GLOBAL ENVIRONMENT OUTLOOK

GEO-6

REGIONAL ASSESSMENT FOR

NORTH AMERICA

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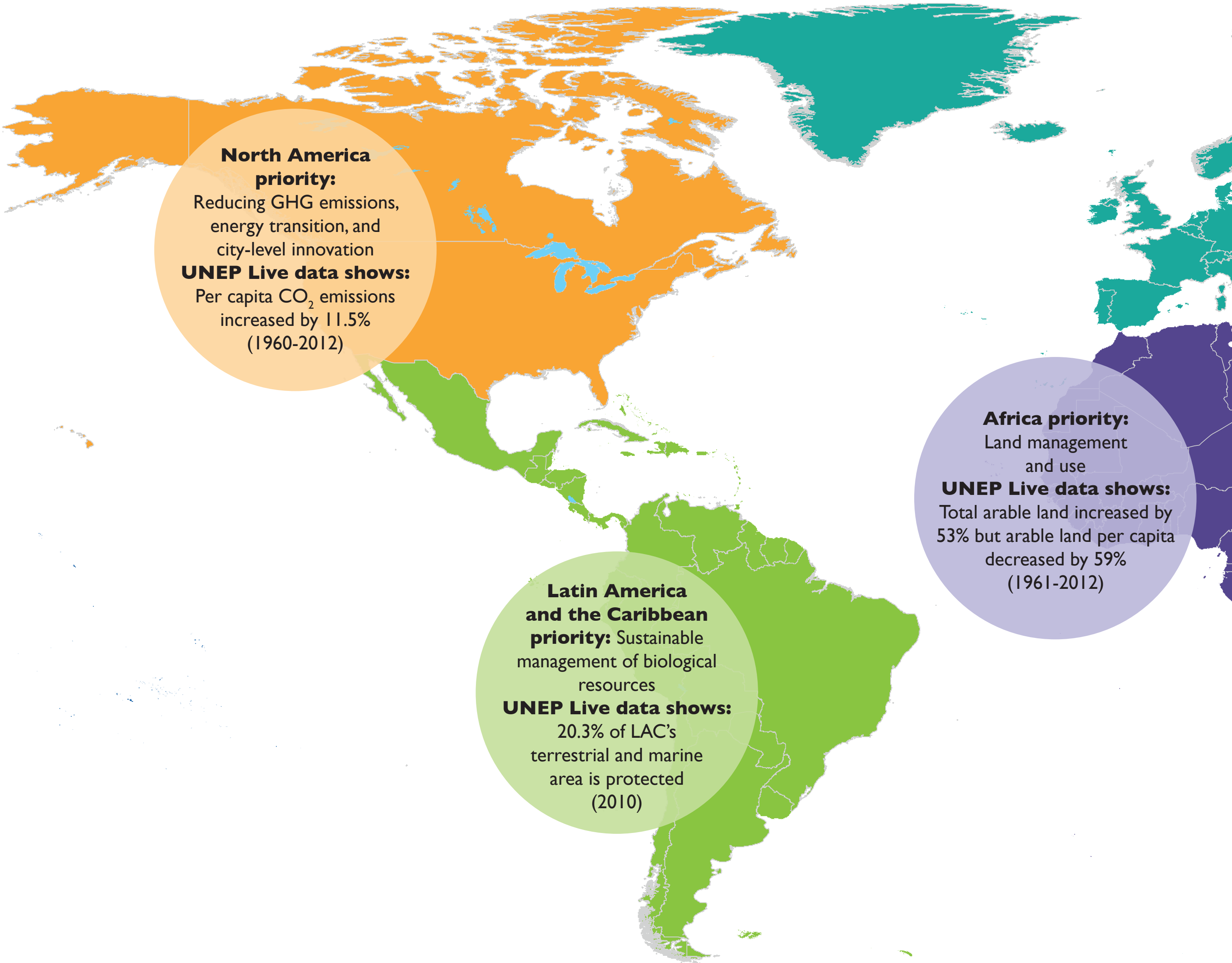
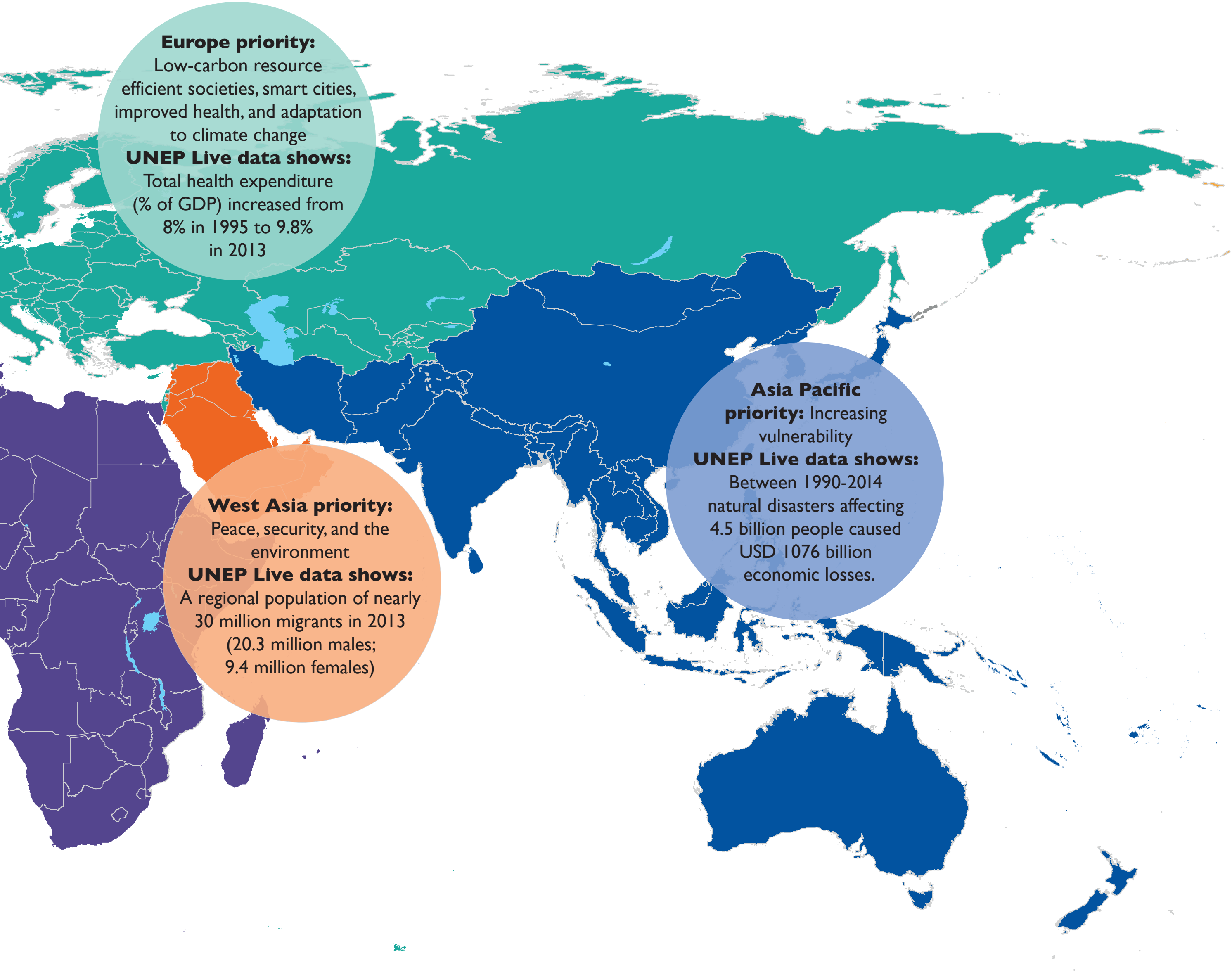

North America priority:
Reducing GHG emissions, energy transition, and city-level innovation
UNEP Live data shows:
Per capita CO_2 emissions increased by 11.5% (1960-2012)
Latin America and the Caribbean priority: Sustainable management of biological resources
UNEP Live data shows:
20.3% of LAC's terrestrial and marine area is protected (2010)
Africa priority:
Land management and use
UNEP Live data shows:
Total arable land increased by 53% but arable land per capita decreased by 59% (1961-2012)


Europe priority:
Low-carbon resource efficient societies, smart cities, improved health, and adaptation to climate change
UNEP Live data shows:
Total health expenditure (% of GDP) increased from 8% in 1995 to 9.8% in 2013
West Asia priority:
Peace, security, and the environment
UNEP Live data shows:
A regional population of nearly 30 million migrants in 2013 (20.3 million males; 9.4 million females)
Asia Pacific priority: Increasing vulnerability
UNEP Live data shows:
Between 1990-2014 natural disasters affecting 4.5 billion people caused USD 1076 billion economic losses.

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Foreword

The sixth *Global Environment Outlook (GEO-6) Regional Assessment for North America* paints a comprehensive picture of the environmental factors contributing to human health and well-being at the regional level. Backed by a large body of recent, credible scientific evidence, regional-wide consultations and a robust intergovernmental process, the assessment demonstrates that regional and global multilateral environmental agreements have improved environmental conditions in North America. It also highlights the complexity of the interlinked environmental, social and economic challenges now confronting decision makers.

The launch of the *GEO-6 Regional Assessment for North America* comes at a critical time. The world is on a new pathway to combat climate change and unleash actions and investment towards a low carbon, resource-efficient, resilient and sustainable future. At the same time, the 2030 Agenda for Sustainable Development provides a clear pathway to a world in which everyone can enjoy prosperity within the ecological limits of the planet.

The outlook for North America is unfolding in a context of improved environmental conditions. The region has a low environmental burden of disease, rich biodiversity levels and large expanses of natural beauty. Improvements in the last decades have been credited to policies that have sparked technological and behavioural change. Some challenges from interactions across complex systems involving multiple pressures, however, pose risks to human well-being and ecosystems.

North American responses to environmental challenges reflect the diversity, energy and ingenuity of the region. Successes have been achieved largely by focusing on individual sectors and applying a small number of policy instruments. Remaining and emerging new environmental challenges will require further application of proven policy options along with continued innovation.

I would like to extend my gratitude to the large body of policymakers, leading scientists and representatives from major stakeholder groups and partners who contributed to this comprehensive and illustrative assessment report. I extend an invitation to the countries in the region to engage with this report and use the opportunity provided to transform the vision of the 2030 Agenda for Sustainable Development and its Sustainable Development Goals into a reality for North America.

Achim Steiner

United Nations Under-Secretary-General and
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Key findings and policy messages

The North American Regional Assessment was carried out in order to characterize the priority environmental issues, states and trends in the region in a systematic, evidence-based manner, as input into the sixth iteration of UNEP's flagship Global Environment Outlook (GEO-6) process.

Experts and government representatives identified regional priorities for North America at the Regional Environmental Information Network (REIN) conference held in Ottawa-Gatineau, 27-29 May 2015. These regional priorities have been used, in part, to inform and guide this regional assessment. This document provides a summary of key findings and policy messages emerging from the assessment.

Environmental conditions in North America have significantly improved over time due to investments in policies, institutions, data collection and assessment, and regulatory frameworks. However, in recent years environmental challenges have emerged that are proving harder to manage within existing policy frameworks. These challenges are the result of interactions across complex systems involving multiple pressures. They pose risks to human wellbeing and ecosystems that are novel in form and magnitude. Approaches to managing these problems that reduce systemic risk and steer sustainable transformations have emerged, generating evidence of their potential to respond to these new challenges.

Conditions have improved because of effective policies

Air quality continues to improve in the region in response to concerted policy action in both countries and favorable trends in technology and energy markets. Regional, national, and local efforts to improve air quality are having substantial, measurable, and important public health benefits which have an estimated value on the order of USD 2 trillion. However, the improvements in air quality are not evenly distributed, with approximately 140 million people exposed to pollution above regulatory thresholds.

Legislation enacted in the early 1970s in North America has led to effective control of point sources of pollution to **surface waters** and delivery of **safe drinking water** to most communities in the region. However, legacy, persistent and emerging contamination continues to put pressure on water quality in some areas. In particular, diffuse sources of water pollutants, such as nutrients, remain a challenge.

Drinking water quality is generally extremely good, but shows signs of backsliding in some areas. Negative trends are chiefly the result of degraded infrastructure and weak governance. These isolated water quality incidents threaten human health, in some cases acutely.

North America's **land resources** are generally in good shape. A rich network of well-managed protected areas is in place and is helping to conserve biological diversity. Large-scale disruptive land use and land cover changes are kept in check by effective governance policies and regulations. However, natural landscapes are becoming more fragmented in some areas in response to both natural causes, such as wildfires and pest outbreaks, and decisions about land management activities, ownership transfers to heirs, and development, particularly at the intersection of the forest, agriculture, and energy sectors.

While progress has been made with many individual species, much **biodiversity** is at risk in North America, with increasing pressures from land use change, invasive species, climate change, and pollution affecting species, both on land and in the coastal marine environment. However, regulatory approaches aimed at habitat protection show promise and biodiversity science is very advanced in the region. Continued efforts to integrate traditional ecological knowledge will further benefit conservation efforts.

Chemicals and waste show mixed trends. Issues arising from those that have been subject to policy focus over the past decades are declining significantly. Other sources, however, such as ash residue from coal scrubbers, abandoned mines, pharmaceuticals, and microplastics, are increasing and pose threats to human health and ecosystems.

In recent years environmental challenges have emerged that are proving harder to manage within existing policy frameworks

Climate change is generating impacts across the region that affect diverse aspects of the environment as well as human health and well-being and, in some cases, human security. The potential for these impacts to worsen in both the near and long term is a priority issue for the region. However, the administrations of both countries are taking steps to mitigate impacts and adapt to those that are unavoidable. The US and Canada have agreed the two countries will play leadership roles internationally in the low carbon global economy over the coming decades, including through science-based steps to protect the Arctic and its peoples, as well as, working together to implement the historic Paris Agreement.

The **Arctic** is an area of special concern because climate change impacts are most pronounced in the high latitudes, and the risk of further significant change in the near term is growing. The Arctic's unique social, institutional, and ecological patterns make it highly vulnerable to continued climate change, especially in light of the difficulties it faces with regard to adaptation, which will trigger cascading risks.

The **energy system** is undergoing rapid changes, providing challenges and opportunities. Challenges arise from the externalities associated with aggressive hydrocarbon extraction methods. These externalities include the potential for increased air emissions, water use and induced seismicity. However, ongoing trends in renewable energy, rising efficiencies, and energy storage technologies are driving opportunities and demonstrating the potential to achieve a sustainable energy system.

New chemical contaminants and new sources of traditional pollutants are manifesting as emerging air and water quality problems that are of concern for public health and the environment.

Water scarcity is of increasing concern in the region. Water demand exceeds sustainable supply in the arid western areas of North America resulting in mining of aquifers, fragmentation and regulation of most western rivers through dams, and vulnerability of urban and rural communities to drought. Depletion of groundwater is exacerbated by a lack of groundwater governance mechanisms. Long-term droughts have accelerated water scarcity problems in some parts of the region, and climate change has most likely contributed to the severity, extent and duration of these droughts.

The **coastal and marine environment** is under increasing threat in the region, both from harmful trends regarding some traditional environmental pressures such as nutrient loads, as well as new pressures such as ocean acidification, ocean warming, sea level rise, and novel forms of marine debris.

Freshwater fisheries are well-regulated in the Great Lakes region and are generally controlled across North America, but face challenges due to factors such as climate change, population pressure, and pollution.

