may originate from either intentional releases—such as pesticides with PBTs as impurities—or unintentional releases—such as combustion byproducts (e.g., dioxins and furans).

PBTs continue to be released as the byproducts of industrial activities. Mercury releases through coal-fired electricity generation, for example, have increased since the beginning of the industrial age in the mid-1800s. Rates of mercury deposition from the atmosphere have increased globally 200–400 percent since the industrial revolution, increasing the potential human health and ecosystem effects of mercury worldwide.

#### Transport

A major concern with some PBTs is the ease with which they can move through the environment. PBTs make their way into remote regions by traveling long distances in a series of “hops” involving a complex cycle of long-range atmospheric transport, deposition and re-volatilization, collectively called the “grasshopper effect.” Eventually, they accumulate in cold regions such as the Arctic by a process called “global distillation” (see illustration).

Because PBTs are often relatively volatile, they may enter the atmosphere where they can be carried with the winds, sometimes for long distances. Through atmospheric processes, either because the molecules are carried down with precipitation or because particulate matter settles, they are deposited onto land or into water ecosystems where they accumulate and may cause damage. From these ecosystems, they may evaporate, again entering the atmosphere, ultimately traveling from warmer temperatures toward cooler regions. Whenever the temperature drops, they condense out of the atmosphere, frequently reaching higher concentrations in circumpolar regions and in high altitudes because there is insufficient thermal energy to go through another evaporation cycle.

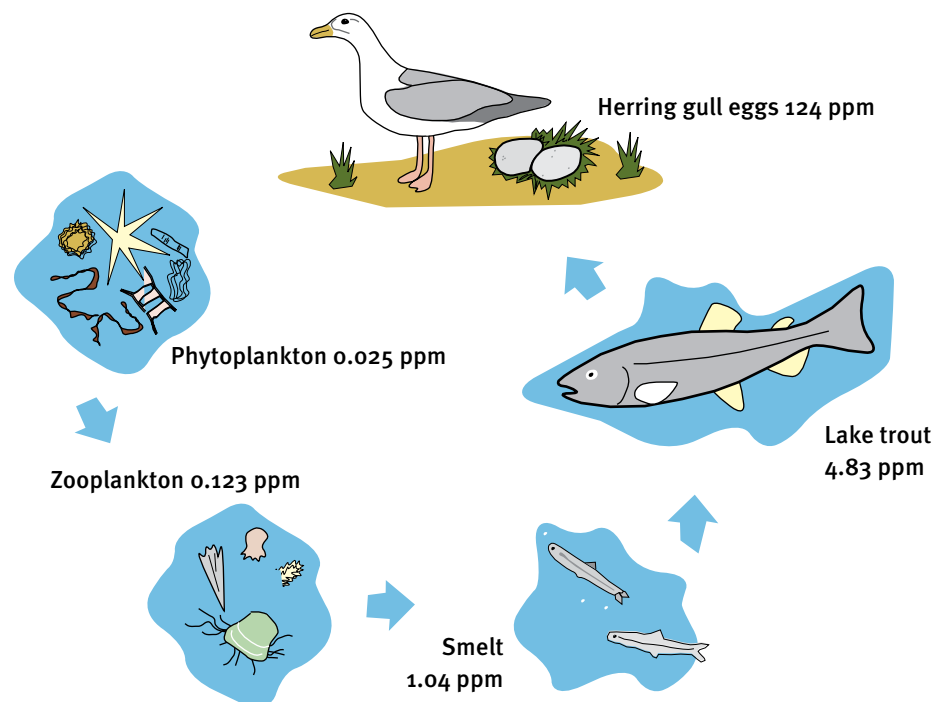
Through these processes, some PBTs can move thousands of kilometers from their sources of emission and accumulate in polar latitudes. In addition to releases within the region, North America is also affected by the long-range atmospheric dispersal of PBTs from global sources.

#### Biomonitoring

The human populations exposed to PBTs include groups of special concern such as children and developing fetuses. Children are especially vulnerable to toxic chemicals because of their unique physiology and developmental and behavioral characteristics. The biomonitoring data needed to measure the occurrence of PBTs in humans are not readily available for North America as a whole, but some insights can be drawn from more localized studies:

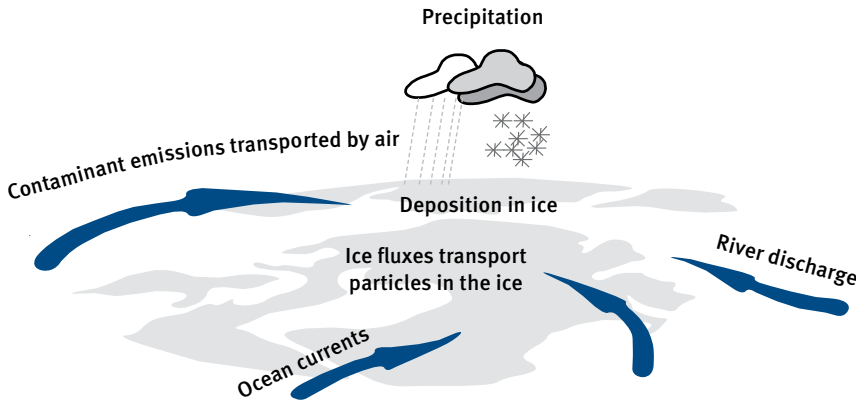
- In the Canadian Arctic, the Arctic Monitoring and Assessment Programme has determined that the high exposure levels found in some Arctic communities may have a negative influence on human health. Although there is still no direct evidence of adverse effects on health status (mortality and morbidity) at

### Changes in the concentration of PBTs as they move up the food chain



Adapted from: US Environmental Protection Agency.

## Pathways of contaminants to the Arctic



Source: Arctic Monitoring and Assessment Programme.

the population level, there is reason for concern and a need to continue to reduce human exposure based on the weight of all available evidence.

- In Mexico, organochlorine (OC) pesticides, which are also PBTs, were measured in the ambient air of Chiapas during 2000–2001. Concentrations of some OC pesticides (DDTs, chlordane, toxaphene) in this area were elevated compared with levels in the Great Lakes region. This finding suggests that southern Mexico may be a source region for this group of chemicals, but comparably high levels have also been reported in parts of the southern United States, where their suspected sources are emissions from historically contaminated soil (DDTs, toxaphene) and past termiticide usage (chlordane). Agricultural workers may be at risk because of exposures to these PBT chemicals.

- In the United States, about 6 percent of women of child-bearing age had 5.8 parts per billion or more of mercury in their blood from 1999 to 2002. Concentrations below 5.8 parts per billion are unlikely to cause appreciable harm. Based on these survey results and the number of births each year, it is estimated that more than 300,000 newborns each year in the United States may have an increased risk of learning disabilities associated with *in utero* exposure to methylmercury.

### What Are the Linkages to Other North American Environmental Issues?

Persistent bioaccumulative toxic substances are linked to biodiversity, international trade and climate change.

#### Biodiversity

The effect of PBTs on biodiversity in North America was first evident when peregrine fal-

cons, eagles and other top predators began to disappear in the 1970s because of DDT in the food chain. Although these highly visible species have recovered through interventions and through the banning of some PBTs, other species may still be affected by the presence of PBTs in the continent's ecosystems.

#### Trade

International trade can introduce PBTs into North America despite rigorous efforts to prevent their release here. Consumer goods and products sold in North America are increasingly manufactured, grown or otherwise handled in nations whose requirements related to PBTs may differ from those in North America. An example is food imported from other countries that have been treated with pesticides still in use there such as DDT, aldrin and chlordane.