Solutions to environmental challenges in the region are emerging

Efforts to **mitigate climate change** by reducing greenhouse gas emissions and enhancing carbon sequestration are beginning to show tangible results and to create a foundation for potentially major advances. Mitigation successes derive from a wide range of measures across the federal, regional and local levels of government and across the public and private sectors, including energy efficiency product standards; low-carbon electricity generation; transportation plans; building codes and standards; and other efforts. The December 2015 Paris climate agreement created a mechanism for all countries to coordinate national efforts and set more ambitious targets moving forward.

At the same time, governments, business and communities are taking action to adapt to **climate change**. For instance, Mayor Michael Bloomberg convened the New York City Panel on Climate Change (NPCC) in 2008 as part of the City's long-term sustainability plan. The NPCC engages scientists who study climate change and its impact, as well as legal, insurance, and risk management experts. The results of the panel's work offers examples for other communities to examine their own vulnerabilities and opportunities to enhance their capacities and resilience. Greater attention is also being given to strengthening and protecting green infrastructure.

Natural Capital Accounting (NCA) provides important tools to integrate natural resource, environmental, economic and social information to address systemic challenges faced by governments, (land and resource) managers, businesses and the public. NCA integrates this information into an accounts framework that is regularly updated to track transactions, identify trade-offs and reveal choices. It also helps to track and evaluate (programme and policy) implementation and will reveal many of the unintended consequences of addressing complex systemic challenges. NCA is being implemented at three levels: national, ecosystem and enterprise. At the national level, water, energy and pollution accounts can be used to understand and improve resource use efficiency, inform allocation of scarce resources (for example, water) and reduce pollution. NCA ecosystem accounts provide a framework that managers can use to identify and track all types of ecosystem services, including regulating, supporting and cultural services, where valuation is a challenge. NCA also provides a framework to identify beneficiaries. Private sector early adopters are using NCA approaches to improve resource use efficiency, manage risks and reduce pollution.

Sustainable Consumption and Production brings together wide-ranging options for reducing environmental pressures by addressing drivers associated with manufacturing processes and consumer demand. These options have the potential to alleviate systemic pressure on the environment across the board, as demonstrated through successful innovations in areas such as water conservation, green building, reduction of packaging waste, and green procurement.

We find in the region evidence of heightened interest in approaches to **adaptive governance** that blend insights from disparate strands of innovation to create a repertoire of action that is enabling progress on the most difficult aspects of the sustainability challenge. This repertoire combines elements that have been on the policy agenda for some time, such as multi-stakeholder policy processes, with new ideas borrowed from resilience, inclusive governance, and system innovation. Progress at the sub-national and transnational levels on a variety of issues is ahead of bilateral federal collaboration.

North America is an energetic driver of the **Data Revolution,** with many proven examples of using environmental informatics and analytics to drive progress and many promising innovations under active development. These innovations combine commitments to regularly updated resource inventories and censuses with breakthroughs in sensor technology; open data practices; mobilization of diverse data communities; social science understanding of how information can drive effective responses; and quantum enhancements in networked information systems to contribute to a rapidly expanding set of responses to environmental challenges in the region.

The outlook for North America is a mixture of emerging possibilities and problems

Advances in science and technology and systemic transformations offer hope for a more sustainable future.

Technological change regarding data and analytics is moving as fast as, if not faster than, the problems that concern the region, bringing with it **the promise to harness the power of the data revolution** to manage these problems.

Many technical and policy innovations that have been incubating for decades are starting to bear fruit or have advanced to the point where major adoption is within reach, and these **innovations offer the promise of systemic transformation** that could help reverse negative trends.

A few North American **cities and smaller communities are serving as living laboratories**, demonstrating how focused attention on pragmatic, coordinated improvements in systems spanning land use, transportation, public health, clean energy and water, and enhanced recycling and waste management can bend the curve toward enhanced resilience and sustainability to improve quality-of-life and lower social costs. Spreading these lessons learned to other communities throughout North America offers hope for creating more sustainable and resilient development pathways to the future. However, persistent environmental challenges remain.

Many **pressures are worsening, leading to deeper uncertainties and complexities** faster than policy responses are able to keep up.

Even for pressures that are moving in the right direction, such as carbon intensity, the **magnitude of improvement is not adequate** to meet mounting challenges.

A wide range of **potentially catastrophic impacts are built in** to the near and medium term climate, so that climate change impacts are highly likely to increase regardless of how fast the region reduces greenhouse gas emissions, and how fast it supports global emissions reductions. The consequences for human lives and livelihoods will depend on measures to adapt to climate change and increase resilience that, while showing signs of promise, are not yet sufficient to meet the threats. The region has been surprised by the emergence of major failures in traditional environmental issues, such as drinking water safety, suggesting that past successes are in jeopardy.

Introduction

Welcome to the North America regional assessment. This assessment provides an objective evaluation and analysis designed to support environmental decision-making.

Existing knowledge has been assessed to provide scientifically credible answers to policy-relevant questions including:

- What is happening to the environment in North America and why?
- What are the consequences for the environment and the human population of North America?
- What is being done and how effective is it?
- What are the prospects for the environment in the future?
- What actions could be taken to achieve a more sustainable future?

The decision to undertake regional assessments was taken at the Global Intergovernmental and Multi-stakeholder Consultation in Berlin, October 21-23, 2014. Participants expressed that the sixth edition of the global GEO assessment should 'build on regional assessments'which would be conducted in similar fashion to the global GEO process (UNEP/IGMS.2 Rev.2).

Member States attending the first United Nations Environment Assembly (UNEA-1) in Nairobi, June 23 –27, 2014, requested:

"the Executive Director, within the programme of work and budget, to undertake the preparation of the sixth Global Environment Outlook (GEO-6), supported by UNEP Live, with the scope, objectives and procedures of GEO-6 to be defined by a transparent global intergovernmental and multi-stakeholder consultation informed by document UNEP/EA.1/INF/14, resulting in a scientifically credible, peer-reviewed GEO-6 and its accompanying summary for policy makers, to be endorsed by the United Nations Environment Assembly no later than 2018"

In addition, Member States also requested (UNEP/EA.1/10):

"the Executive Director to consult with all United Nations Environment Programme regions regarding their priorities to be taken up in the global assessment"

Following this request, the regional priorities for North America were established through the Regional Environmental Information Network (REIN) Conference for North America held in Ottawa- Gatineau, 27-29 May 2015. These regional priorities have been used to guide the analysis conducted in this regional assessment

The assessment includes four main Chapters:

- **Chapter 1** provides an overview of the regional priorities addressed in the report, explains why each is important to the region, and provides a summary of the overall assessment.
- **Chapter 2** discusses the state of the environment in the region according to key environmental themes (air, water, land, biota, and chemicals and waste) as well as cross-cutting challenges (climate change, the Arctic, energy, non-point source contaminants and contaminants of emerging concern), and analyses the key trends for each issue.
- **Chapter 3** reviews policy responses on these environmental issues in North America.
- **Chapter 4** reviews the main trends that will affect the region's environment in the future and explores the actions needed for the region to achieve a more sustainable future.

The data underpinning the assessment can be found in UNEP Live **(uneplive.unep.org).** The full assessment is also available through UNEP Live, as a PDF and as an eBook.

CHAPTER 1

Regional context and priorities

1.1 The state of the environment in North America

Environmental conditions in North America have improved in recent decades and are now generally very good. Improvements have been largely due to the application of policies that have sparked technological and behavioural change. However, in some cases success has not been uniformly achieved, while in others progress is showing signs of reversal (see **Table 1.1.1**).

Successes in this region haven been achieved largely by focusing on individual sectors and applying a small number of policy instruments. Remaining and emerging environmental problems suggest that these traditional responses may be inadequate on their own. Achieving more complete success on traditional environmental issues, and rising to the challenge of new priorities, will require the ongoing application of proven policy options along with continued innovation.

1.2 Regional priorities

This assessment is guided by a set of regional priorities identified by scientists and government experts at the Regional Environmental Information Network conference for North America, held in Gatineau, Quebec, on May 27-29, 2015.

They fall into three main categories (see **Table 1.2.1**):

- Environmental challenges that fall within the GEO-6 environmental themes;
- Cross-cutting challenges; and
- Foundational responses with the potential to provide wide-ranging benefits.

Regional priorities for North America reflect a number of key ideas—notably, systems thinking, a place-based perspective, and the need to combine traditional policy approaches with new and innovative ones (see **Figure 1.2.1**). They also highlight North America's unique strengths.

Many environmental issues are characterized by complex patterns of causality and feedback. Regional priorities that are sensitive to systems behaviour include:

- **climate change**, including particular impacts on and **accelerated changes in the Arctic**;
- **water security**, including impacts of **contaminants of emerging concern** and **non-point source contaminants** on water quality; and
- **land fragmentation**, including losses of biodiversity.

Effectively addressing these issues requires understanding problems in terms of dynamic, linked systems. Policy responses that support a systems approach to addressing environmental issues include:

- implementing **natural capital accounting**;
- encouraging **sustainable consumption and production**;
- promoting **adaptive governance**; and
- optimizing environmental information and analytics as well as harnessing the **data revolution**.

Environmental challenges and their impacts vary considerably from place to place. For example, the Arctic was identified as a regional priority due to the alarming changes occurring there.

Solutions also vary by place, making city-level innovation a priority. Urban responses to sustainability challenges are a potentially valuable source of insight into effective responses to priority problems.

Despite facing some serious environmental challenges, North America also has significant strengths to draw on. Policy and governance trends in North America that support effective responses to environmental problems include its history of data leadership, coalitions of effective governance tools, and cities as living laboratories for sustainability.

The following subsections provide an overview of each regional priority and its significance, as well as key findings from the assessment.

Table 1.1.1: Environmental Issues that have been the focus of sustained policy attention since the 1970s

Environmental Issue	Signs of Success	Drivers of Success	Remaining or Emerging Problems
Air Quality	Reductions in pollutant concentrations. Achievement of ambitious targets in most areas.	Regional air quality targets; technology standards.	Periodic exceedances; communities with persistently high exposure.
Land	Land resources designated as important are largely protected; large-scale degradation has been halted.	Protected areas policies; zoning; application of land conservation measures.	Fragmentation in select areas; poorly managed mineral extraction.
Biota (Biodiversity and Ecosystem Services)	Successful conservation of endangered species.	Legal requirements to minimize impacts on endangered species	Threats from invasive species and climate change.
Surface Water Quality	Reductions in pollutant concentrations. Achievement of targets in many areas.	Wastewater treatment; product standards; regional action plans.	Rise in eutrophication episodes.
Drinking Water Quality	Clean, reliable, healthy water in almost all communities.	Municipal water infrastructure	Contaminated water supplies stemming from deteriorating infrastructure in some areas.
Water Scarcity	Water access and availability is largely unproblematic for most communities and users.	Water allocation rules; storage and distribution infrastructure.	Groundwater depletion stemming from lack of targeted governance; increased frequency of scarcity problems driven by consumption patterns and drought.
Chemicals and Waste	Concentrations of tracked pollutants decreasing by 70 per cent or more since the 1980s.	Decrease has resulted from public demand, legislative action, and technological innovation.	Non-traditional pollution sources present new threats to human and ecosystem health. They include new combinations of toxic materials and hazardous compounds resulting from fracking and tar sands exploitation.

1.2.1 A rapidly changing Arctic

The Arctic has been a world apart, detached from mainstream societies by the cold of winter and the difficulties of transportation and communication in other seasons. Now, however, the peoples of the Arctic are facing accelerating changes beyond their previous experiences. They are witnessing climate change impacts such as melting ice, thawing permafrost, increased industrial activity, and heightened natural resource development.

These changes are having a devastating effect on human settlements in the Arctic: the ground is shrinking and changing shape as permafrost thaws; food sources are

Table 1.2.1: Categories for regional priorities

Environmental challenges	Cross-cutting challenges	Foundational responses
• Land fragmentation • Water security • Biodiversity loss	• Climate change • A rapidly changing Arctic • Energy transition • Non-point-source contaminants • Contaminants of emerging concern	• Natural capital accounting • Sustainable consumption and production • Adaptive governance • Environmental information and analytics • City-level innovation

disappearing as biotic ranges shift and species dwindle in number; rising sea levels and increased storminess are consuming the shorelines and piers of villages and towns along the coast; and unprecedented flooding is tearing away at inland settlements.

They also have global implications. Climate change impacts, such as the loss of summer sea ice cover, are driving weather systems and climate extremes that reach far south of the Arctic Circle into Europe and Asia, as well as North America. Rising temperatures are also thawing the frozen ground at an accelerated rate, releasing carbon dioxide and methane that lead to further warming.

For more information, see the State and Trends chapter—particularly subsections 2.7 and 2.9.2—and subsection 3.2 in the Policy Response chapter.

1.2.2 Climate change

Outside of the Arctic, climate change has been widely viewed in North America as something that will happen in the future. In the past decade, however, the region has experienced climate change impacts such as intense and enduring regional droughts; ecosystem and species migration that can disrupt livelihoods and lifestyles; hurricanes leading to loss of life and infrastructure damage; and temperature and precipitation extremes that damage the built environment, challenge regional and global food security, and threaten the livelihoods and opportunities of American and Canadian citizens.

Recent studies have proposed and demonstrated new mechanisms by which the changing Arctic may be affecting weather patterns in North America and globally, resulting in more extreme weather. As long as greenhouse gas (GHG) emissions continue unabated, Arctic warming and its wide-ranging impacts are also expected to continue.

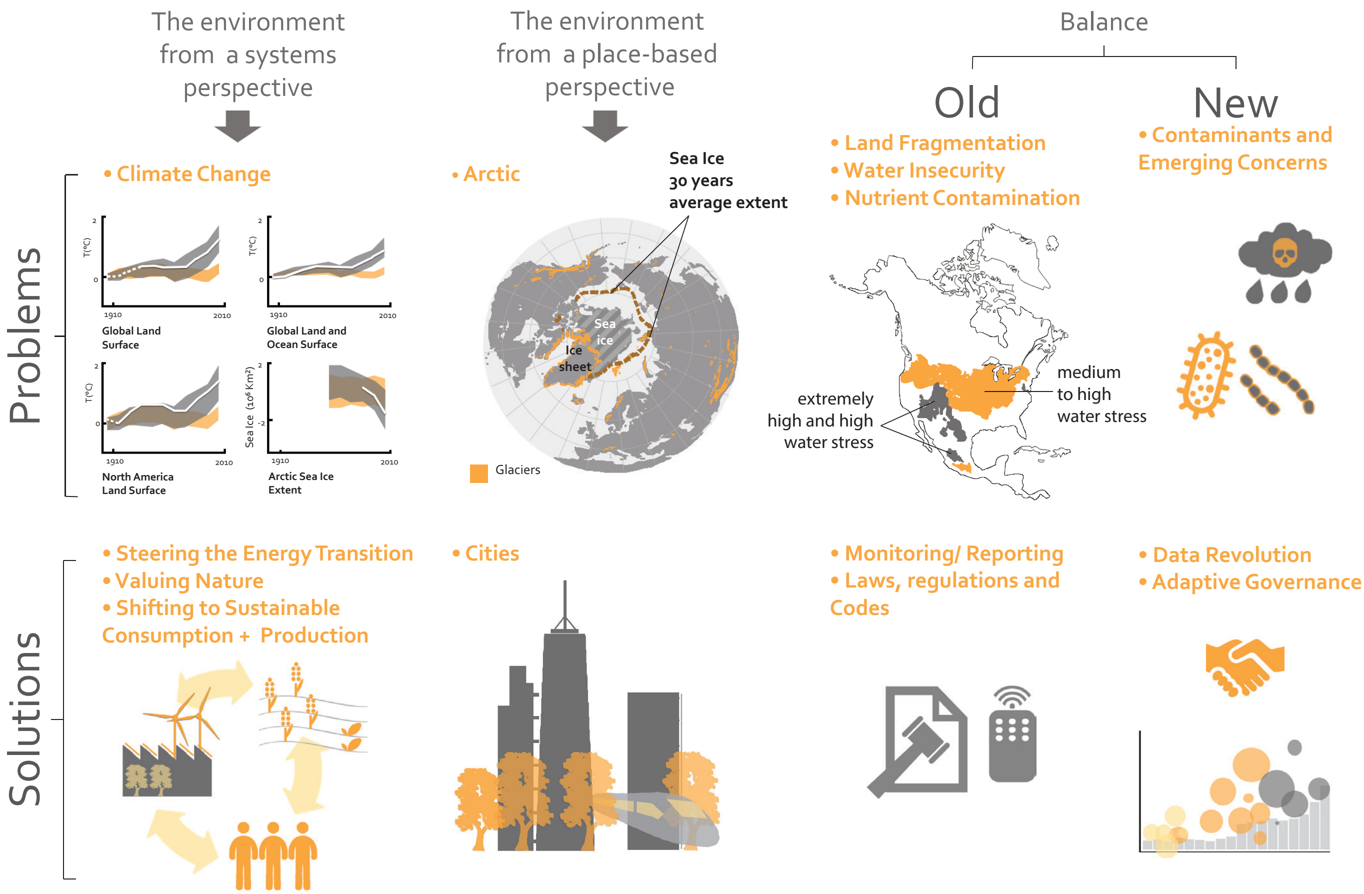
Climate change research has increasingly focused on assessing impacts that would occur under different warming scenarios and how economies might adapt to changing climatic conditions. Meanwhile, efforts to address climate change have aimed to mitigate its impacts and adapt to those that are unavoidable. Mitigation efforts include, for example, no-till farming; forestry conservation; carbon taxes; renewable energy sources; and resource efficiency. Adaptation efforts range from changes in infrastructure design; behaviour patterns; and zoning restrictions to ecosystem-based approaches.

For more information, see subsections 2.8 and 2.9 in the State and Trends chapter and the Land, Water, and Biodiversity analyses in the State of the Environment chapter and the Policy Response chapter.

1.2.3 Energy transition

The recent Paris Agreement marks significant progress towards strengthening the global response to climate change and shifting to a sustainable energy system. However, emissions from the use of fossil fuels continue and contribute significantly to the historic increases in atmospheric GHG concentrations (IPCC 2011).

Figure 1.2.1: Conceptual illustration framing the overarching narrative of the North America assessment



Since the oil, gas and coal reserves that were easiest to access are being exhausted, continuing on the fossil fuel path now involves more complex activities: hydraulic fracturing, extracting energy from oil sands, drilling and mining in more difficult locations. These strategies present new risks—for example, higher greenhouse gas emissions, induced seismicity and elevated water use (Farahbod *et al.* 2015; Weingarten *et al.* 2015; Folger and Tiemann 2014, Nicot and Scanlon 2012; Webb 2015; Jackson 2014; US EPA 2014; Jordaan 2012; Brandt 2012).

While North American governments committed in 2009 to end fossil fuel subsidies, they continue to provide powerful incentives to continue, if not increase fossil fuel production (Bast *et al*. 2015). At the same time, governments have used subsidies to promote renewable energy, driving technology improvements and cost reductions. Renewable energy technologies are opening a path to a sustainable energy future and affording the possibility to achieve Sustainable Development Goal number 7 in North America (IPCC 2014; Jacobson and Delucchi 2011; Delucchi and Jacobson 2011; Jacobson *et al.* 2015).

For more information, see subsection 2.9 as well as the Land, Water, and Climate Change analyses in the State and Trends chapter, the Policy Response chapter and the Outlooks.

1.2.4 Land fragmentation

Natural landscapes in North America are becoming more fragmented in certain areas in response to both natural causes, such as wildfires and pest outbreaks, and land management and development decisions, particularly at the intersection of the forest, agriculture, and energy sectors. Inter-generational transfers of land from owners to their heirs are also contributing to fragmentation.

Drivers such as population growth and economic development will cause greater land use change pressures that may further fragment forests, croplands, and rangelands. Continued fragmentation threatens wildlife and human communities that depend on well-functioning ecosystems for their wellbeing.

The recent adoption of ecosystem approaches that exploit the ability to explore and map wide areas using modern technology offers hope for increased habitat resilience and defragmentation. A few North American cities and smaller communities are making pragmatic, coordinated improvements in land use, transportation, public health, clean energy and water, and enhanced recycling and waste management that can bend the curve toward enhanced resilience and sustainability to improve quality-of-life and lower social costs. Spreading these lessons learned to other communities throughout North America has the potential to create more sustainable and resilient development pathways to the future.

For more information, see the Land and Biota analyses in the State and Trends chapter and the Policy Response chapter.

1.2.5 Water security

Water security in the US and Canada is quite high: most communities have safe and reliable access to water at an affordable cost. However, water demand exceeds sustainable supply in the arid western areas of North America and, at times, in eastern and central regions of the US, resulting in the mining of aquifers, fragmentation and regulation of most western rivers by dams, and vulnerability of urban and rural communities to drought. The disparities between demand and supply are projected to become more severe with population growth, increasing economic aspirations and climate change.

Extreme drought has been a recent feature in much of western North America. The human and environmental costs of drought include the overuse of groundwater, long-term impacts on water supply resilience, decreases in agricultural production, damage to aquatic and terrestrial ecosystems, increases in airborne dust and pollutants, and decreases in economic activity.

At least 150 million people in the US and 10 million in Canada (nearly half of North America's population), including most of those living in rural areas, rely on groundwater for drinking and other household uses. Responses to aquifer depletion will need to include increased efficiency as well as development of surface and other sources of water.

For more information, see subsection 2.4 as well as the Land, Climate Change and Energy analyses in the State and Trends chapter, the Policy Response chapter and the Outlooks.

1.2.6 Contaminants of emerging concern

Municipal and industrial wastewater management in North America has achieved relatively consistent and good treatment of traditional pollutants such as ammonia and biological oxygen-demanding matter. Since the 1970s, an effort to install and upgrade wastewater treatment across the region has resulted in improved water quality in the region's waters (US EPA 2000).

For example, the percentage of Canadian freshwaters rated good or excellent increased while the percentage rated poor or marginal decreased between 2003–2005 and 2010–2012 (Environment and Climate Change Canada 2015).

However, a growing list of new contaminants—at least 40 000 unique compounds—are not routinely monitored in the environment but have the potential to cause adverse ecological or human health effects (Halden 2015; Rosi-Marshall *et al*. 2013). They include a wide variety of synthetic chemicals and engineered particles, ranging from pharmaceutical drugs, personal care products, nanomaterials and microplastics, plastic debris (Bellenger and Cabana 2014) to artificial sweeteners (Spoelstra *et al*. 2013) and illicit drugs (Rosi-Marshall *et al*. 2015).

Many of these contaminants are found widely in aquatic systems, and their effects on aquatic food webs and human health are not well understood. They remain a challenge to regulate due in part to their diversity and quantity, the complexity involved in monitoring them, the lack of standard products against which to compare them and uncertainty regarding their environmental and health impacts.

For more information, see the Chemical and Waste and Water Quality analyses in the State and Trends chapter.

For more information, see the Chemical and Waste and Water Quality analyses in the State and Trends chapter.

1.2.7 Non-point-source contaminants

Legislation in North America enacted in the early 1970s has led to effective control of point sources of pollution to surface waters in the region. In contrast, non-point sources of pollutants, especially nutrients such as nitrogen, remain a significant threat to water quality. These sources are generally not regulated under the US Clean Water Act or any Canadian federal or provincial law, with the exception of confined feedlot manure and centralized sewage discharges.

Water quality problems in North America have in certain instances outgrown the regulatory tools of the past and require new mechanisms for integrated water resource management. For example, since the US Clean Water Act was passed in the early 1970s, individual states and the US EPA have developed more than 6 000 location-specific standards for nutrient total maximum daily loads (AskWaters; US EPA 2015c). While these standards have driven lower nutrient limits from point-source discharges, it is difficult to evaluate whether their development has resulted in reduced nutrients from non-point sources. Non-point sources of air pollution are also a concern, though water contamination is a higher priority in the region.

For more information, see the Chemical and Waste and Water Quality analyses in the State and Trends chapter.

1.2.8 Sustainable consumption and production

With humans now consuming more resources than ever before, current patterns of development across the world are not sustainable. To achieve sustainable development, we need to make a rapid and strong transition towards sustainable consumption and production (SCP).

SCP is a policy approach that aims to reduce pressures on the environment by changing which goods are purchased and how they are produced. Its elements include:

- promoting sustainable procurement policies among large private and public sector consumers;
- promoting life cycle assessment methodologies to encourage identification and adoption of low-impact product design;
- coordinating across industries, across raw material suppliers and users, and across manufacturers and consumers to maximize waste reduction; and
- developing land use plans, zoning regulations, building codes, and industrial enterprise areas to maximize resource efficiency and minimize waste.

For more information, see the Policy Response chapter, as well as additional discussion throughout the report.

1.2.9 Natural capital accounting

Natural capital accounting (NCA) provides important tools to integrate natural resource, environmental, economic and social information to address systemic challenges faced by governments, land and resource managers, businesses and the public. NCA integrates this information into an accounts framework that is regularly updated to track transactions, identify trade-offs and reveal choices. It also helps to track and evaluate policy implementation and will reveal many of the unintended consequences of addressing complex systemic challenges.

NCA is being implemented at three levels, national, ecosystem and enterprise. At national levels water, energy and pollution accounts can be used to understand and improve resource use efficiency, inform allocation of scarce resources, e.g. water, and reduce pollution. NCA Ecosystem accounts provide a framework that managers can use to identify and track all types of ecosystem services, including regulating, supporting and cultural services, where valuation is a challenge. Private sector early adopters are using NCA approaches to improve resource use efficiency, manage risks and reduce pollution

In the US, scientists and economists are working together to promote the establishment of NCA standards and methodologies by the central accounting system in the US government. Meanwhile, NCA and ecosystem service approaches are widely used in federal agencies.

For more information, see chapter 3.2.9 in the Policy Response chapter.

1.2.10 Adaptive governance

Adaptive governance approaches are continually responsive and iterative, with the flexibility to accommodate changing circumstances. Well-suited to the "wickedness" of environmental problems, adaptive governance is showing the potential to support transformative breakthroughs that once seemed elusive.

Adaptive governance approaches are being applied in North America and are experiencing real success. For example, Washington's Skagit County is working to restore shellfish in Samish Bay by applying the lean management principle. First applied in the private sector, lean management is a continuous improvement methodology used to engage teams of front-line staff to generate rapid responses and solutions. It is well-regarded for its ability to deliver improved speed, quality, and cost effectiveness.

For more information, see Section 3.3.1 as well as additional discussion throughout the the Policy Response chapter.

1.2.11 Environmental information and analytics: harnessing the data revolution

North America is in the midst of a renaissance in the application of data, information and analytics as powerful tools for managing environmental problems. This has in part been driven by the data revolution – the confluence of increasing processing power, falling costs and the widespread diffusion of data technology. But it goes beyond that, and it is triggering multiple pathways by which environmental problems are being managed more effectively. Big datasets that capture the complex nature of the environment and human behaviour can yield incredible scientific results. New ways of linking datasets to derive meaningful insights and creative techniques for visualizing data provide powerful information for decision-making. The rapid transformation of real time information on environmental systems can be a powerful tool for policy development.

North America has a long and rich history of using data effectively to act on environmental challenges. In this era of increased connectivity, advanced analytics and improved computing, it will be required more than ever to demonstrate leadership in creating value from analytics.

In the US, public-private partnerships have shown how information can be assembled, analysed and used to inform policy responses and educate the public. Open data programmes such as open.canada.ca and data.gov are an increasingly popular way to find data and resources for research. Data collection tools, ranging from satellite imagery and novel sensors to smart meter technologies, are effecting transformation and providing better options to respond to environmental emergencies (data.gov 2015).

For more information, see the analysis in Section 3.2.2 in the Policy Response chapter, as well as additional discussion throughout the report.

1.3 Rising to the challenge

Both Canada and the US were supporters of the adoption of the Sustainable Development Goals (SDGs) in 2015. These codified, at the global level, an approach which is marked by explicit concern for systems and issue linkages, by attention to place and scale, and by recognition of the need to combine the best traditional policy approaches with the most promising new ones with an eye on learning. The environmental problems of highest priority in the region highlight a new sensibility to this. In the cases of climate change, land fragmentation, water security, and contaminants of emerging concern, for example, a rising appreciation of the need to understand problems in terms of dynamic, linked systems can be seen. In the case of the growing interest in steering North America towards sustainable patterns of consumption and production, and with moving towards operational capabilities for natural capital accounting, a heightened interest in broadening the scope of traditional environmental policy-making can be seen. The dynamic changes in the energy sector reflect all these elements coming together, in the context of growing appreciation of the far-reaching and complex ways that energy systems affect environmental conditions, of the dramatic differences across regions with respect to threats and opportunities, and of the power to steer rapid changes in how energy is produced and used through application of multiple policy levers.

A broad overview of the state and trends of the North American environment shows these same themes. For example, although environmental conditions with regard to air, land, water and biota are broadly positive, largely due to investment in vigorous policy implementation over past decades, there are locations where trends are negative and conditions warrant concern. But there are problems that are not yet being adequately addressed; these cases are often characterized by complex often unanticipated interaction across systems. Finally, across the board, policymakers in North America are combining the best of the traditional environmental policy toolkit with innovative approaches, and there is evidence that this blending is bearing fruit.

See links for Chapter 1

See references for Chapter 1

CHAPTER 2

State and trends

2.1 Air

2.1.1 Drivers and emissions

Anthropogenic air pollution emissions are driven by population, economic activity, energy consumption and technology. Through implementation of pollution controls and improved efficiency measures, both Canada and the US have seen a decoupling of gross domestic product (GDP) and other economic and behavioural drivers from emissions. Overall emissions continue to trend downwards in the region, while economic development continues to increase.

Figure 2.1.1 shows that, between 1970 and 2013, US GDP increased by 234 per cent, vehicle miles travelled by 168 per cent, population by 54 per cent and energy consumption by 44 per cent. During the same time period, total emissions of the six main air pollutants – sulphur dioxide, nitrogen oxides, volatile organic compounds, carbon monoxide, particulate matter and lead – fell by 68 per cent. The figure also shows that between 1970 and 2012, carbon dioxide emissions increased by 24 per cent.

In addition, from 1990 to 2008, emissions of 187 hazardous air pollutants regulated under the US Clean Air Act declined by about 62 per cent. These pollutants, often referred to as air toxics, are known or suspected to cause cancer or are associated with other serious health or ecological effects. Examples of air toxics include benzene, which is found in gasoline; perchloroethylene that is emitted from some dry cleaning facilities; and methylene chloride, which is used as a solvent and paint stripper by a number of industries. Other examples of air toxics include dioxin, asbestos, and metals such as cadmium, mercury, chromium and lead compounds. The reductions are the result of implementing regulations on stationary and mobile sources.