#### Climate Change

Normal atmospheric conditions carry mercury and some other PBTs emitted by fossil fuel combustion and other industrial activities northward, where these substances eventually settle on land or water surfaces. For example, the boreal forest region in northern Canada and Alaska is a resting place for years of past emissions. Because climate change affects northern forests and wetlands, mercury previously deposited into cold, wet soils may be released again through wildfires. In response to the drier conditions in northern regions, soil will relinquish its hold on hundreds of years of mercury accumulation, sending it back into the air. The projected increases in boreal wildfire activity stemming from climate change are expected to increase atmospheric mercury emissions, exacerbating exposure in northern food chains. 🦉

## Selected Industries and Processes Associated with PBTs

Manufacturing	Thermal processes	Certain products with PBT impurities	Recycling processes
<ul style="list-style-type: none"> <li>■ Production of chlorinated organic chemicals</li> <li>■ Pulp and paper production</li> <li>■ Oil refining and catalyst regeneration</li> <li>■ Chlorine production using graphite electrodes</li> </ul>	<ul style="list-style-type: none"> <li>■ Iron ore sintering for blast furnaces</li> <li>■ Primary copper smelting</li> <li>■ Secondary scrap metal processing</li> <li>■ Cement kilns</li> <li>■ Mineral processing: lime, ceramic, glass, brick</li> <li>■ Waste incineration: municipal, hazardous, medical/clinical</li> <li>■ Coal and oil combustion vehicles and stationary motors</li> </ul>	<ul style="list-style-type: none"> <li>■ Pesticide/herbicide application</li> <li>■ Preservatives for wood/leather/textile</li> <li>■ Solvent use and application</li> <li>■ Industrial bleaching processes</li> <li>■ Textile/wool/leather dyeing and finishing</li> </ul>	<ul style="list-style-type: none"> <li>■ Metal, paper and plastics recycling</li> <li>■ Sewage and paper sludge and effluent application on land</li> <li>■ Solvent and waste oil recovery</li> <li>■ Pentachlorophenol-treated wood</li> </ul>

Source: United Nations Environment Programme.

## Case Study – Toxics in Osprey Eggs: An Indicator of Contaminants in the Fraser and Columbia River Basins

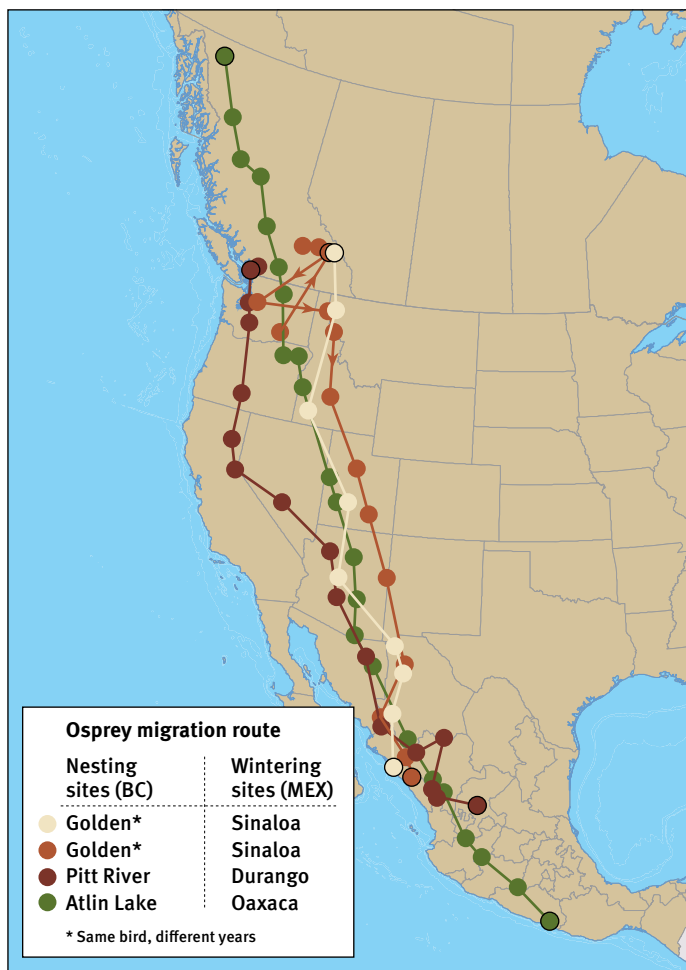
Ospreys, which are fish-eating migratory birds, are exposed to pollutants that accumulate in aquatic food chains and, as a result, are a good indicator species of aquatic ecosystem health.

A long-standing monitoring study of the levels of chemicals found in migrating ospreys has provided information about the PBTs that have accumulated in the birds and the origins of the substances. The results also suggest important questions about exposure and bioaccumulation in humans.

Ospreys migrate between Latin America and the Fraser and Columbia River Basins in the Pacific Northwest of North America. The PBTs found in ospreys include industrial OCs (dioxins, furans and PCBs), OC pesticides (DDT metabolites, dieldrin, chlordane and toxaphene) and mercury. In particular, DDT, PCBs, and dioxins and furans are historically associated with reproductive failure and population declines in osprey.

Researchers have found that some of the toxic contaminants in the ospreys originate from industrial sites still operating in the Fraser and Columbia River Basins and the sites of closed industries

### Satellite telemetry of osprey migration routes



Adapted from: J. Elliott, D. P. Shaw and D. Muir, "Factors Influencing Domestic and International Sources of Chlorinated Hydrocarbons to Fish and Ospreys in British Columbia," Toxic Substance Research Initiative, Final Report, TSRI #224. Vancouver, (unpublished).

where residues remain. The remaining toxics originate in Asia and potentially in food sources at the osprey's wintering grounds in Latin America.

The Canadian Wildlife Service, along with Mexican and US agencies, has collected data on the migratory habits of ospreys. They were tracked from their nesting grounds in the Fraser River Basin to areas of intensive agriculture in Mexico (see map), and other Central American countries.

From 1997 to 2004, the osprey population along the lower portion of the Columbia River increased from 94 to 225 occupied nests, almost a 14 percent annual rate of increase. The rate of population increase was associated with higher reproductive rates than in previous years and significantly lower egg concentrations of most OC pesticides, PCBs, dioxins and furans. Indeed, the levels of observed egg residue concentrations in 2004 indicated that reproduction at few, if any, nests was adversely affected by the presence of such pesticides. As recently as 1997–1998, the DDT metabolite DDE was still causing reproductive failure for a portion of this population. Only mercury showed a significant increase in eggs over time, but the concentrations in 2004 remained below those established to have effects on birds.

Because ospreys feed on a variety of sport fish species, the ongoing monitoring of contaminant levels in this bird serves as an early warning about the toxic substances potentially consumed by humans.



Osprey.



## Water Quality

### Key Findings

- The biological, chemical and physical characteristics of water affect its ability to sustain life and its suitability for human consumption and use. Several water quality issues have persisted for decades, including sedimentation, nutrient overenrichment and bacterial and toxic contamination.
- Many human activities yield waste products such as sewage, runoff, urban industrial releases and air pollution that affect the quality of water. Likewise, landscape modifications can undermine the natural processes of water purification through wetlands and infiltration of water through soil into groundwater.
- Although freshwater quality in many parts of North America is good, a significant portion of North American surface freshwater is degraded. A similar assessment of groundwater is not possible, but in certain areas it is known to be degraded by nitrates, pesticides and salinity.
- Conventional pollutant discharges from industrial point sources have largely fallen over the last 30 years in North America, but nonpoint and diffuse pollutant sources such as agricultural runoff, stormwater runoff and atmospheric deposition have become relatively larger contributors to impairment of water quality.

**Water quality** refers to the physical, chemical and biological characteristics of surface and groundwater. These characteristics affect the ability of water to sustain human communities, as well as plant and animal life.

### What Is the Environmental Issue?

The health of humans, wildlife and ecosystems depends on adequate supplies of clean water. But as populations grow and expand into previously undeveloped areas, governments are finding it more and more difficult to ensure water quality. The byproducts of this growth—increased and accelerated runoff, sewage, inadequate infrastructure, land clearing, industrial point sources, air pollution—also pose risks for water quality. Meanwhile, development can undermine the self-maintenance of water resources—wetlands and infiltration of water through soil are the natural ways in which water is purified. Draining wetlands and impervious paving reduce these natural purification processes in terrestrial and aquatic ecosystems.

The three North American countries have different definitions and procedures for measuring surface water quality. A comparable assessment of North American water quality is therefore challenging. But it is clear that, based on national reporting, the overall percentage of North American surface freshwater in degraded condition is significant.

Canada's water quality index, which is based on various parameters such as nutrients, assesses surface freshwater quality for its ability to protect aquatic life, including fish, invertebrates and plants; it does not assess the quality of water for human consumption or use. According to the most recent information available, freshwater quality in southern Canada was rated "excellent" or "good" at 44 percent of monitored sites, "fair" at 33 percent of sites, and "marginal" or "poor"



at 23 percent of sites. Phosphorus, a nutrient derived mainly from human activities and a key driver of the water quality index, is a major concern for surface freshwater quality in Canada. Phosphorus levels exceeded limits set under the water quality guidelines for aquatic life over half the time at monitored sites.