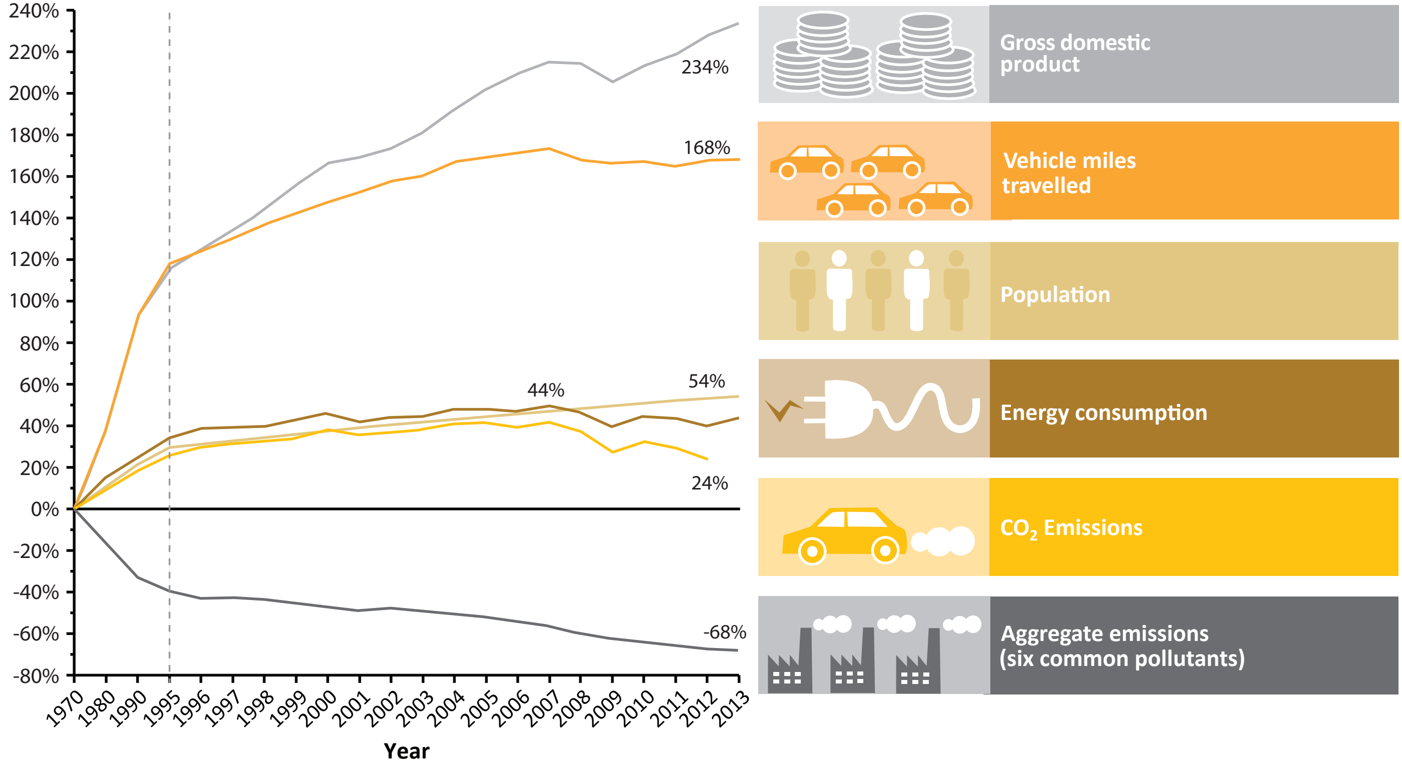
Similarly, over the past two decades, Canada has seen a decoupling of economic growth from air pollution and greenhouse gas emissions as technological improvements and regulations have been adopted and implemented in various economic sectors, particularly in the power sector.

Key messages: Air

Air quality continues to improve in the region, in response to concerted policy action in both Canada and the US and favourable trends in technology and energy markets.

- Regional, national, and local efforts to improve air quality are having substantial, measurable, and important public health benefits which have an estimated value in the order of USD 2 trillion.
- Robust regulatory systems in Canada and the US have been successful in significantly reducing air pollution in North America, as seen in national trends for pollutant emissions, concentrations and deposition.
- Despite significant progress, improvements in air quality are not evenly distributed in North America, with approximately 140 million people exposed to pollution above regulatory thresholds, exceeding levels considered harmful to public health.
- Providing information to the public about air pollutant emissions, concentrations, and health implications has helped individuals mitigate their own exposure and create public demand for air pollution control.

Figure 2.1.1: US trends in drivers and emissions, 1970–2013



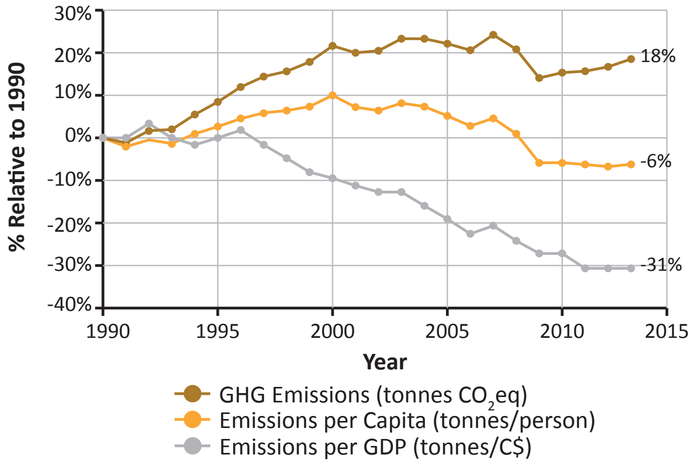
Source: Adapted from US EPA Air Quality Trends Report 2014

Canada's physical geography, demographic changes, and economic growth all affect air pollution and greenhouse gas emissions.

Canada's highly variable climate contributes to relatively higher energy use for space heating and cooling compared to other industrialized countries. While vast, Canada is sparsely populated, leading to longer travel times and increased demand for transport. In addition, Canada has seen faster than average population and economic growth relative to other developed countries between 2000 and 2012, as well as high international demand for its natural resources, including oil and gas (Environment Canada 2015a). **Figure 2.1.2a** shows that although total greenhouse gas emissions increased by 18 per cent between 1990 and 2013, both emissions per person (tonnes per person) and emissions intensity (emissions per CAD of GDP) have decreased by 6 per cent and 31 per cent, respectively. This decreasing trend of emissions per person and emissions intensity is projected to continue through 2020.

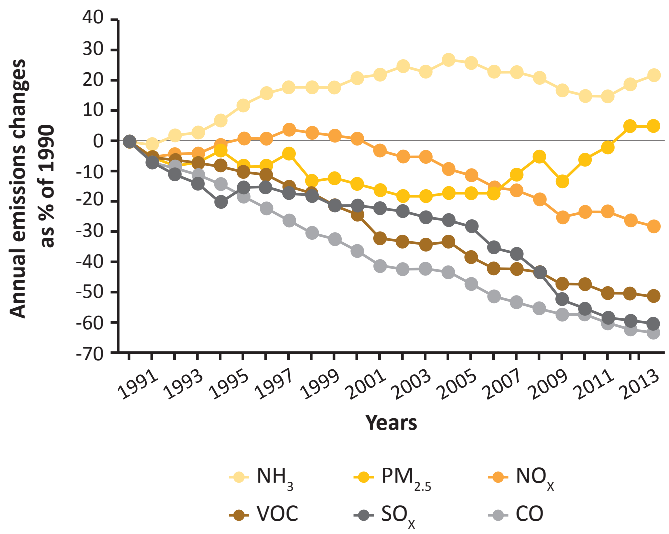
Although absolute emissions of GHGs has increased, emissions of many traditional air pollutants have declined, some dramatically, as seen in **Figure 2.1.2b**. In Canada between 1990 and 2012, emissions of mercury, lead and cadmium to the air have been reduced by 90 per cent, 87

Figure 2.1.2a: Canadian greenhouse gas emissions trends and indicators, 1990-2013



Source: Environment Canada 2015

Figure 2.1.2b: Relative change in air pollutant emissions in Canada, 1990-2013



Source: Environment and Climate Change Canada 2016

per cent and 90 per cent respectively, mainly due to reduced emissions from industrial sources.

Figure 2.1.3 provides a comparison of the absolute magnitude and relative contribution of different sources to emissions of sulphur dioxide, nitrogen oxides and volatile organic compounds in both the US and Canada in 2012. Note that emissions from forest fires and natural sources are not included in this comparison. Notably, industrial emissions make up a larger fraction of total emissions in Canada than in the US, where power plants and motor vehicles play a more important role.

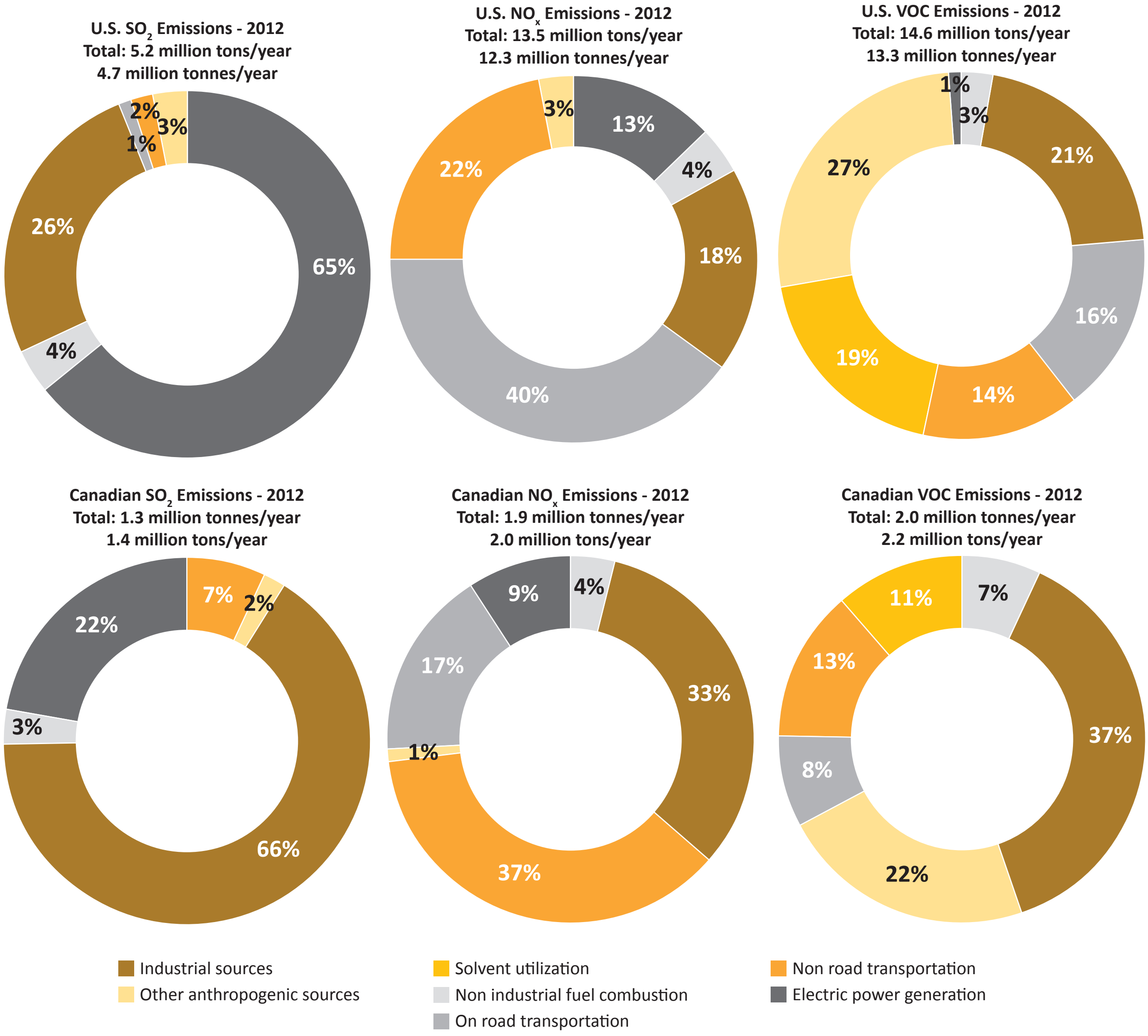
In both countries, ammonia emissions are increasing or relatively constant, with the largest contributions coming from livestock and fertilizer application. Ammonia is an important precursor to fine particulate matter ($PM_{2.5}$) formation along with nitrogen oxides and sulphur dioxide emissions. Although the sensitivity of $PM_{2.5}$ formation to ammonia emissions may decrease in the future, controlling ammonia emissions is expected to continue to be an effective strategy to achieve further reductions in winter $PM_{2.5}$, even considering the planned reductions in nitrogen oxides and sulphur dioxide emissions (Pinder *et al.* 2008).

2.1.2 Concentrations and deposition

In both Canada and the US, ozone and $PM_{2.5}$ remain the most prevalent air pollution problems in terms of health endpoints. Peak levels of both pollutants are declining in both Canada and the US (**Figure 2.1.4a-d**).

Significant control programmes have been introduced to decrease emissions from electric power plants and the transportation sector; **Figure 2.1.5a** and **b** show the effect of electric power plant controls on nitrogen dioxide emissions between 2005 and 2011 as seen by Ozone Monitoring Instrument on NASA's Aura satellite. These controls were put in place primarily to decrease the interstate and international transport of ozone and its precursors across eastern North America (NASA 2015).

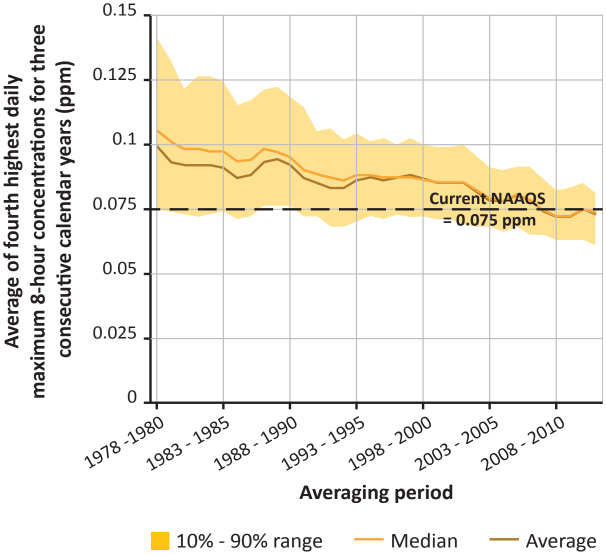
Figure 2.1.3: US and Canadian national emissions by sector for selected pollutants, 2012



Source: Adapted from Canada-US Air Quality Committee 2014

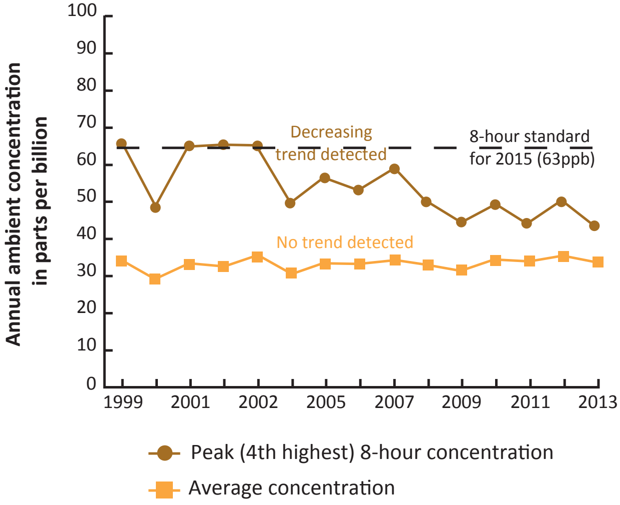
Figure 2.1.4: Ozone and fine particulate matter ($PM_{2.5}$) trends in Canada and the US