In the United States, over 40 percent by length of small wadeable streams sampled in 2004–2005 showed substantial disturbances to sensitive communities of small water-dwelling

of impairment were excess levels of nutrients, metals (primarily mercury), sediment and organic enrichment from agricultural activities; hydrologic modifications; atmospheric deposition; and discharges from industrial, unknown or unspecified sources.

Mexico monitors surface water for biochemical oxygen demand (BOD), fecal coliform, nitrogen, phosphorus and other substances. BOD measures the amount of oxygen consumed by microorganisms in decomposing organic matter

levels of nitrogen and phosphorus in surface water are also a problem for Mexico. Elevated levels of pollutants containing these elements were detected at a majority of monitored sites.

Pollution and contaminants associated with surface water also affect groundwater: point source contamination (bacteria, organics), nonpoint source pollution from agriculture (nitrates and pesticides), industrial contamination (heavy metals, organic compounds), and naturally occurring contaminants such as arsenic. Groundwater depletion can create cracks, fissures and fractures through land subsidence that permits contaminants to enter deeper groundwater aquifers. Salt water intrusion into coastal aquifers is a problem throughout the Gulf of Mexico and Gulf of California regions of Mexico and the United States as salt water replaces the freshwater being removed from the aquifer. Because there are no comprehensive surveys or sources of information on groundwater, regional patterns or trends in groundwater quality for North America are unknown.

## Mercury most often enters North American water resources via the deposition of mercury emitted to the air from mining, industrial processes, and combustion of fossil fuels, municipal and medical waste.

creatures, indicating significant pollution and habitat modification. The most widespread stressors were nitrogen, phosphorus, streambed sediments and riparian disturbance. About a third of sampled stream length contained high nitrogen or phosphorus concentrations, and a quarter revealed streambed sediments or riparian disturbance. As of 2002, almost half of assessed stream length and lake area and one-third of assessed bay and estuarine areas were not clean enough to support human uses such as fishing and swimming. The leading causes

in water. The greater the BOD, the more rapidly oxygen is depleted in the stream and the more stress is placed on higher forms of aquatic life. In 2006, 16 percent of monitored sites had an average annual BOD of more than 30 milligrams per liter, indicating unacceptable contamination under Mexican standards. Fecal coliform are bacteria fed by human or animal waste that serve as indicators of contamination. In 2006, 58 percent of monitored sites in Mexico had average annual concentrations above acceptable levels for drinking water. And, as in the rest of North America,

### Why Is This Issue Important to North America?

Sustainable access to clean water is vital to the human and ecological life of North America. As North Americans have experienced the vulnerability and finite nature of clean water supplies, they have realized that they must protect and conserve this essential resource. Water quality concerns that have persisted in North America over the last 30 years include sedimentation,

Sites in which algal blooms have led to animal and plant deaths in North American coastal waters (1993–2002)



Source: Institut français de recherche pour l'exploitation de la mer.



eutrophication, pathogenic diseases and persistent toxics (mercury and organic chemicals).

### Sedimentation

Soil erosion and sedimentation (deposition of eroded soil) in lakes, waterways and coastal areas are major water quality problems throughout North America. Although erosion, sediment transport and sedimentation are natural processes, human activity may exacerbate these processes in certain parts of the continent, and in local or regional situations may be the primary cause. Sediment affects water quality by reducing water clarity, smothering aquatic habitats and acting as a transport mechanism for pollutants such as pesticides and fertilizer. In the United States, sedimentation is associated with over 60 percent of degraded stream miles. Similarly, Environment Canada has identified sediment as a Canadian water quality issue, whereas in Mexico, soil erosion is a major environmental issue. Erosion and sedimentation stem primarily from human modification of the landscape. As populations continue to grow and land use changes, sedimentation will continue to be an issue.

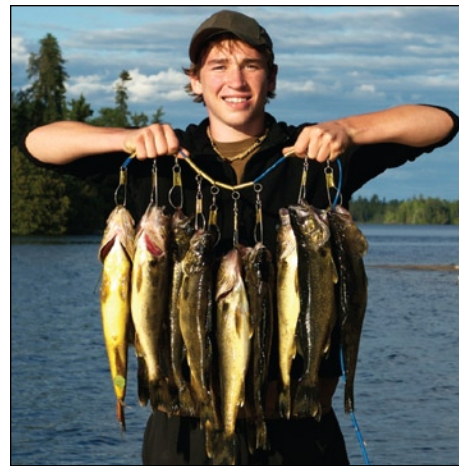
### Eutrophication and Nutrient Overenrichment

Eutrophication and high nutrient loadings affect both freshwater and coastal systems. In eutrophication, excessive plant growth (bloom) occurs in water bodies receiving excessive nutrient loads. Eutrophic conditions can occur naturally in lakes as they age and in estuaries, but in North America human activities have led to widespread nutrient levels and eutrophication that far exceed natural levels. Eutrophication encourages the growth of toxic algae, which in some instances in the marine environment is also known as “red tide” (see map). Decomposition of these excess algal blooms reduces the level of oxygen in the water to the point that other organisms die (hypoxia).

Canada, Mexico and the United States all struggle with nutrient overenrichment of water resources caused by poor sewage treatment, use of fertilizers and deposition of combustion byproducts (nitrogen oxides). In the United States, about 55 percent of freshwater impairments and some 20 percent of coastal system (estuaries, bays) impairments stem from nutrient loads or eutrophication. The Gulf of Mexico dead zone, a product of nutrient inputs (primarily nitrogen) from the Mississippi River basin, is the largest expanse of human-caused hypoxia in the Western Hemisphere. In Canada, similar concerns have arisen about St. Lawrence estuary hypoxia caused by factors such as nitrogen.

### Pathogens

Contamination of water resources with pathogenic organisms (as indicated by fecal coliform bacteria) is still a concern in many areas of North America. The source of pathogen contamination of most concern is poorly treated and untreated sewage. In some areas, however, agricultural operations and wildlife are also a factor. Although 71 percent of the US population is served by sewage treatment plants, beaches were closed or health advisories were issued because of bacterial contamination for 18,000 instances in 2003, up from 3,000 days in the mid-1990s. A similar portion (72 percent)



Walleye fishing.

of the Canadian population is served by sewage treatment plants, but municipal wastewater discharges still represent one of the largest sources of pollutant releases by volume to Canadian waters. In Mexico, where only 35 percent of the people are served by sewage treatment plants, bacterial contamination of freshwater and coastal systems is a significant issue.

### Mercury

Mercury is a metal that accumulates in human, fish and animal tissue, sometimes reaching toxic levels (see case study). In aquatic ecosystems, mercury can enter the food chain through the action of bacteria and benthic organisms. Consumers of mercury-contaminated organisms can then accumulate mercury to toxic levels—even where concentrations of mercury in water are barely detectable.

Mercury most often enters North American water resources via the deposition of mercury emitted to the air from mining, industrial processes and combustion of fossil fuels, municipal and medical waste. In recent years, Canada and the United States have reduced their mercury emissions: Canada by 80 percent

over 1990–2003 and the United States by 45 percent over 1990–1999. However, high mercury levels in fish still account for over 90 percent of fish consumption health advisories issued in Canada and 80 percent issued in the United States for both freshwater and coastal fisheries. In 2000–2003, mercury was found in 100 percent of fish sampled as part of the national fish tissue study in the United States. Even after inputs to contaminated systems cease, mercury can continue to accumulate in the food chain for decades. And because mercury is easily transported long distances in the atmosphere, mercury emissions from other continents contribute to the mercury contamination of North American fisheries.

### Persistent Organic Pollutants

Persistent organic pollutants are organic chemicals that accumulate in human and animal fatty tissue, possibly reaching toxic levels. The North American countries have long worked to reduce the use and release of persistent organic pollutants such as DDT, polychlorinated biphenyls (PCBs), dioxins and chlordane, and yet these compounds still persist in soils, sediment and fish tissue. In the United States, for example, PCBs, dioxins and furans, and DDT were widely detected in fish sampled in 2000–2003. Although long banned in the United States, PCBs were still found in 100 percent of both predator and bottom-dweller composite samples. Long-term monitoring of fish populations in the Great Lakes has documented a decline in PCBs, DDT and other persistent contaminants, but the concentrations of some of these constituents still exceed the human and wildlife health criteria in various regions of the Great Lakes.