(a) Ambient 8-hour ozone concentrations in the US, 1978–2013



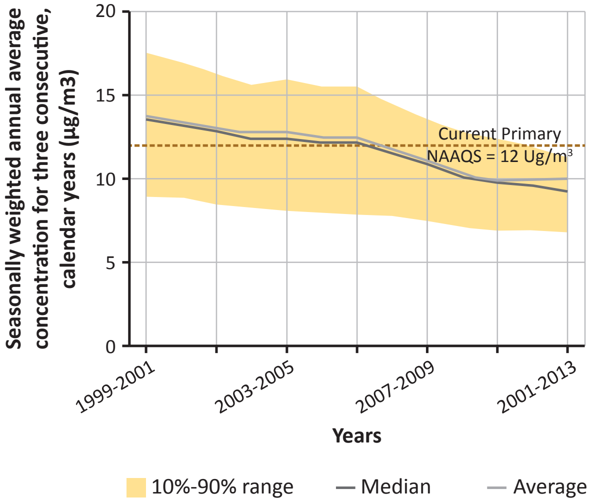
Source: US EPA 2014 b

(b) Annual ambient 8-hour ozone concentration in Canada, 1999-2013 (parts per billion)



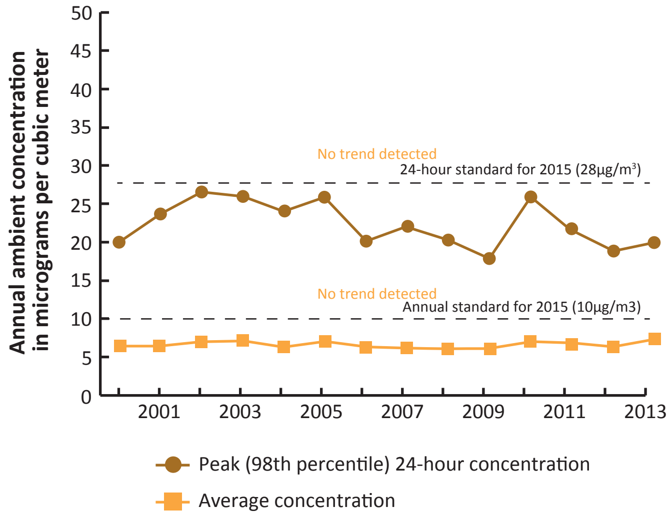
Source: Environment and Climate Change Canada 2016a

(c) Ambient annual fine particulate matter ($PM_{2.5}$) concentrations in the US, 1999-2013 (micrograms per cubic metre)



Source: US EPA 2014

(d) Annual ambient concentration of fine particulate matter ($PM_{2.5}$) in Canada, 2000-2013 (micrograms per cubic metre)



Source: Environment and Climate Change Canada 2016b

Figure 2.1.5a: Annual average tropospheric nitrogen dioxide column in 2005

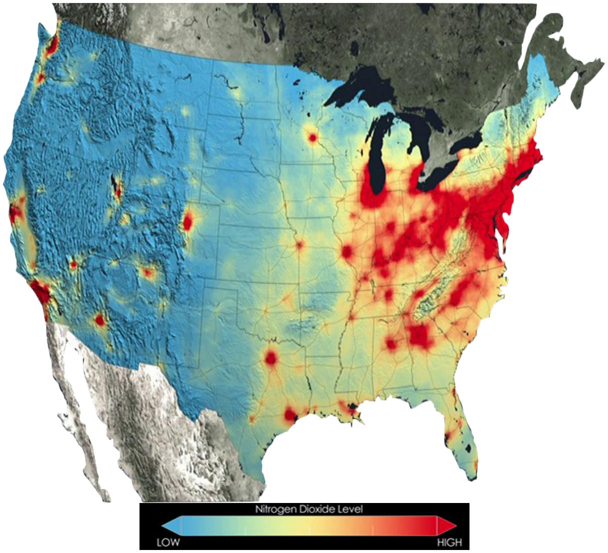
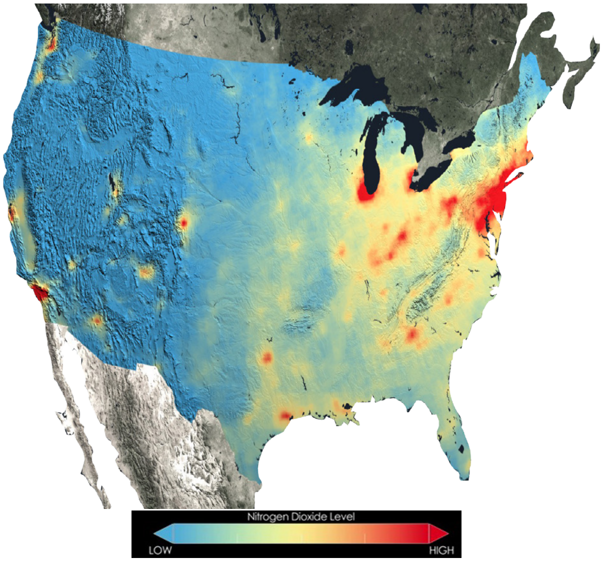


Figure 2.1.5b: Annual average tropospheric nitrogen dioxide column in 2011



Source: NASA 2015

Canada and the US have also made significant progress in decreasing acidifying deposition, working together under the auspices of the 1991 Canada–US Air Quality Agreement. **Figures 2.1.6 a-d** show the spatial patterns of decrease in annual wet sulphate and nitrate deposition in the US and Canada between 1990 and 2012, showing the dramatic impact of air pollution controls. In the US, total deposition of sulphur and nitrogen compounds, the sum of wet and dry deposition, decreased overall between 1989–1991 and 2011–2013, and reductions were larger for sulphur than for nitrogen compounds. At 34 long-term monitoring sites in the eastern US, where data are most abundant, average total sulphur deposition decreased by 75 per cent between 1989–1991 and 2011–2013, while average total nitrogen deposition decreased by 39 per cent (US Report on Environment).

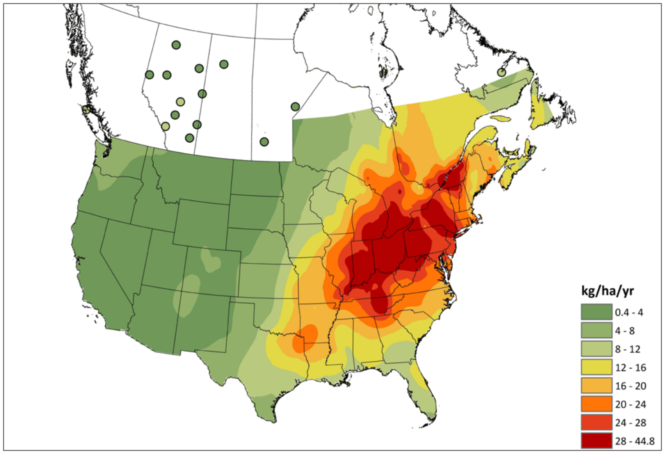
2.1.3 Health and ecosystem impacts

Despite great progress in decreasing emissions, some significant air quality problems persist. Newer scientific studies have shown that some pollutants can harm public health and welfare even at very low levels. In recent years, the US has revised its national ambient air quality standards (NAAQS) for five of the six common pollutants because new, peer-reviewed scientific studies showed that the existing standards were not adequate to protect public health and the environment (Shi *et al*. 2016).

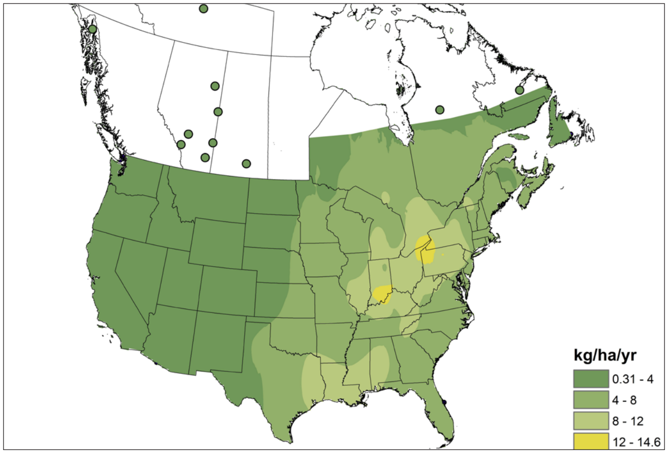
In 2015, more than 130 million people in the US (nearly one third of the population), lived with pollution levels above the NAAQSs. **Figure 2.1.7** shows the spatial distribution of US counties that do not attain NAAQSs. Between 2010 and 2012 about 28 per cent of Canadians, about 9.8 million people, lived in communities with ozone levels above the Canada-wide standards (CWS) target, and 2 per cent of Canadians, around 700 000 people, lived in communities with $PM_{2.5}$ levels above the CWS target (CCME 2014).

The air quality and human health benefits of emissions control programmes adopted over the last decade will continue to grow over time as they take full effect. In 2011, the US EPA estimated that by 2020 air pollution controls

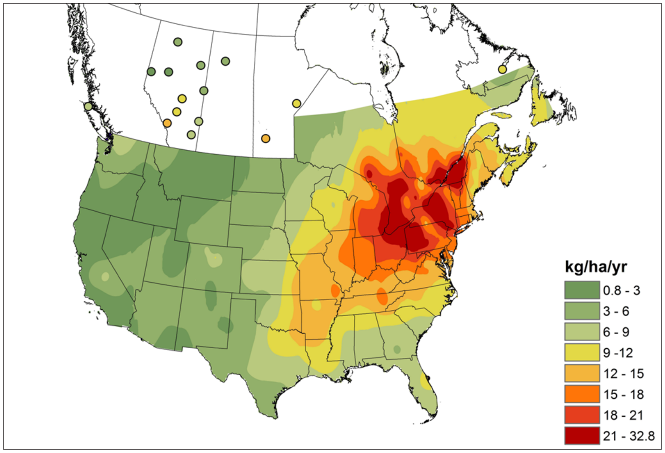
Figure 2.1.6a: Canada and the US, annual wet sulphate deposition, 1990



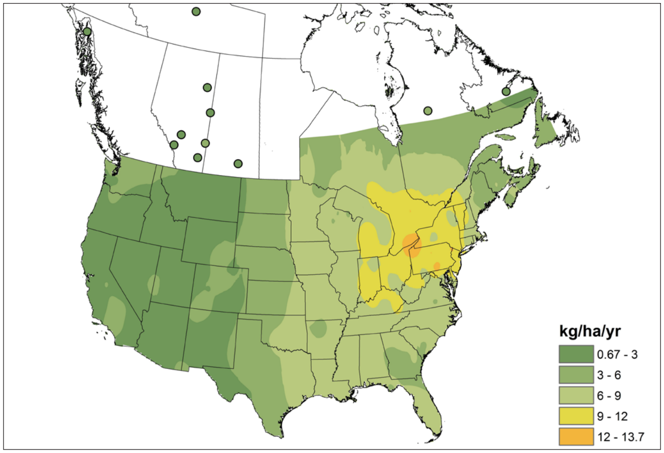
b. Canada and the US, annual wet sulphate deposition, 2012



c. Canada and the US, annual wet nitrate deposition, 1990

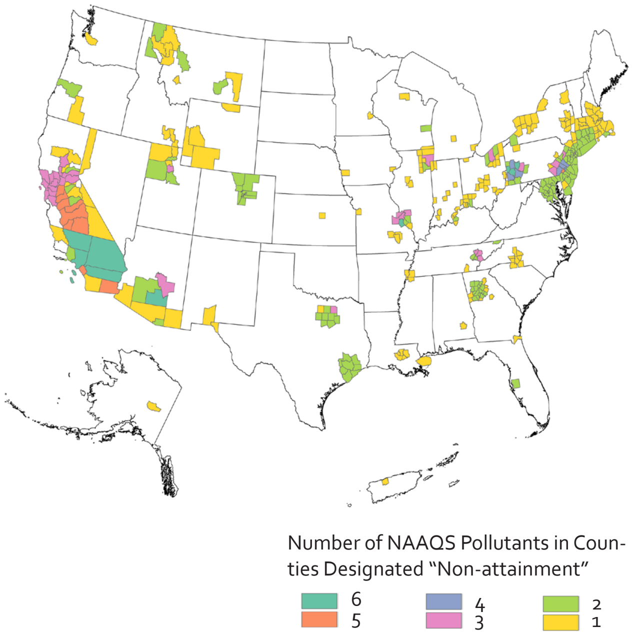


d. Canada and the US, annual wet nitrate deposition, 2012



Sources: EC 2012; NADP 2012

Figure 2.1.7: US counties that do not attain NAAQS, 2015



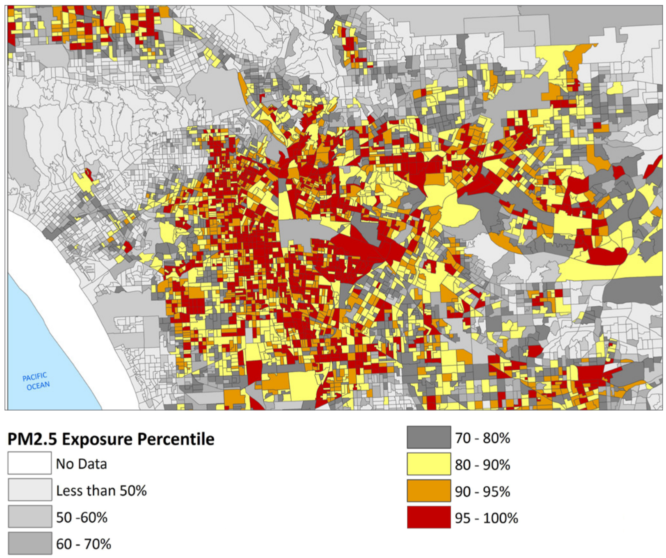
Source: US EPA 2015

resulting from the requirements of the 1990 Clean Air Act Amendments would prevent more than 230 000 early deaths per year. About 85 per cent of the economic benefits attributable to reductions in premature mortality are associated with reductions in ambient particulate matter. The remaining benefits are roughly equally divided among three categories of human health and environmental improvement: Preventing premature mortality associated with ozone exposure; preventing morbidity, including acute myocardial infarctions and chronic bronchitis; and improving the quality of ecological resources and other aspects of the environment, the largest component of which is improved visibility. The central estimate of quantifiable benefits of USD 2 trillion in 2020 exceeds costs by more than 30-to-1 – the high benefits estimate exceeds costs by 90-to-1 and the low benefits estimate exceeds costs by about 3-to-1 (US EPA 2011).

Pollution sources and human populations are not uniformly distributed and thus some populations, particularly those who are economically disadvantaged, are exposed to greater amounts of pollution than the average. The US EPA estimated that in 2005 almost 14 million people in more than 60 urban areas have lifetime cancer risks greater than 100 in a million due to the inhalation of air toxics. Since that assessment, additional air toxics emission reductions have been implemented. However, hot spots still remain.

The US EPA and Environment and Climate Change Canada strive to provide to all people the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn and work. To help achieve this goal, they have developed tools, such as EJScreen (http://ejscreen.

Figure 2.1.8: EJScreen, national percentile exposure to $PM_{2.5}$ for Los Angeles



A screen shot of the EJScreen online tool showing an index for PM2.5 exposure in Los Angeles. The shading in the diagram indicates the percentage of the national population that has an equal or lower value.
Source: US EPA

epa.gov/mapper/) which allows people to view data about the state of air quality and other environmental exposures where they live and to map them against demographic and socio-economic characteristics **(Figure 2.1.8**).