### What Are the Linkages to Other North American Environmental Issues?

Water quality is affected by activities within a watershed or groundwater recharge area, as well as by the global climate and atmospheric transport from areas farther away.

### Climate Change

As climate patterns change, precipitation and runoff patterns in North America will also likely change, bringing more drought in some areas and more flooding in others. Under drought conditions, pollutants can become concentrated in water resources to harmful levels. With greater runoff and flooding, even more pollutants (by quantity and in greater varieties) are washed into surface waters.

## Land Use

Several studies have identified links between quality of water resources and land use in a watershed. Land clearing can increase the transport of sediment into surface waters. Pesticides and fertilizers applied to the land can be washed into surface waters or percolate into groundwater aquifers, as can any material spilled on land, such as toxic chemicals, oil from cars or gasoline.

## Energy

Levels of demand for energy are linked to water pollution. Water used in oil and gas exploration and production may become laden with toxics that must be removed before it is safe for use by humans or wildlife. Combustion byproducts from power plants, such as nitrogen oxides, sulfur dioxide and mercury, can travel long distances in the atmosphere and affect water resources far from the facility site, changing the pH, contributing nitrogen to the nutrient load and contaminating fisheries.

## Biodiversity and Ecosystems

Plants and animals living in surface waters are accustomed to particular water quality conditions. If the water quality of a lake or stream changes, some plants and animals can no longer survive there. Because poor water quality is known to reduce biodiversity, the United States and Canada use the biodiversity of aquatic communities as an indicator of surface water quality. Changes in aquatic communities because of poor water quality can change the way in which the aquatic ecosystem functions, as well as the associated terrestrial plant and animal communities.

## Pollutants

Greater runoff is associated with greater loading of sediments, nutrients, toxic contaminants and other pollutants—all of which have an effect on the quality of drinking water supplies and aquatic ecosystems. Meanwhile, as land is converted to urban or suburban uses, point source pollution also increases—a byproduct of the additional wastewater treatment facilities constructed to meet the needs of the expanding population and new industries. The cumulative influence of increased point and nonpoint sources can affect the suitability of water to support aquatic ecosystems and other desired water uses. The presence of new contaminants such as flame retardants, personal care products and pharmaceuticals is also beginning to be detected, although the overall and cumulative levels of risk for humans and ecosystems are still unknown. 🦋

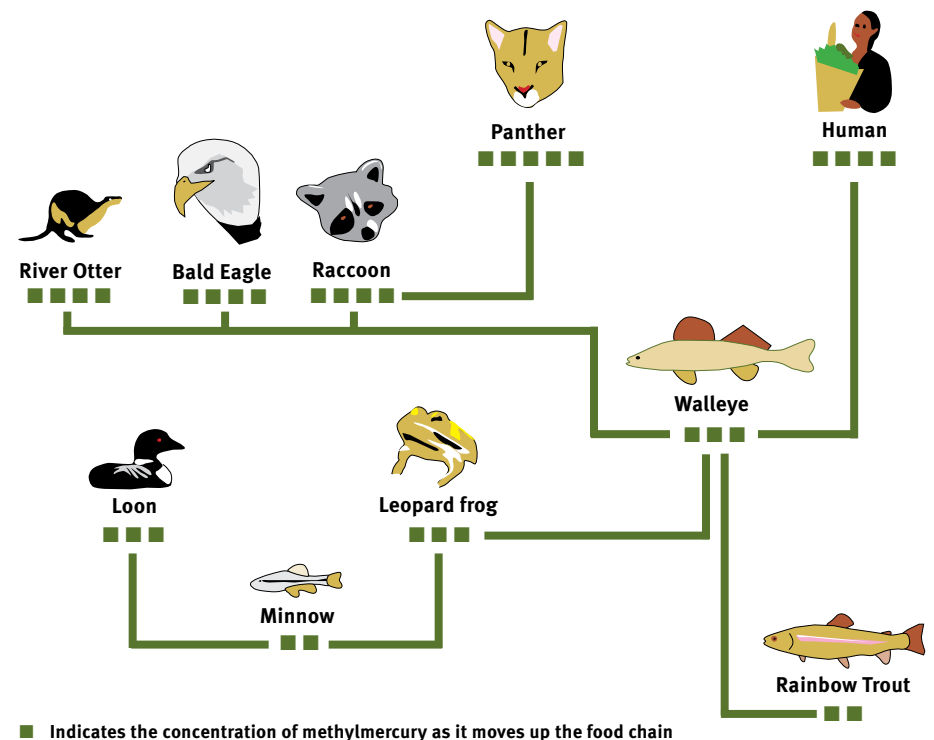
## Case Study – Mercury in North American Waters

Mercury is a naturally occurring metal that can damage the liver, brain, heart, kidneys, lungs and immune system of humans, fish and wildlife. Industrialization has increased the proliferation of mercury globally. In most of its chemical forms, mercury is easily transported through the atmosphere. Atmospheric mercury is the primary source of mercury in North American freshwaters and marine waters. Indeed, virtually no place on earth is untouched by the deposition of atmospheric mercury. As a result, mercury contamination is pervasive throughout North America, occurring even in areas far from cities and industry.

Mercury concentrations in most North American waters are too low to have toxic effects on those who come in contact with or ingest the water. However, under the right conditions mercury in the water can move into the food chain. In most organisms, mercury binds to proteins and accumulates in the tissues as methylmercury. When predators eat mercury-contaminated prey organisms, the mercury from the prey's tissues is transferred to the predator's tissues (see illustration). Thus the higher an organism is in the food chain, the more it can accumulate mercury in its tissues and the greater is the potential for toxic effects.

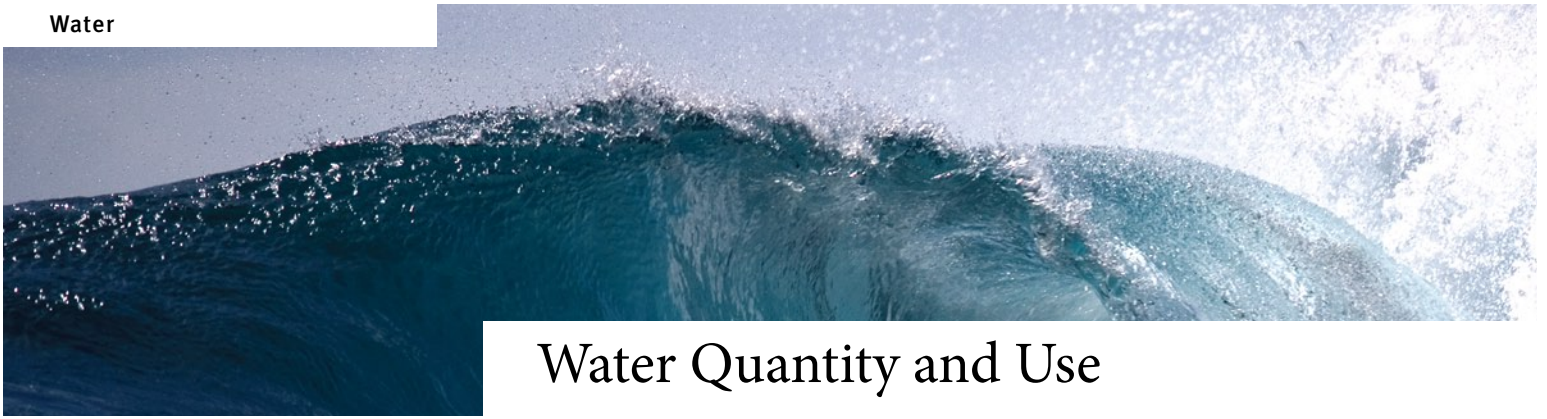
In the freshwater and marine systems of North America, methylmercury in fish is a concern. When they ingest mercury-contaminated fish, North American birds, animals and humans face the possibility of accumulating toxic levels of mercury in their tissues. Those whose diets consist primarily of fish are at greater risk of experiencing the health effects of mercury accumulation.

### Accumulation of mercury through the food chain



Source: National Wildlife Federation, <<http://www.nwf.org/mercury/bioaccumulation.cfm>>.





# Water Quantity and Use

## Key Findings

- Fresh surface water and groundwater are a common denominator for life. Continued access to freshwater is a concern in several areas across North America.
- The distribution of freshwater varies widely across North America. Industrial and agricultural uses account for the majority of North American water withdrawals, and in some areas human use competes with ecological requirements.
- Total water withdrawals in the United States grew from 1970 until 1990, but since then they have been relatively constant despite continued population growth. In Canada and Mexico, total water withdrawals have continued to rise.
- Climate change, land use and population growth affect the availability of freshwater throughout North America. As climate changes, patterns of precipitation and runoff are also likely to change. In response to expected population growth and patterns of development, heightened competition among water users is anticipated.

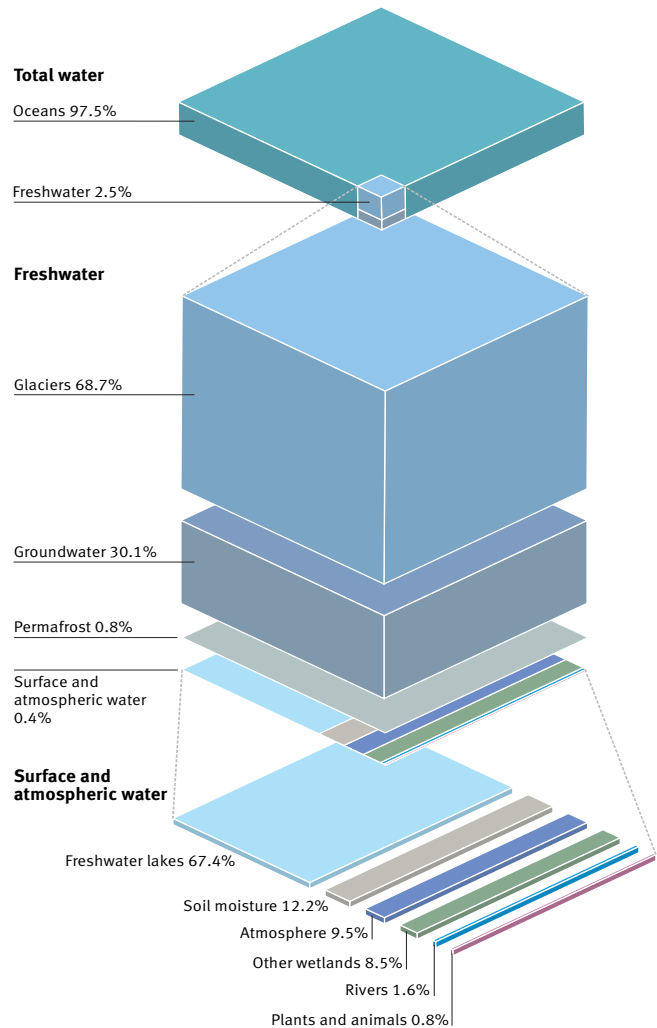
**Water quantity and use** are directly related to a variety of human and ecological needs: agricultural, industrial, domestic and environmental. Human development and the environment depend on adequate supplies of clean water.

## What Is the Environmental Issue?

Water—a finite but renewable resource—is essential to sustain life, development and the environment. Although over 70 percent of the

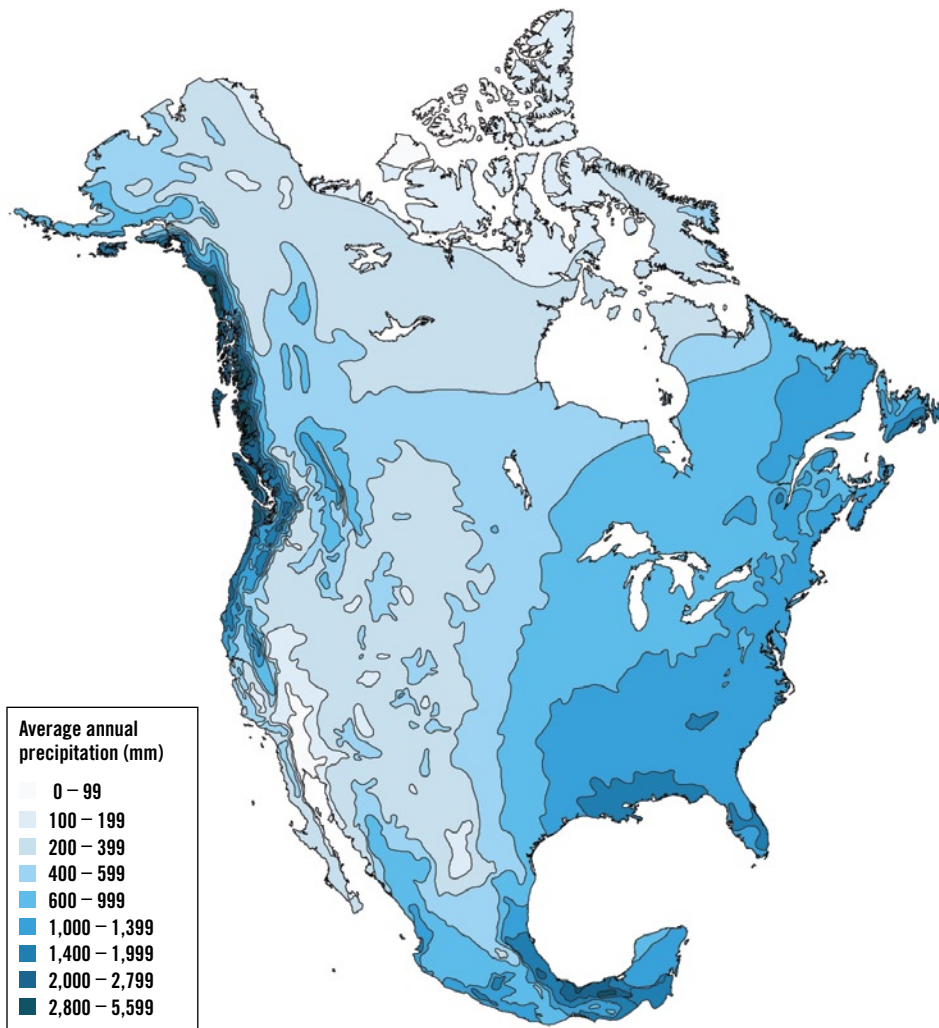
earth’s surface is covered by water, 97 percent is salty ocean water and less than 3 percent is freshwater (see figure). Of the freshwater, 69 percent is frozen in glaciers and permanent snow, and an additional 30 percent is “hidden”

## Global distribution of the world’s water



Source: United Nations Environment Programme.

## Average annual precipitation in North America



Source: ESRI.

groundwater. Thus less than 1 percent of the earth's water is present as fresh surface water and atmospheric vapor.

Fresh surface water and groundwater are a common denominator for life in all countries. Not only does water sustain all life, but there are no substitutes for it in many commercial and industrial processes, and especially in growing agricultural crops. The use of freshwater

for public water supplies, irrigation, industrial processes and cooling of electric power plants exerts pressure on water resources. Meanwhile, the patterns of freshwater use affect public water supplies, the salinization of freshwater bodies in coastal areas, food production and competition among various end uses. Another factor is that aquatic ecosystems typically need both minimum and maximum flows at specific

### North America's internal renewable water resources (km<sup>3</sup>/yr)

	Canada	Mexico	United States	North America
Surface water produced internally	2,840	361	2,662	5,863
Groundwater recharge	370	139	1,300	1,809
Total (adjusted for overlap)	2,850	409	2,800	6,059

Source: Food and Agriculture Organization.

### Freshwater withdrawals for domestic, industrial and agricultural uses in North America (2000)

Use	Canada	Mexico	United States
Total withdrawal (km <sup>3</sup> /yr)	46	78	479
Domestic	19%	17%	13%
Industrial	69%	6%	46%
Agricultural	12%	77%	41%

Source: Food and Agriculture Organization.

times of the year to sustain their various communities of aquatic organisms.

### Why Is This Issue Important to North America?

Freshwater resources are of major environmental and economic importance to North America, but the distribution of these resources varies widely. Canada has some 20 percent of the world's total freshwater resources. Much of it, however, is in remote locations or retained in lakes, underground aquifers and glaciers. By contrast, Mexico is primarily an arid country in which freshwater is abundant in some local areas only. Not just the amount of freshwater is important, but also how rapidly this water is replenished through rainfall and runoff. In many parts of North America, humans' needs and uses for water compete with the need for water to sustain aquatic life.