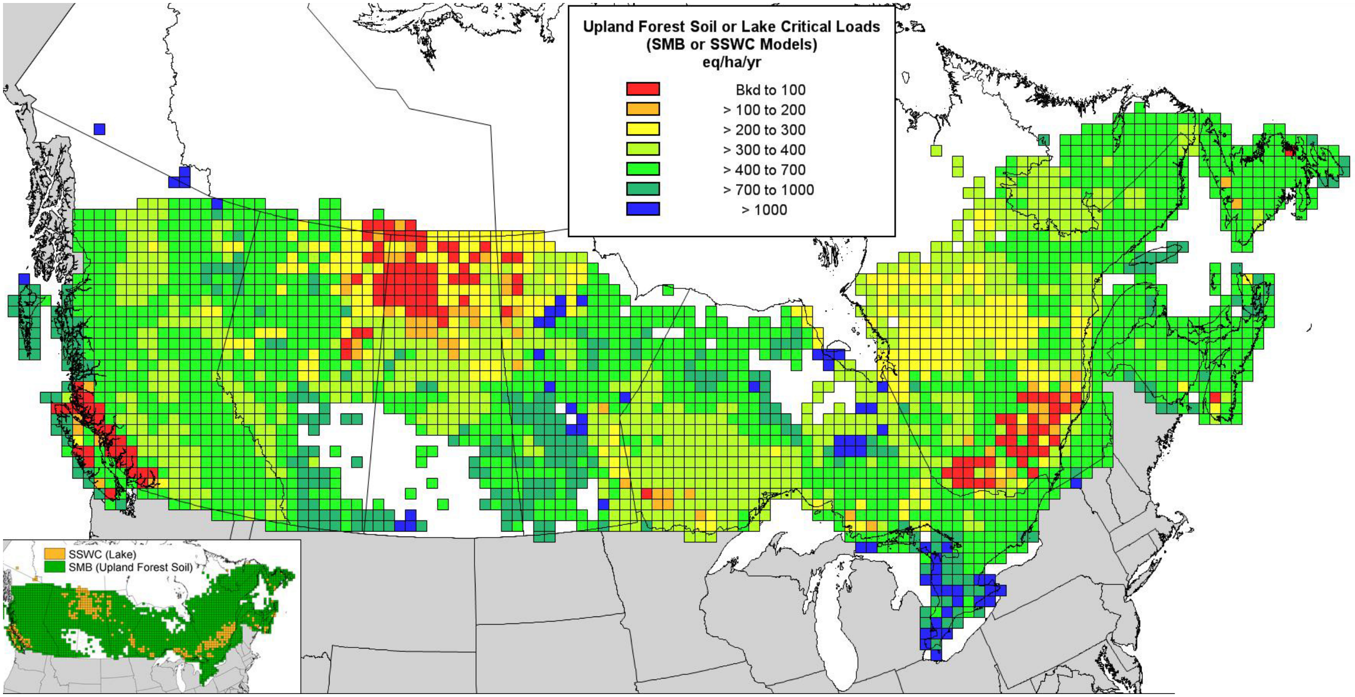
In Canada, the concept of critical loads has been used to assess and manage deposition of pollutants and their impact on ecosystems. A critical load is a rate of deposition at which harmful ecological effects are not anticipated and ecosystems damaged by past exposures may eventually recover. **Figure 2.1.9** presents a new critical load map for acidifying deposition for Canada. In the US, land management agencies and researchers have begun to use critical loads to assess the cumulative impacts of nearby development and other stressors on ecosystems, but the approach has not yet been accepted into official planning and regulatory development.

2.1.4 Developing trends

Urbanization

Continued urbanization, or urban sprawl, is an important driver for air pollution and greenhouse gas emissions across North America. As urban areas spread over a landscape, there is more demand for transportation and energy, and an increase in the associated emissions. As land uses change, so does the population density and proximity to emissions sources, changing the patterns of exposure to air pollution.

Figure 2.1.9: Critical loads of acidity for lakes or upland forest soils across Canada



Source: US/Can AQA 2014

State and trends

Table 2.1.1: Smart growth principles and associated case studies

Smart growth principle	Case study
Mix land uses	Eighth and Pearl, Boulder, Colorado Legacy Town Center, Plano, Texas
Take advantage of compact building design	Belmont Dairy, Portland, Oregon Highlands' Garden Village, Denver, Colorado
Create a range of housing opportunities and choices	Hismen Hin-Nu Terrace, Oakland, California Benedict Commons, Aspen, Colorado
Create walkable neighborhoods	Northwest Landing, DuPont, Washington Bethesda Row, Bethesda, Maryland
Foster distinctive, attractive communities with a strong sense of place	The Can Company, Baltimore, Maryland Downtown Brea, Brea, California
Preserve open space, farmland, natural beauty, and critical environmental areas	Abacoa, Jupiter, Florida East Lake Commons, Decatur, Georgia
Strengthen and direct development towards existing communities	Mizner Park, Boca Raton, Florida Uptown District, San Diego, California
Provide a variety of transportation choices	King Farm, Rockville, Maryland The Crossings, Mountain View, California
Make development decisions predictable, fair, and cost effective	Green Tape Program, Silver Spring, Maryland Compact Development Endorsement Program, San Francisco, California
Encourage community and stakeholder collaboration in development decisions	Barrio Logan, San Diego, California East Russell, Louisville, Kentucky

Source: http://www2.epa.gov/smartgrowth/smart-growth-illustrated

In addition, the high density of vehicle-related emissions in urban cores typically affects the sensitivity of ground level ozone formation to controls of nitrous oxide or volatile organic compound emissions. In most areas of North America, ground level ozone formation is most sensitive to changes in nitrous oxide emissions. However, in and directly downwind of many big cities, there is a region where decreasing nitrous oxide emissions increases ozone concentrations locally by decreasing ozone destruction, and ozone formation is most sensitive to volatile organic compound controls. As land uses and associated emissions evolve, air pollution control programmes have to change accordingly.

A number of North American cities have attempted to limit urban sprawl through the implementation of smart-growth policies. **Table 2.1.1** presents a list of ten smart-growth principles and web links to case studies in 20 communities where they have been applied.

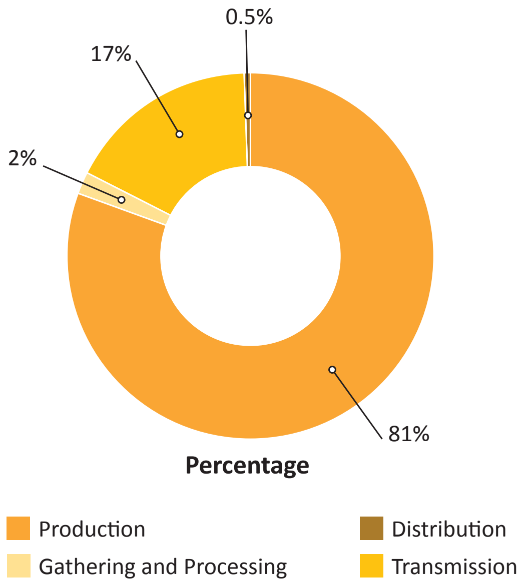
Oil and gas development

Oil and gas development, both conventional and unconventional, has expanded rapidly across North America and is contributing to existing air pollution problems and creating new ones. Some of the highest ozone levels in the US have been observed in rural Utah and Wyoming in wintertime. This is due to a combination of emissions associated with natural gas development, topography and meteorology which trap the emissions in valleys, and clear skies and snow-covered ground, which reflects sunlight back into the atmosphere driving the photochemical production of ozone, even at cold temperatures (Field *et al*. 2014). To address the methane and volatile organic compound by-products of oil and gas development, the US EPA's Natural Gas STAR programme encourages industry, in the US and abroad, to adopt proven, cost-effective technologies and practices that improve operational efficiency and decrease emission. Voluntary programmes, such as Natural Gas STAR, give regulated entities options to reduce emissions in advance of regulatory requirements. In addition, the US EPA recently proposed a suite of regulatory requirements to help combat climate change, reduce air pollution and clarify permit requirements for the oil and natural gas industry (US EPA 2015).

These programmes are showing promising results. During calendar year 2014, 61 per cent of US partners submitted annual reports detailing their 2013 voluntary activities that resulted in domestic emissions reductions of around 1.44 billion cubic metres for the year **(Figure 2.1.10).** These methane emissions reductions have cross-cutting benefits on domestic energy supply, industrial efficiency, revenue generation and greenhouse gas emission reductions. The 2013 emission reductions are equivalent to:

- revenue of more than USD200 million in natural gas sales, assuming an average natural gas price of USD 4.00 per thousand cubic feet (28.3 cubic metres);
- the avoidance of 24 million tonnes of carbon dioxide equivalent;
- the carbon sequestered annually by 7.7 million hectares of US forests.

Figure 2.1.10: Sources of voluntary methane emission reductions reported by the oil and gas industry to US EPA's Natural Gas STAR programme, 2014



Source: US EPA 2015

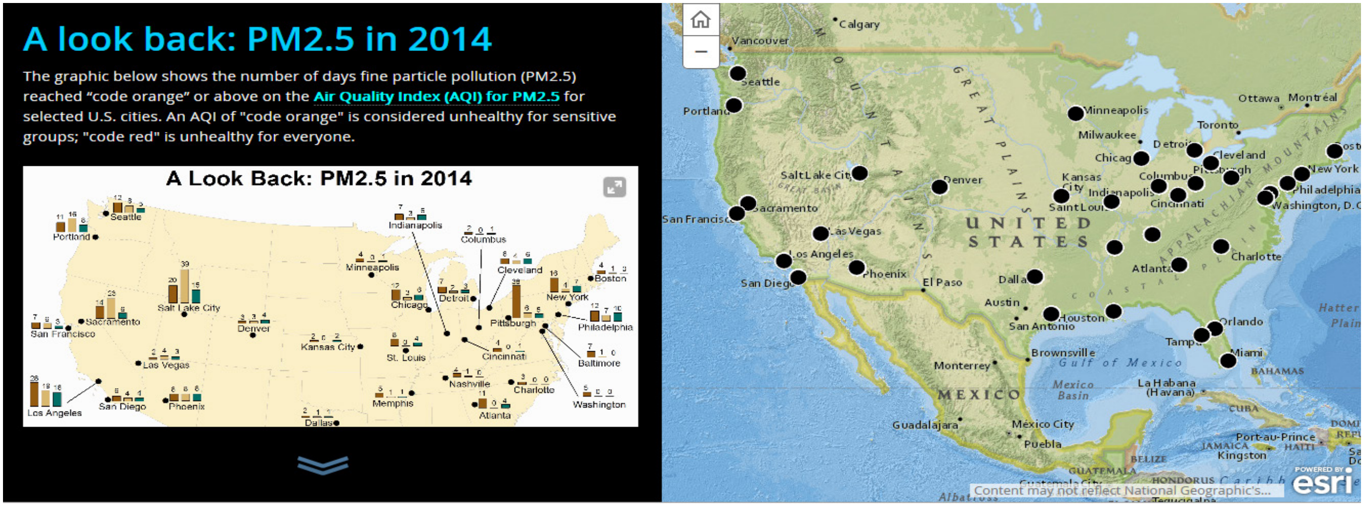
Real time data and small sensors

The AirNow programme (www.airnow.gov) was started by the US EPA in 1997 as a way of sharing real-time air quality data with the public. Currently, AirNow provides daily coverage of ozone and particulate levels for the US, Canada and much of Mexico. In addition, forecasts are available in more than 400 cities across the US. The AirNow programme has demonstrated the value of providing citizens with data they can use to mitigate exposure to unhealthy air (**Figure 2.1.11**).

Besides a web presence, AirNow established partnerships with media entities such as USA Today, the Weather Channel and weather service providers to get air quality data and forecasts from newspapers, radio, and television.

An AirNow application for smartphones allows users to get this information even more easily – millions of users visit the AirNow website every year. AirNow, which has become an exemplar of how to effectively communicate air quality to the public, has expanded to include international partners and its software is now being used in Shanghai,

Figure 2.1.11: AirNow story map interactive summary of air quality observations at key locations



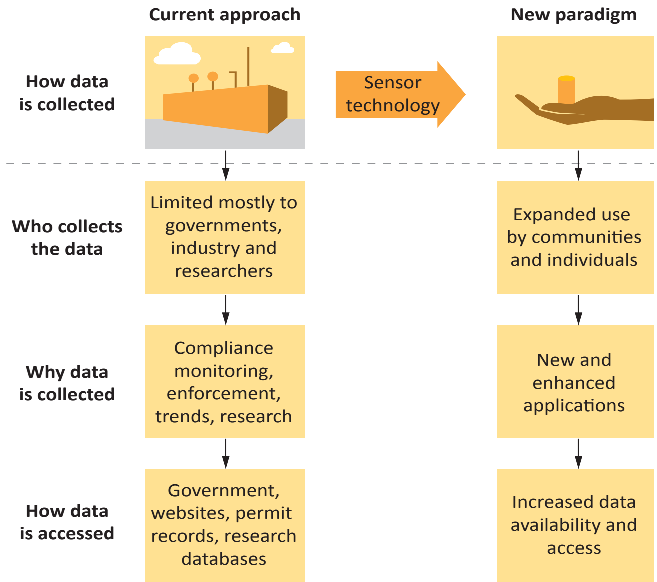
The first page of an AirNow story map – an interactive display that allows the user to drill down geographically – shows a summary of the past year's air quality.
Source: AirNow 2014

China, and in three Mexican states. In countries with difficult air quality issues, AirNow is being considered as a step towards informing the public of the nature and severity of air pollution, and creating a demand for clean air and air pollution control.

While the AirNow system provides access to data from traditional ground-based monitoring networks operated by air quality management agencies, these networks are no longer the only source of air quality observations. **Figure 2.1.12** shows how the air pollution monitoring paradigm is changing rapidly as a result of recent advances in the development of portable, lower-cost air pollution sensors reporting data in near-real time with a high time resolution, increased computational and visualization capabilities and wireless communication infrastructure. These advances can support traditional air quality monitoring by supplementing ambient air monitoring and enhance compliance monitoring. Sensors are beginning to provide individuals and communities with the tools they need to understand their environmental exposures. With the resulting data, individual and community-based strategies can be developed to reduce pollution exposure as well as to understand links to health indicators (Jiao *et al*. 2015).

As sensor costs drop, and if their accuracy and precision rise as expected, these new sensors may represent the best monitoring option for developing countries, as well as for addressing community exposure concerns. Air quality managers in both Canada and the US, however, will face the difficult task of relating these measurements to the observations from their fixed location monitoring networks and their longer-term national standards. To help communities take advantage of this new technology, the US EPA has created a toolbox with information on the capabilities of various sensors and guidance on how to use them effectively.

Figure 2.1.12: The transformation of the air quality monitoring paradigm



Source: US EPA 2015

2.2 Land

For many, the idea of North America evokes an image of open spaces, endless forests, mighty rivers and prairies stretching to the horizon. In the past century, major cities with towering skyscrapers at their core, surrounded by a suburban ring and an outer peri-urban zone, are included in the vision. Canada and the US have converted landscapes, built infrastructure, and consumed energy on a vast scale. Over four centuries, forests, grasslands, and wetlands have been cleared for agriculture. In the 20th century, some previously farmed land has reverted to forests while others have become peri-urban, suburban, and urban areas.

A focus on events since European settlement overlooks the much longer history of the region's original inhabitants, many of whom struggled with land use and resource allocation issues that had both biophysical and social/cultural dimensions. Those struggles have only intensified since European settlement. Current controversies over resource development and land use, such as oil and gas extraction and pipeline development, show that land and resource decisions are still entwined with biophysical, social and cultural questions, including democratic participation and community autonomy.