### Distribution of Water Resources

North America's internal renewable water resources include the average annual flow of rivers and the recharge of groundwater (aquifers) by precipitation within a country's borders (see table). Surface water produced internally represents the average annual flow of rivers generated from internal precipitation and the base flow generated by aquifers. Groundwater recharge is estimated by measuring rainfall in arid areas where rainfall is assumed to infiltrate aquifers, although the uncertainties about these estimates are considerable. The total of the two accounts for any overlap occurring when surface waters recharge aquifers, or when aquifers release to surface flow. Natural incoming flows originating outside a country's borders are not included in the total in the table.

Freshwater resources are not distributed uniformly across North America (see map). In

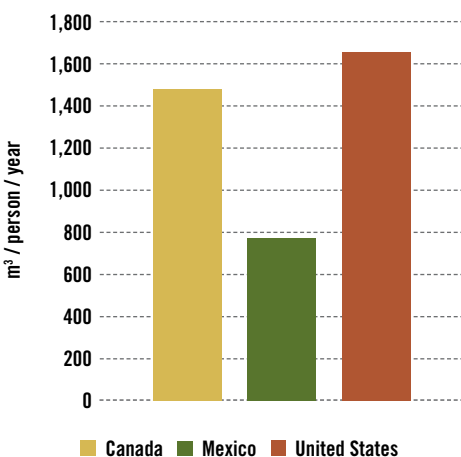
general, the eastern regions of North America are considered water-rich or precipitation-dominated, although droughts can significantly affect water availability on a periodic basis. Annual normal precipitation values of 800 millimeters or greater are generally associated with water-rich areas in Canada, southeastern Mexico and the eastern United States. Annual normal precipitation values of less than 600 millimeters are associated with arid and semiarid regions, including the Great Plains regions of Canada and the United States and much of Mexico. This distribution plays a role in the withdrawal of surface versus groundwater for use.

### Uses of Water Resources

In North America, about 85 percent of water withdrawals are by industry and agriculture combined, but the distribution among uses varies by country (see table). In Canada, 69 percent of withdrawals are used by industry and 12 percent by agriculture, whereas in Mexico agriculture uses about 77 percent and industry only 6 percent. In the United States, agricultural and industrial withdrawals are roughly similar.

Not all freshwater withdrawals have the same implications for the water supply. Agriculture is a highly consumptive use, returning only a small portion of water withdrawn back to the source. The rest is lost to evaporation or used for irrigation and livestock watering. Industrial uses are often much less consumptive because water is recycled internally and eventually returned in part downstream. An example is electric thermal power genera-

### Per capita water use in North America based on all withdrawals (2000)



Source: Food and Agriculture Organization.

### Case Study – The Pitfalls of Groundwater Mining



Subsidence in San Joaquin Valley, California  
Photo: US Geological Survey.

Land subsidence, or even collapse, can occur when groundwater withdrawal exceeds recharge and a void is created in the underground aquifer. One example is the San Joaquin Valley, one of the most productive agricultural areas in the United States. The California Central Valley, which includes the San Joaquin Valley, produces about 25 percent of US table food on only 1 percent of US farmland. From 1900 until the 1970s, groundwater was mined to irrigate and grow this food. But eventually groundwater withdrawals significantly exceeded recharge, and the over 75 years of pumping groundwater for irrigation caused the land to drop (subside) by over 8 meters. In this photo of a site near Mendota in the San Joaquin Valley, the top sign on the pole indicates the level of the land surface in 1925 compared with the level when the photo was taken, about 1977.

tion, which accounts for a large proportion of industrial withdrawals. Some of the water is converted to steam to drive the generator producing the electricity, but most of the water is used for condenser cooling and later released. In domestic water use, returns are largely via sewage, which is treated in most areas before being returned to surface waters. Other human uses of freshwater—such as those for hydroelectric power generation, shipping and recreation—are in-stream uses that are not counted as withdrawals.

Withdrawals can also be expressed on a per capita basis (see graph). The United States and Canada are the highest per capita water users in the world when withdrawals for all uses are considered. Per person usage is more than two and a half times that in Asia or Europe and over six times that in Africa. One reason is the low cost of water relative to that in other industrialized countries. Per capita water use in Mexico is more comparable to that in other areas of the world, although it is still slightly higher.

Total water withdrawals in the United States grew from 1970 until 1990, but since then they have been relatively constant, even

though the population has grown by about 16 percent. In Canada and Mexico, total water withdrawals have continued to rise. Between 1972 and 1996, Canada's rate of water withdrawals increased by almost 90 percent, although its population rose by only 34 percent over the same period. Mexico has also experienced higher water withdrawals over the last 30 years.

Irrigation is partly responsible. Land under irrigation has increased since 1960, doubling in Canada and Mexico and increasing by more than 50 percent in the United States. Much of this increase has occurred in arid or semiarid regions, where groundwater is the primary water source. Slightly over a tenth of North America's cultivated area is irrigated, of which over 75 percent is in the United States and slightly more than 20 percent in Mexico. In the United States, areas equipped for irrigation account for about 12 percent of cultivated land. In Mexico, almost a quarter of cultivated land is irrigated. By contrast, less than 2 percent of Canada's cultivated area is under irrigation.

The majority of withdrawals in North America are from surface water, but ground-

water withdrawals also serve many uses, from domestic supply to irrigation. Although globally the amount of groundwater exceeds that of surface water (i.e., about 30 percent groundwater to less than 1 percent surface water), surface water is much more rapidly replenished (through precipitation) than groundwater. Some groundwater is called “fossil water,” because its rate of recharge or renewal is measured in geologic time (millions of years), whereas the renewal of surface waters is measured in days or weeks.

In many areas of North America, the groundwater table is declining; withdrawals are simply outweighing recharge. In some areas of Mexico and the United States, the ground overlying these declining aquifers has collapsed or subsided. Mexico City has experienced up to 18 meters of subsidence over the past 100 years because of groundwater withdrawal. Since the late 1980s, authorities in Mexico City have managed groundwater use in an effort to reduce subsidence, and yet the observed rate of subsidence during the last 20 years has been on the order of 20–30 centimeters per year. In the United States, more than 43,500 square kilometers in 45 states have been directly affected by subsidence (see case study).

### What Are the Linkages to Other North American Environmental Issues?

Water is a pervasive factor in all aspects of the environment, but linkages with certain issues merit further consideration.

#### Climate Change

Water vapor is not only the most important greenhouse gas, but also a major influence on the earth’s climate. Water patterns are both affected by and influence climate change. Patterns of increased rainfall and drought have been linked with El Niño and La Niña events in North America, based on changes in the sea surface temperature. As climate patterns change, precipitation and runoff patterns are also likely to change, with more drought in some areas and more flooding in others. Scientists may not be able to predict the precise patterns of change with certainty, but they do understand that climate change will lead to changes in water availability in North America.

#### Land Use

Like climate change, changes in land use, particularly those stemming from population growth, are linked to water quantity and

use. In general, population growth and land use changes are expected to play a greater role than climate change in the scarcity of water resources over the next 25 years. Certain areas of North America are likely to have greater water shortages than others, however, because of the spatial differences in the distribution of renewable and available water within countries and across geographic areas. In some areas, the trends in climate change, population change and land use are occurring simultaneously. Land use can also affect water supply by expanding the impervious surfaces that limit the extent of groundwater recharge.

#### Biodiversity and Ecosystems

Precipitation and runoff sustain both terrestrial and aquatic ecosystems, as well as provide the freshwater required to sustain estuarine ecosystems. Competition for water between humans and aquatic ecosystems can significantly alter flow regimes—that is, as water is withdrawn for other uses, the lowered flow no longer supports aquatic communities. Aquatic ecosystems require more than just a minimum

amount of water for maintenance; they also require flooding with the right frequency and magnitude to sustain the system. Dams and other flow impediments can alter both the timing of flows and the amount of water that flows in streams, significantly affecting the downstream biodiversity (see case study).

#### Pollutants

Runoff is usually accompanied by increased loading of sediments, nutrients, toxic contaminants and other pollutants—all of which affect the quality of drinking water supplies and aquatic ecosystems. As land is converted to urban or suburban uses, point source pollution increases as additional wastewater treatment facilities are constructed to treat the waste from an expanding population. Impervious surfaces in developed areas also promote additional runoff that may not have an opportunity to be filtered through natural processes. The cumulative influence of increased point and nonpoint sources can affect the suitability of water to support aquatic ecosystems and to meet other desired water uses. 🦋

### Case Study – Colorado River Delta



An image of the Colorado River Delta taken September 2000 by the Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Photo: National Aeronautics and Space Administration.

The Colorado River Delta is located in the region below the California-Mexico border, where the Colorado River has historically flowed into the Gulf of California (Sea of Cortez). This oasis of 7,800 square kilometers used to be one of the largest desert estuaries in the world. In the 1920s, naturalist Aldo Leopold commented on the rich diversity of waterfowl, freshwater and brackish aquatic life, jaguar, deer, beaver and other wildlife found in the Colorado River Delta. Today, the Delta is only about 5 percent of its original size, and it no longer supports this rich biodiversity because its historical inflow no longer consistently reaches this estuary. Upstream dams and diversion canals have significantly reduced and altered flow in the Colorado River. Even though estuaries such as the Delta are naturally brackish, these ecosystems must have freshwater inflows to sustain their biodiversity and productivity.



## Shared Water Resources

### Key Findings

- Shared water resources are water bodies that span political boundaries. Along the borders of the United States with Canada and Mexico, the effective management of the quality and use of these water bodies is a shared responsibility.
- Climate change, population growth, pollution, invasive species and land use change affect the quantity and quality of shared water resources and their ability to support aquatic ecosystems.
- In 2005 the US Environmental Protection Agency rated several important shared water bodies. The Gulf of Mexico was rated as in “fair” condition and the Great Lakes as in “fair to poor” condition. The Gulf of Maine was in generally better condition than the rest of the northeastern coastal region, which was rated as in “poor” condition.
- It is difficult to characterize overall trends across all the important features of shared water resources. In the Great Lakes, for example, trends in ecosystem conditions show improvement in some areas and worsening in others.

*Shared water resources* are the rivers and estuarine regions that form borders or flow across borders, the lakes that span political boundaries, marine areas with multiple jurisdictions, and the groundwater aquifers that lie beneath political boundaries.

### What Is the Environmental Issue?

Water is a shared global resource. The hydrologic cycle transports water around the globe through atmospheric vapor and ocean currents. On land, water (streams and rivers) forms the political borders between many nations. Countries also share the lakes that span their political boundaries and the groundwater aquifers that lie beneath those boundaries.

Because water is essential for supporting all life processes, many nations view its adequate

availability as a fundamental human right. Conflicts over water rights were recorded as early as 2500 B.C., and such conflicts are expected to arise more frequently in the future as human populations and economic development continue to grow and climate patterns change.

### Why Is This Issue Important to North America?

North America has extensive shared water resources, but there are vast differences in the



A view of the Rio Grande river bordering the United States (left) and Mexico as seen from an international bridge in the border city of Ciudad Juárez, Mexico. Photo: REUTERS/Tomas Bravo.

quality and quantity of those resources across the continent. Along the northern border between Canada and the United States and the southern border between Mexico and the United States, the management of shared water resources—both for quantity and quality—is an important issue.

#### Management of Shared Water Resources

Canada and the United States share water along their almost 9,000-kilometer border from the Atlantic to the Pacific, and across a gradient from the relatively water-rich areas in the east to the more arid regions in the west. Likewise, Mexico and the United States share water along their 3,000-kilometer border, which runs amid

the arid regions from Texas to California. But even with these gradients, many of the water quantity and quality issues among North American countries are similar. Potential conflicts over shared water resources in North America are addressed through bilateral water treaties, agreements and protocols.

The largest shared water resource between Canada and the United States is the Great Lakes–St. Lawrence River system, which contains one-fifth of the freshwater in the world. Other shared Canada-US resources range from the Gulf of Maine in the east to the Red River of the North in the central region to the Pacific Ocean in the west. Over the years, the United States and Canada have negotiated agreements

to resolve water issues. As early as 1909, the Boundary Waters Treaty established the International Joint Commission to prevent and resolve disputes between the two countries. In 1972 Canada and the United States signed the first Great Lakes Water Quality Agreement (later revised in 1978 and 1987) to control pollution in these waters and to clean up wastes from industries and communities. The 1987 revisions introduced the concepts of Areas of Concern, Lakewide Management Plans and other elements generally recognizing an ecosystem approach toward restoration and maintenance of the Great Lakes.

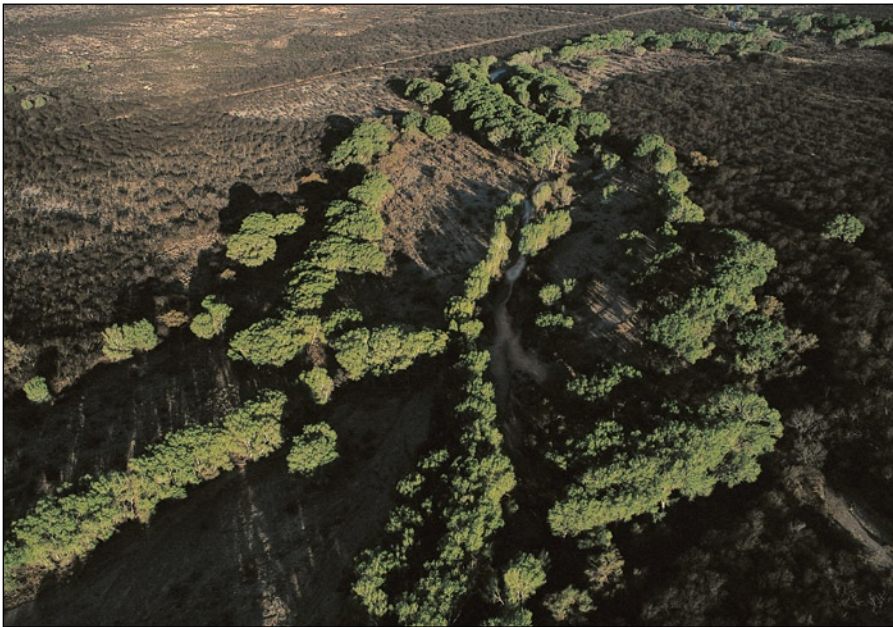
The water quantity and elevations of the Great Lakes are a concern for both Canada and the United States. Recently, the water levels of some of the Great Lakes have declined (notably Lakes Michigan and Huron). Some of the environmental consequences of lower water levels are smaller wetland areas, nursery areas, fish habitat and wildlife habitat, including resting and nesting areas for migratory waterfowl. As lake levels fall, dredging will be required to maintain shipping lanes. But dredging can disturb and resuspend contaminated sediments throughout the Great Lakes. Associated economic consequences are lower shipping tonnage because of shallower drafts in harbors, loss of recreation and less-efficient thermoelectric power generation.

Major shared resources between Mexico and the United States are the Colorado River and Rio Grande/Rio Bravo and the Gulf of Mexico. Many other surface water and groundwater resources important to local communities, states and provinces also lie along these borders. Ensuring that both countries have sufficient shared water resources has been one of the driving factors in treaties, agreements and protocols along the Mexico-US border. The Convention of 1906 between Mexico and the United States addressed water distribution issues for the Rio Grande. Several decades later, the US-Mexico Water Treaty of 1944 distributed waters in the lower Rio Grande, the Colorado River and the Tijuana River and also created the US-Mexico International Boundary Water Commission. In 1983 Mexico and the United States enacted the Border XXI Agreement to prevent, reduce and eliminate sources of pollution.

#### Water Quality

Since 1994, Environment Canada and the US Environmental Protection Agency have jointly evaluated the Great Lakes, publishing the results

### Case Study – Resolving Water Quantity Issues in the San Pedro River



The San Pedro River. Photo: Adriel Heisey.

The San Pedro, which has its headwaters in Sonora, Mexico, and flows north into southern Arizona, is the largest undammed river in the southwestern United States. Water quantity is an issue for this river because the San Pedro is in an evaporation-dominated region, with low rainfall. During dry months, groundwater maintains flow in portions of the San Pedro, and so it is an oasis in the arid Chihuahua and Sonoran Deserts. However, groundwater has been depleted because of withdrawals for mining and ranching in Mexico and domestic withdrawals by Sierra Vista and Ft. Huachuca in Arizona. In response, citizens formed the San Pedro National Conservation Area in 1988, and those on both sides of the border implemented collaborative measures, management measures—such as creating land preserves, implementing county codes for water use and promoting water conservation practices (e.g., low-flow water fixtures, toilets, washers)—and stakeholder outreach and education programs. Monitoring programs are in place to track progress toward achieving goals for sustainable groundwater levels in order to restore and protect the San Pedro River.