Recent trends in land-use and land-cover change – together with debates over land rights and the processes by which land and resource decisions are made – set the stage for some of the region's most pressing environmental challenges: habitat fragmentation, the spread of invasive alien species, and the local and cumulative effects of agriculture and resource extraction.

Since the end of World War II, the development of urban, suburban, and peri-urban areas has been a dominating factor in North American land-use changes, driven in large part by an early 20th century technological innovation—the automobile. The result is that urbanization in North America reflects a different pattern than elsewhere around the world; less dense, less compact, and more reliant on the automobile (Jackson 1985; Hofmann *et al.* 2005). The US (240 million cars) and Canada (17 million cars) together have one-quarter of the world's total number of vehicles, 1 015 billion (Davis *et al.* 2014; WardAuto 2015). Public transit in Canada serves less than 1 in 5 commuters; 1 in 20 in the US (McKenzie and Rapino 2012).

The automobile has created flexibility in routing and timing of commuting that has contributed to urban development patterns vastly different in North America from other countries. Elsewhere, urban expansion was more heavily influenced by the hub-and-spoke patterns of surface rail or street car transit, or the grid-pattern associated with early walking-oriented cities (Jackson 1985). The increase in automobiles was one of the principal forces that drove decentralization of the workplace and greater physical separation of home from work (Baum-Show 2010). Many of the North American developed landscapes now include low-density residential and commercial development predicated

Key messages: Land

North America's land resources are generally in good shape. Developed landscapes are largely meeting society's needs for housing, economic development, and community well-being. Natural landscapes—forests, croplands, rangelands, and tundra—are providing clean fresh water, healthy habitats for wildlife and fish, quality outdoor recreation opportunities, and satisfying many food and fiber needs of North Americans, while also contributing to global food and fiber supplies.

- Large-scale disruptive land-use and land cover changes are kept in check by effective governance policies and regulations. However, natural landscapes are becoming more fragmented in some areas in response to both natural causes, such as wildfires and pest outbreaks, and decisions made about land management activities, ownership transfers to heirs, and development decisions, particularly at the intersection of the forest, agriculture, and the energy sectors.
- Where further fragmentation occurs, it often exacerbates landscape-level resource management challenges and leads to reductions in the ecosystem services that both wildlife and human communities depend on for their wellbeing.
- A few North American cities and smaller communities are serving as living laboratories, demonstrating how focused attention on pragmatic, coordinated improvements in systems spanning land use, transportation, public health, clean energy and water, and recycling and waste management can enhance resilience and improve sustainability.
- Spreading these lessons learned to other communities throughout North America offers potential solutions for creating more sustainable and resilient development pathways to the future.

on automobile usage. Suburban and peri-urban residents are generally reluctant to pay the taxes and fares associated with building and operating convenient and frequent public transit to serve them (McKenzie 2015).

Thanks to insights gained through monitoring programmes, satellite imagery and computer assisted ecological classification systems, the understanding of land-cover change has been growing over the past two decades – understanding that can inform management strategies. Governments and academics have adopted standard greenhouse gas inventory systems established by the United Nations Framework Convention on Climate Change (UNFCCC) and they benefit from concepts and research on land-use, land-use change, and forestry led by the Intergovernmental Panel on Climate Change (Watson *et al*. 2000). Together, these measures offer opportunities to link evidence to policy and practice in support of sustainable and equitable land decisions.

Several different reports prepared by both countries document changes in land-use. Both countries prepare national communications, national inventory reports, and common reporting format tables for the UNFCCC using the same definitions, but these only cover *managed* land (**Table 2.2.1**). In Canada, 71 per cent of its land is considered unmanaged for UNFCCC reporting. Both countries conduct national inventories of their forests and report information to FAO using standard definitions as part of its global forest resources assessment process. But the Canadian report to FAO includes 50 per cent more forest land than reported to the UNFCCC. Thus while there is consistency in reporting for both countries to these two separate UN processes, there is inconsistency between the reporting requirements of the

Table 2.2.1: Land-use trends in Canada and the US ('000 hectares)

Land-use categories	1990	2005	2010	2013
	----------------------------------'000 hectares---			
US				
Forest	298 598	300 848	302 033	302 386
Croplands	170 448	160 107	159 243	159 230
Grasslands	350 109	347 142	346 439	346 430
Settlements	38 602	49 676	50 624	50 614
Wetlands	44 453	44 060	43 330	43 025
Other land	34 021	34 397	34 562	34 545
Subtotal, US	936 231	936 230	936 231	936 230
CANADA	1990	2005	2010	2013
Forest	232 715	232 085	231 847	231 709
Croplands	49 120	50 018	50 152	50 236
Grasslands	7 890	7 399	7 253	7 166
Settlements	1 881	2 214	2 360	2 411
Wetlands	1 065	453	521	519
Other land	705 796	706 298	706 334	706 426
(Unmanaged forest & wetland)	(265 220)	(355 462)	(265 632)	(265 772)
Subtotal, CANADA	998 467	998 467	998 467	998467

two processes. This makes a thorough analysis difficult as different numbers exist in the published literature for the same land-uses, which requires further explanation and reconciliation.

Both countries also produce agricultural censuses every five years that provide detailed analyses of changes in land-use associated with farming and ranching. The shifts in production reported are driven by market signals and policy changes. These shifts in production have impacts on the environment, through greenhouse gas emissions, as well as impacts on rural economies.

After analysing data from all these sources, three types of land-use changes emerge as most significant in recent years: (1) forest to cropland; (2) cropland to settlement; and (3) forest to settlement.

2.2.1 Canadian land-use change

Between 1989 and 2006, the amount of cropland in Canada rose by around 1 per cent per year, net, primarily due to land-use shifts of forest to cropland (Environment Canada 2014; Statistics Canada 2012). But the trend over the past 25 years is a declining one. The forest-to-cropland changes have ranged from +2.6 per cent for 1989–1990, to +1.3 per cent in 2004–2005, and +1 per cent of cropland area for 2009–2010 at the national scale. The cropland-to-forest changes have been on the order of one-fifth of the annual forest-to-cropland shifts, resulting in a long-term declining, but still positive, rate of forest-to-cropland change. In absolute terms rather than percentages, from 1993 to 2013, 405 000 hectares of Canadian forest were converted to cropland use. This is down from the 1 286 000 ha of forest converted to cropland from 1970 to 1990.

Farmland conversion has been more common in eastern Canada. Since 1993, 83 per cent of forest-to-cropland conversions occurred in eastern Canada and only 10 per cent in the Prairie Provinces. The cropland-to-forest changes are largely occurring on privately-owned lots where marginal cropland is being taken out of production and planted with trees. This transition has primarily affected croplands where production was abandoned some years ago (e.g., old Christmas tree plantations, vineyards and old fields that naturally transitioned to woody species), and that in the most recent forest inventory finally had enough woody species to meet the definition of forest. The area of marginal cropland left to naturally transition to forest has not been quantified either by the current national forest inventory programme or the Census of Agriculture. Marginal agricultural land remains classified as cropland until sufficient tree cover emerges to meet the forest definition.

Unfortunately, inventories and monitoring programmes relied on for estimating land-use changes for greenhouse gas reporting, do not currently estimate the amount of cropland converted to settlements. However, other reports have documented significant changes. Canada's agricultural land is classified based on its quality and constraints for production. The top three classes are called 'dependable agricultural land' (DAL) and total 49.3 million hectares. DAL is valuable because it has no severe constraints on production and because it is scarce;accounting for only 5 per cent of all agriculture land. Hofmann (2001) found that from 1971 to 1996, urban areas had consumed 1.2 million hectares of land; half of that being DAL. By 1996, urban areas covered 2.8 million hectares across Canada and 52 per cent of the urban area was on DAL. Hofmann *et al*. (2005) reported further loss of DAL to development, reporting that in 2001, urban areas occupied 3 per cent of all DAL; more importantly, 7.5 per cent of Class 1 DAL. When urban and rural built-up areas are combined with transportation and utility corridors and other developed land, 4 million acres of DAL—8.1 per cent of the nation's endowment—was in non-agricultural land-use. A corroborating analysis by Statistics Canada (2014) found that settlements on DAL increased by 19 per cent from 2000 to 2011. By ecozone, the largest increase of urban intrusion onto dependable agricultural land occurred in the Mixed Wood Plains, where the settled area on dependable agricultural land grew by 128 030 hectares (+27 per cent)—over half this growth came from the Greater Golden Horseshoe region. The second largest increase was noted in the Prairies ecozone, where settled area on dependable agricultural land increased 59 807 hectares (+16 per cent). As Canada's population grows and cities develop and spread outward, the loss of some of the country's best farmland will likely continue, given that many population centers are located near some of the best farmland in the country.

Conversion of other land-uses to settlement also continues. In the four years from 2010 to 2014, settlements added 499 600 hectares; the vast majority (498 790 hectares) from forest land-use (Government of Canada 2014). A small amount of grassland (820 ha)—mostly tundra in far northern regions—also was converted to settlements. While that conversion of forest to settlement use was tiny (0.13 per cent), it demonstrates that forest areas surrounding settlements are a target for urban expansion across the country.

2.2.2 US land-use change

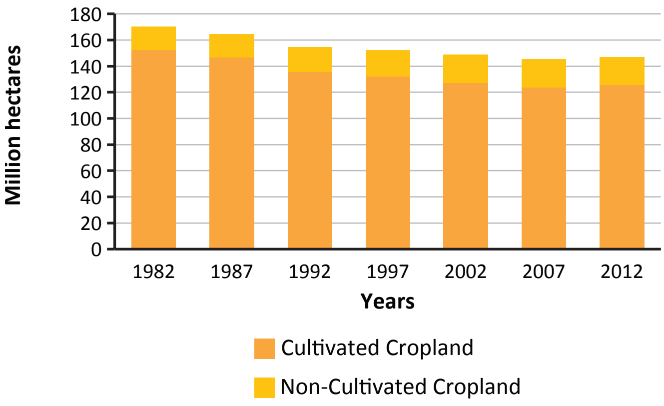
Forests account for 30 per cent of the US land area; grazing and pasturelands, 27 per cent; cropland, 18 per cent; and urban areas, 3 per cent. The proportions vary widely by region. The Great Plains and Rocky Mountain regions together have more than three-quarters of the nation's grazing land and a third of the cropland. The northern states have the largest percentage of land in forests (41 per cent) and 35 per cent of the nation's cropland, while the southern states have the largest percentage of the nation's timberland (40 per cent). Population is heavily concentrated in urban areas. The West has 90 per cent of its population in urban areas, the northeast has 85 per cent, and the Midwest and the South each have 76 per cent (US Census Bureau 2012).

Cropland area trends

The land area dedicated to crop production in 2012 was 146.9 million hectares. This is an increase of 1.56 million hectares since 2007; the first reported increase since 1982 (USDA 2015a; **Figure 2.2.1**). Despite this recent overall gain, the longer term trend was loss of cropland. Increases in urban land are responsible for part of this decline. Trends in land-use change since 2007 have not been analyzed in a consolidated and comprehensive way because updated information from the Natural Resources Conservation Service's National Resources Inventory (NRI) report is absent.

The Conservation Reserve Programme—which provided financial incentives to farmers to take highly erodible and other marginal land out of production—lost 3.34 million hectares between 2007 and 2012, nearly 2.22 million hectares or 77 per cent of which had been planted grasslands and lands formerly used for pasture or hay production. Lark *et al*. (2015) found that the principal crops grown on this new cropland were maize, 26 per cent; wheat, 25 per cent; soybeans, 20 per cent; and alfalfa, 7 per cent. However, they did not attribute the crop production gains to a driving force, such as shifting commodity prices or biofuels mandates.

Figure 2.2.1: US Cropland, by year



Source: US Department of Agriculture 2012

Developed land increased by 1.23 million hectares, or 2.7 per cent. Forty-six per cent of that was converted forest, 37 per cent rangeland and pastureland, and 23 per cent cropland.

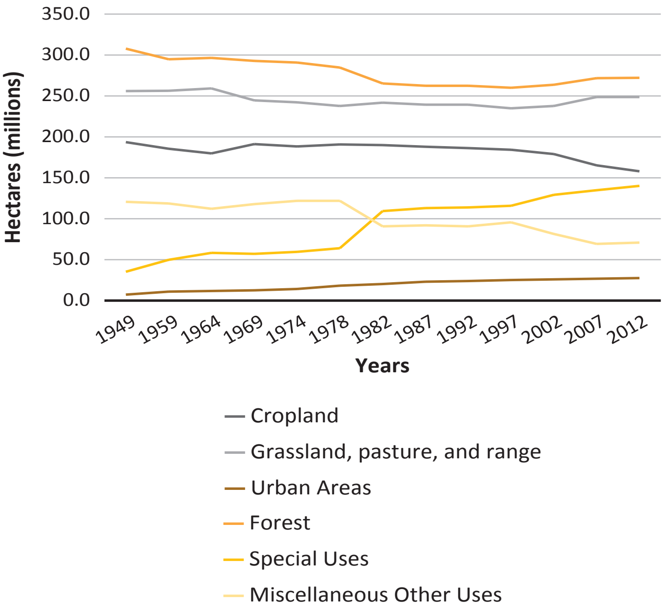
Grazing land area trends

Pastureland and grazing land estimates vary for the US, depending on the data source and definitions. The National Resources Inventory (NRI) of the Natural Resources Conservation Service classifies 49.0 million hectares as pasture and an additional 164.2 million hectares as rangeland, of an estimated total 213 million hectares (USDA 2015b). The 2012 Census of Agriculture, on the other hand, classifies 168.1 million hectares as pasture or rangeland for grazing, plus 11.3 million hectares of woodland grazed, for a total of 175.4 million hectares – an increase of 7.3 million hectares since 2007. A broader estimate of land available for grazing from a third Department of Agriculture agency, the Economic Research Service, totals about 248.7 million hectares, and includes grassland and other non-forested pasture and rangeland (US EPA 2010). If forestlands used for grazing and cropland pasture are also included, the total estimate for grazing lands is 314.4 million hectares for 2007, representing 35 per cent of US land area (US EPA 2010). However, three to four year delays by the Natural Resources Conservation Service in releasing the NRI information from the 2007 and 2012 surveys have prevented the Economic Research Service from updating the data (Nickerson *et al.* 2011, **Figure 2.2.2**). This lack of timeliness in processing and releasing data significantly reduces the usefulness of the NRI for policy and generates confusion for analysts.

Forest area trends

Forests are managed by a complex array of interests to meet multiple purposes, including recreation, public water supplies, timber production, and providing habitat for a variety of species. Oswalt *et al*. (2014) reported 310 million hectares of forestland in the US in 2012, of which 211 million hectares were considered as 'timberland'—land with no constraints on harvesting wood. Forests that are not timberland include land reserved from timber production, such as designated

Figure 2.2.2: Major uses of land (US), 1949-2012



Source: Adapted from Nickerson *et al.* 2011

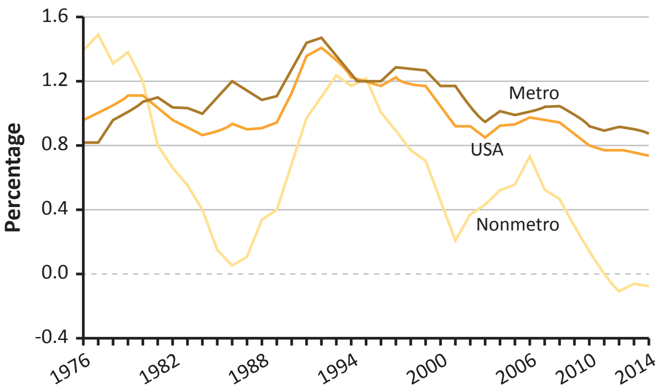
wilderness areas and National Parks, or land with trees where other factors, such as steep slopes, constrain timber harvesting. There were 29.7 million hectares in the 'reserved' category and 69.4 million hectares in the 'other' category in 2012. The area of timberland grew by just over 2.8 million hectares since 2007 and the area of forest by 5.7 million hectares, implying that the forest identified as 'reserved' or 'other' also gained 2.8 million hectares since 2007. This total reflects a net gain of about 14.6 million hectares, 6 per cent, between 1977 and 2012, which is attributed largely to reversion of pasture and other agricultural lands to forest, as well as reclassification of some National Forest lands to align with classifications used on other land ownerships (Oswalt *et al.* 2014).