## Case Study – Addressing Water Quality Issues in Lake Erie

During the late 1960s and early 1970s, water quality in Lake Erie deteriorated to the point that the lake was declared “dead.” Because Lake Erie is the shallowest of the Great Lakes, high phosphorus concentrations were contributing to serious eutrophication problems such as beaches covered with algal scum, loss of oxygen to support fish and other aquatic life in the bottom waters, and replacement of fish such as walleye with pollution-tolerant species such as carp.

In 1972 Canada and the United States signed the Great Lakes Water Quality Agreement and began to work on reducing phosphorus loading to the Great Lakes. Great Lakes provinces and states worked to reduce phosphorus in municipal and industrial effluents and to eliminate phosphorus from detergents. As a result, total phosphorus and chlorophyll concentrations decreased dramatically. Fish species richness increased with the return of pollution-intolerant species such as burbot, lake whitefish, smallmouth bass and white sucker and a decline in pollution-tolerant species such as brown bullhead, common carp and white crappie.

Over the last decade, however, Lake Erie’s concentrations of phosphorus have been on the rise again. Tributary loadings of dissolved phosphorus are increasing. Hypoxia and anoxia in the central basin are more extensive and occur over a longer period of time. Blooms of the hazardous cyanobacteria *Microcystis* and the extensive growth of *Cladophora*, a clinging filamentous green alga, are beginning to rival those of the 1970s. As a result, nutrient management, particularly for phosphorus, remains the top priority for improving the lake, and the United States and Canada are developing a new binational nutrient management strategy for the lake. Although yellow perch stocks are now recovering throughout the lake, the top predator species populations of walleye, lake trout and lake whitefish continue to struggle.



Lake Erie shore.

in the *State of the Lakes Ecosystem* (SOLEC) report. SOLEC assesses the Great Lakes basin ecosystem components using a suite of ecosystem health indicators. For 2007, the overall status of the Great Lakes ecosystem was assessed as mixed because some conditions or areas were good or improving, and others were poor or worsening. Some of the improving conditions were declining levels of most contaminants in herring gull eggs and predator fish, the achievement of phosphorus targets, improving lake trout stocks, and the partial recovery of mayfly (*Hexagenia*) populations. Some of the negative trends were the increasing concentrations of the flame-retardant polybrominated diphenyl ethers (PBDEs) in herring gull eggs, the nuisance growth of the green alga *Cladophora*, the persistence of pervasive non-native species, unsustainable groundwater withdrawals, the growing number of impervious surfaces in urban areas, the long-range atmospheric transport of polychlorinated biphenyls (PCBs) and other contaminants, the ongoing shoreline development, and the declining populations of some species of amphibians and wetland-dependent birds.

In 2005 the US Environmental Protection Agency scored several large shared water bodies based on a large amount of monitoring data collected between 1997 and 2000. In this assessment, the Gulf of Mexico was rated as in “fair” condition and the Great Lakes as in “fair to poor” condition. The Gulf of Maine was in generally better condition than the rest of the northeastern coastal region, which was rated as in “poor” condition, but signs of degraded water quality condition were still noted throughout the area north of Cape Cod and along the coastline of Maine.

Many of the water quality issues along country borders are similar. DDT and other chlorinated hydrocarbon pesticides, as well as PCBs and associated arochlors (aromatic chlorinated hydrocarbons), have contaminated fish tissue from the Gulf of Maine to the Great Lakes to the Gulf of Mexico. PCB and DDT concentrations are also a concern in the Rio Grande separating Mexico and the United States. Mercury contamination of fish tissue is widespread as well, not only in North America, but also globally. The mercury concentrations in top predator fish, such as walleye and largemouth bass, have been so high that fish consumption advisories have been issued for tributaries to the Great Lakes and along the Canada-US border. King mackerel have mercury concentrations high enough to trigger consumption advisories throughout the Gulf of Mexico.



Salinity is another problem—it rises as irrigation water seeps through mineral-rich soils and then returns to surface water, thereby transporting these dissolved minerals. In the Colorado River, salinity rose over the first half of the twentieth century as irrigated acreage increased in the Colorado River Basin. In 1973 the International Boundary and Water Commission adopted Minute 242 to address the salinity issues in the Colorado River.

Rivers and streams throughout North America also exhibit degraded water quality because of the loading of oxygen-consuming organic matter, sedimentation that decreases water clarity and water depth and volume and nutrients that contribute to nuisance and harmful algal blooms.

### What Are the Linkages to Other North American Environmental Issues?

Shared water resources are vitally linked to other important environmental topics such as climate change, land use, biodiversity and pollutants.

#### Climate Change

As climate patterns change, precipitation and runoff patterns are likely to change, with more drought in some areas and greater flooding in others. The warming temperatures of the Great Lakes have increased their evaporation during winter when they used to freeze, which, in turn, has contributed to lower lake levels. Warmer future temperatures are also expected to further reduce the Colorado River's stream flow and water supplies. Meanwhile, increased runoff will result in greater loading of sediment, organic matter, nutrients and toxic contaminants to aquatic ecosystems throughout North America. Overall, reduced water quantity and degraded water quality will make it more difficult for all three countries to satisfy international treaty requirements.

#### Land Use

Along with climate change, population growth and changes in land use will play a greater role in the scarcity of water resources over the next 25 years because of the growing urbanization and competition among water users, both within countries and along international borders. In view of the spatial differences in the distribution of renewable and available water within countries and across geographic areas, certain areas of North America are likely to have greater water shortages than others.

#### Biodiversity and Ecosystems

Biodiversity in aquatic ecosystems is affected by both water quantity and quality, as illustrated by the examples of the San Pedro River and Lake Erie (see case studies). Biodiversity is also affected by the introduction of invasive species, which have already affected biodiversity in shared resources. Examples are zebra mussels in the Great Lakes and water hyacinth in the Rio Grande. Zebra mussels not only outcompete native mussels for habitat, but also affect food web dynamics by filtering the food needed by other organisms out of the water column. Water hyacinth are clogging the Rio Grande and its tributaries with their dense growth, blocking sunlight for native plants and depleting the water of oxygen needed to support fish and other aquatic organisms.

#### Pollutants

Pollutants often cross political boundaries. Although DDT has been banned and PCB use has been restricted for decades, the atmospheric transport and deposition of these compounds are continuing to maintain concentrations in fish tissue from the Great Lakes to the Gulf of Mexico. Canada and the United States have identified Areas of Concern and developed Remedial Action Plans for the Great Lakes (see map). Nutrient overenrichment has contributed to the hypoxia problem in the Gulf of Mexico and to eutrophication of lakes, reservoirs, streams and rivers throughout North America. Atmospheric nitrogen contributes as much as 30 percent of the nitrogen loading to Chesapeake Bay. Atmospheric sources also contribute nitrogen to the Great Lakes and Gulf of Mexico. 🦋

Areas of concern identified for water quality improvement in the Great Lakes by Canada and the United States



- |  |                     |   |
|--|---------------------|---|
| 1 Nipigon Bay                                | 15 White Lake       | 30 Eighteen Mile Creek                    |
| 2 Thunder Bay                                | 16 Saginaw Bay      | 31 Rochester Embayment                    |
| 3 St. Louis Bay/River                        | 17 St. Clair River  | 32 Oswego River (delisted)                |
| 4 Torch Lake                                 | 18 Clinton River    | 33 St. Lawrence River/ (Cornwall/Massena) |
| 5 Deer Lake – Carp Creek/River               | 19 Detroit River    | 34 Bay of Quinte                          |
| 6 Manistique River                           | 20 Rouge River      | 35 Port Hope                              |
| 7 Menominee River                            | 21 River Raisin     | 36 Toronto and Region                     |
| 8 Fox River/Lower Green Bay                  | 22 Maumee River     | 37 Presque Isle Bay                       |
| 9 Sheboygan River                            | 23 Wheatley Harbour | 38 Severn Sound (delisted)                |
| 10 Milwaukee Estuary                         | 24 Black River      | 39 Sarnish Harbour                        |
| 11 Waukegan Harbor                           | 25 Cuyahoga River   | 40 St. Marys River                        |
| 12 Grand Calumet River/ Indiana Harbor Canal | 26 Ashtabula River  | 41 Peninsula Harbor                       |
| 13 Kalamazoo River                           | 27 Presque Isle Bay | 42 Jackfish Bay                           |
| 14 Muskegon River                            | 28 Buffalo River    |   |
|  | 29 Niagara River    |   |

Source: International Joint Commission.







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