Urban and developed area trends

The number of people living in rural counties stood at 46.2 million in 2014; nearly 15 per cent of US residents spread across 72 per cent of the nation's land. Rural areas lost population to developed urban and suburban areas between July 2013 and July 2014, continuing a 4-year trend. Rural population growth from net migration peaked in 2006, then declined precipitously and shifted geographically in response to rising unemployment, housing-market challenges, and energy sector developments, among other factors. Suburban expansion and migration to scenic retirement or recreation destinations have been primary drivers of rural demographic change for several decades, but since the onset of the 2007-2008 recession, their influence has considerably weakened, **Figure 2.2.3** (USDA 2015).

The loss of population and decline in rural communities reflects a "hollowing out" of the vast central regions of the country, where both agriculture and industry drove economic growth and middle-class prosperity in the last half of the 20th century. Although many studies document the departure of young people, ages 20-24, from rural areas and characterize it as a "brain drain," a recent study by Cromartie *et al.* (2015) offers reasons why people return to settle in rural areas. The majority of the returnees were in their early to mid-30s with young children. Their primary

Figure 2.2.3: Population change by metropolitan/nonmetropolitan census status, 1976-2014



Source: USDA, Economic Research Service 2015 motivations for returning included being closer to relatives, proximity to outdoor recreation (camping, fishing, and hunting were prominently mentioned), opportunities for civic leadership and volunteering, and shorter commutes to work. The primary barriers were low wages and lack of career opportunities, which required creative strategies to overcome, lack of cultural events, and limited amenities, shopping and dining options. The rural communities benefitted from an influx of well-educated professionals who brought business contacts, leadership skills, and an interest in community well-being, especially primary and secondary education. Thus rural counties experiencing population growth may be at the forefront of benefitting from the returnees' talents. Increasing in-migration to rural areas and stemming the departure of young people will require local civic and political leadership capable of dealing with complex cultural and socio-economic factors to shape policy approaches while helping keep the local economy and landscapes healthy and resilient (Center for Rural Affairs 2015).

2.2.3 Recent trends in North American land cover

Land-cover change analysis has made remarkable progress in the past 20 years. The advance resulted from shifting imagery platforms – from aerial film photography to digital imagery from new sensors on satellites or aircraft – and greatly increased computing power. The most useful sensors for land cover analyses at a broad landscape scale are the 30 metre Thematic Mapper (TM) sensor on the LANDSAT platform and the 200 metre MODIS sensors on the TERRA and AQUA platforms. There has been much experimental work with higher resolution sensors and with synthetic aperture radar, called LIDAR. But not many operational monitoring programmes are using LIDAR at large spatial scales, such as those that cover provinces or large states. LIDAR imagery is more appropriate for smaller spatial scales because the very large and dense LIDAR datasets require substantial storage and very high-speed processors for analysis.

Beyond better sensors and digital imagery, geo-spatial analysis software has also become more available and powerful. In the 1990s, geo-spatial software generally required dedicated workstations and software. In 1999, software was introduced that ran under the Microsoft Windows operating system. This vastly expanded the pool of users and created an integrated set of tools for creating, analyzing, and storing geospatial data and information products that were more accessible to analysts and policy makers. The recent introduction of cloud-based computing has also made geo-spatial information products more widely available.

These new tools are increasingly being used by governments and non-governmental organizations at all spatial scales for decision-making. A strong attribute of these products is the data layers behind them, which when used with advanced geospatial software, can help local and county governments, state and provincial governments, and federal agencies make better policies, set relevant priorities, and plan management activities effectively. By making the data openly available to all, citizens are better able to visualize and participate in policy-making and decision-making. Indeed, better data leads to better dialogue, which leads to better decisions.

Two North American teams have taken advantage of these advances to develop land cover change datasets and maps. Under the auspices of FAO's North American Forestry Commission (NAFC), a team of experts from Canada, Mexico and the US worked for more than a decade to develop an ecoregional database that can generate consistent tables and maps of forests across all three countries (**Figure 2.2.4**). The second team of experts worked on the North American Land Change Monitoring System (NALCMS), under the auspices of the Commission for Environmental Cooperation (CEC). This team produced a land cover transition matrix (**Table 2.2.2**) and an ecological zone map for North America (**Figure 2.2.5**). The same team also analyzed the causes of tree cover changes. They found that large fires were more prevalent in more northerly latitudes in the Yukon, Alberta, Saskatchewan, and Quebec, while fires were smaller and spread out more extensively in southerly parts of those provinces.

Table 2.2.2: US land-cover change in grasslands and shrublands by owner category, 2001–2011

	Rangeland area by owner class			NLCD area change (2001-2011)	Rate of loss	
Region	Non-Federal	Federal	Total Area		Non-federal	All owners
	--------------------------hectares--------------------------				----------per cent----------	
Northeast	3 113 459	134 382	3 247 841	22 267	0.72	0.69
Pacific Northwest	626 319	927 642	1 553 962	24 839	0.40	0.16
Pacific Southwest	8 198 406	5 178 725	13 377 130	95 297	1.16	0.71
Northern Great Plains	40 031 766	6 185 198	46 216 964	282 688	0.71	0.61
Eastern Prairies	12 026 022	301 817	12 327 839	178 584	1.48	1.45
Everglades region	42 295	60 736	103 031	1 641	3.88	1.59
Southern Great Plains	34 151 588	1 454 754	35 606 343	202 947	0.59	0.57
Southeast	5 872 553	791 318	6 663 871	63 124	1.07	0.95
Interior West	26 675 292	48 957 685	75 632 977	148 913	0.56	0.20
Desert Southwest	6 322 660	13 109 595	19 432 255	88 979	1.41	0.46

Note: figures may not sum due to rounding
Source: Reeves 2015; NLCD 2015

The impact of the mountain pine beetle outbreak in central British Columbia is evident. In subsequent work reported by BiodivCanada, the transitions from tree cover to some other cover and from the other cover class back to forest were also depicted.

The transition matrix for Canada, Mexico and the US shows that the most common shifts were:

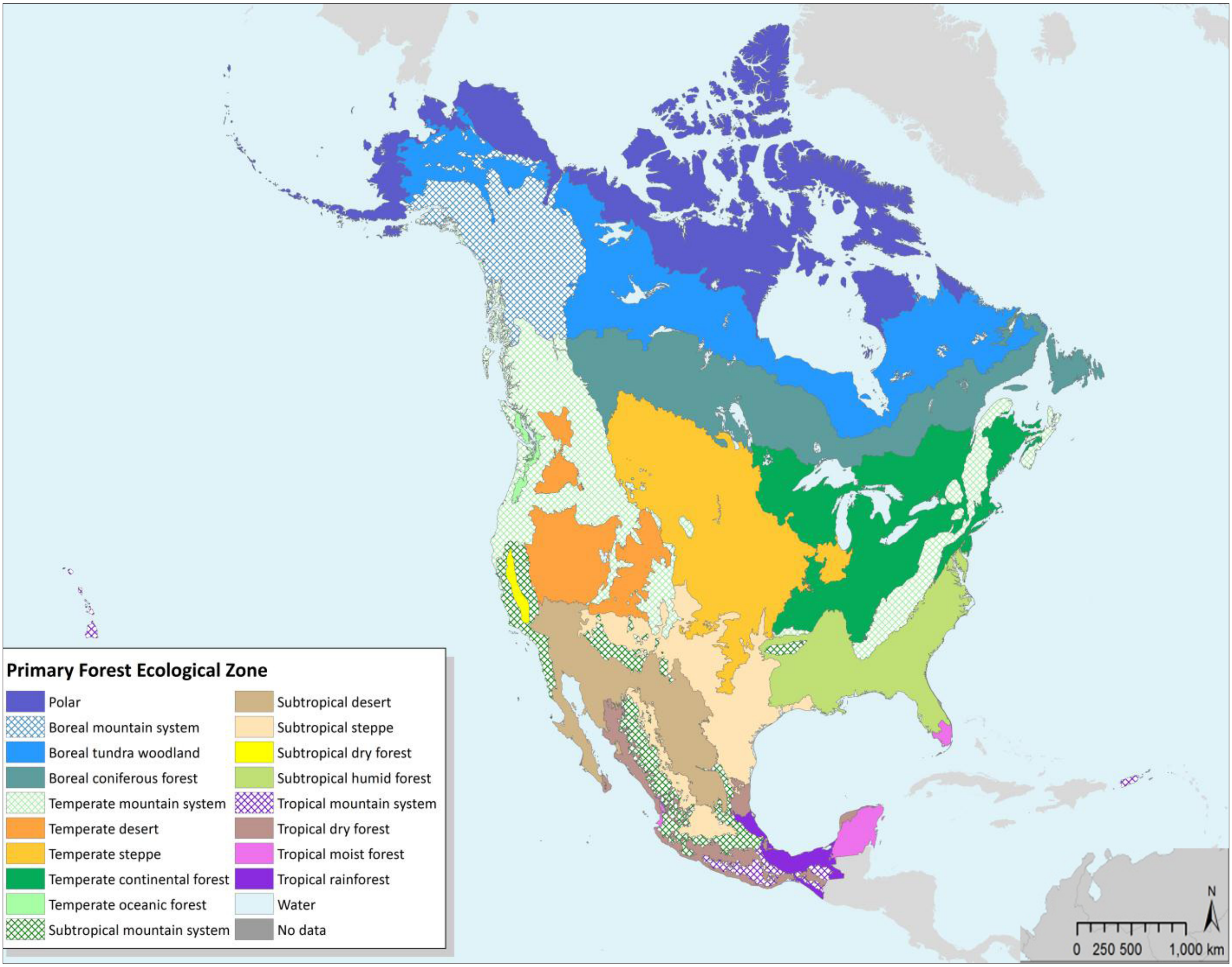
- needle-leaved forest → shrubland and herbaceous land;
- mixed forest→ deciduous forest, shrubland and herbaceous land;
- shrub land → deciduous forest and mixed forest;
- herbaceous → shrub land (shrubs and trees invading grasslands);
- wetland → needle-leaved forest (ecological succession, herbaceous shrubs to trees);
- cropland → herbaceous and urban/built up areas;
- water → barren land;
- snow and ice → barren land and needle-leaved forest.

On a percentage basis, the largest declines were in needle-leaved forest, − 2.17 per cent and wetlands, − 0.84 per cent. The largest increases were in herbaceous, +2.36 per cent; deciduous forest, +1.22 per cent; and shrubland, +0.68 per cent . The remaining changes were all less than ± 0.3 per cent.

Canadian land cover and land cover changes

The Canada Center for Remote Sensing (CCRS) has produced a number of national scale land cover databases with 1 km spatial resolution, including the land-cover time series 1985–2005 from the US National Oceanic and Atmospheric Administration (NOAA) advanced very high resolution radiometer (AVHRR) (Latifovic and Pouliot 2005) and SPOT/VEGETATION data (Latifovic *et al*. 2004). The most recent land cover database of Canada produced from 0.25 km spatial resolution MODIS data, has improved accuracy, spatial resolution and thematic content. The new database includes two thematic layers based on the Federal Geographic Data Committee/Vegetation Classification Standard (FGDC/

Figure 2.2.4: North American ecological zones, 2011



Source: Commission for Environmental Cooperation, based on UN-FAO-NAFC data

Figure 2.2.5: North American land cover, 2011

Source: Commission for Environmental Cooperation, NALCMS project

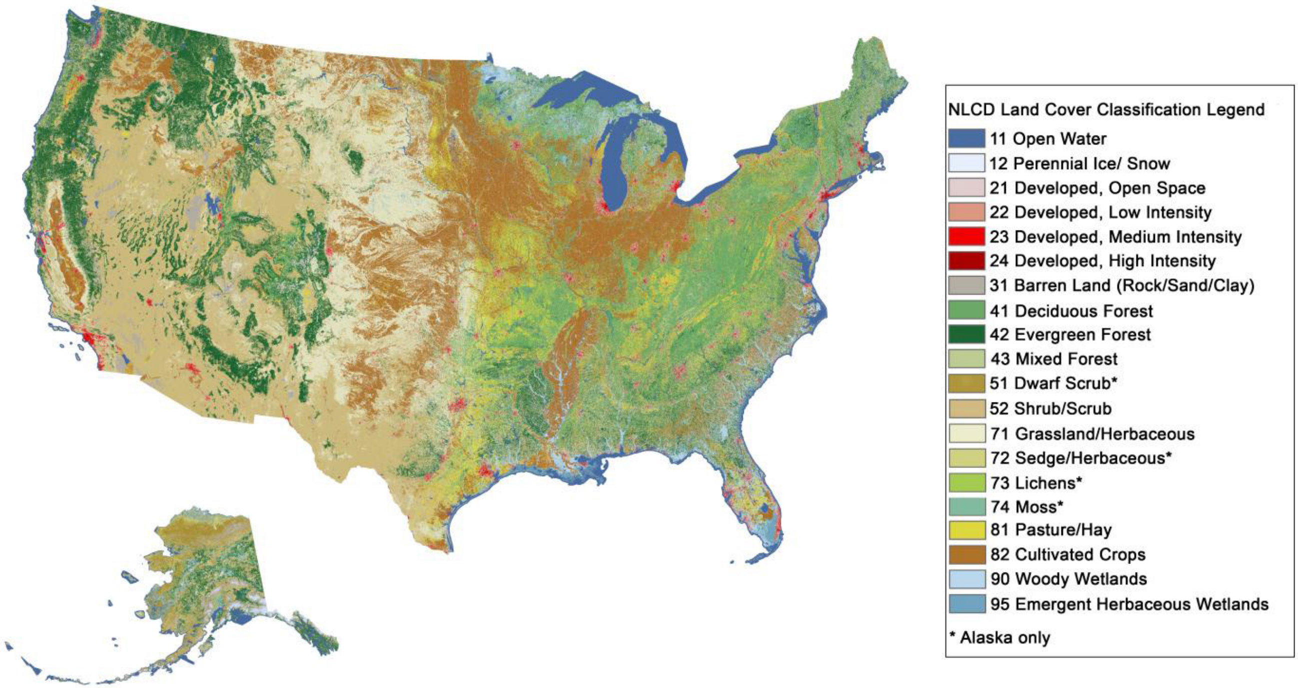
NVCS) modified for use in Canada and the International Geosphere Biosphere Programme (IGBP) land cover classes. The new database served as the primary source of Canadian land cover information in the North American Land Cover Database.

US land cover and land-cover change

In 1993, US Forest Service researchers produced the first national map of forest cover based on satellite imagery from NOAA's AVHRR satellites in combination with field data from the agency's Forest Inventory and Analysis programme (Zhu and Evans 1994). Following the success of this project, seven federal agencies combined their expertise and funding under the auspices of the Multi-Resolution Land Characteristics (MRLC) Consortium to produce the National Land Cover Dataset (NLCD). Maps of increasingly higher quality resolution, based on TM and MODIS imagery, and with richer sets of characteristics were developed in 2001, 2006, and 2011.

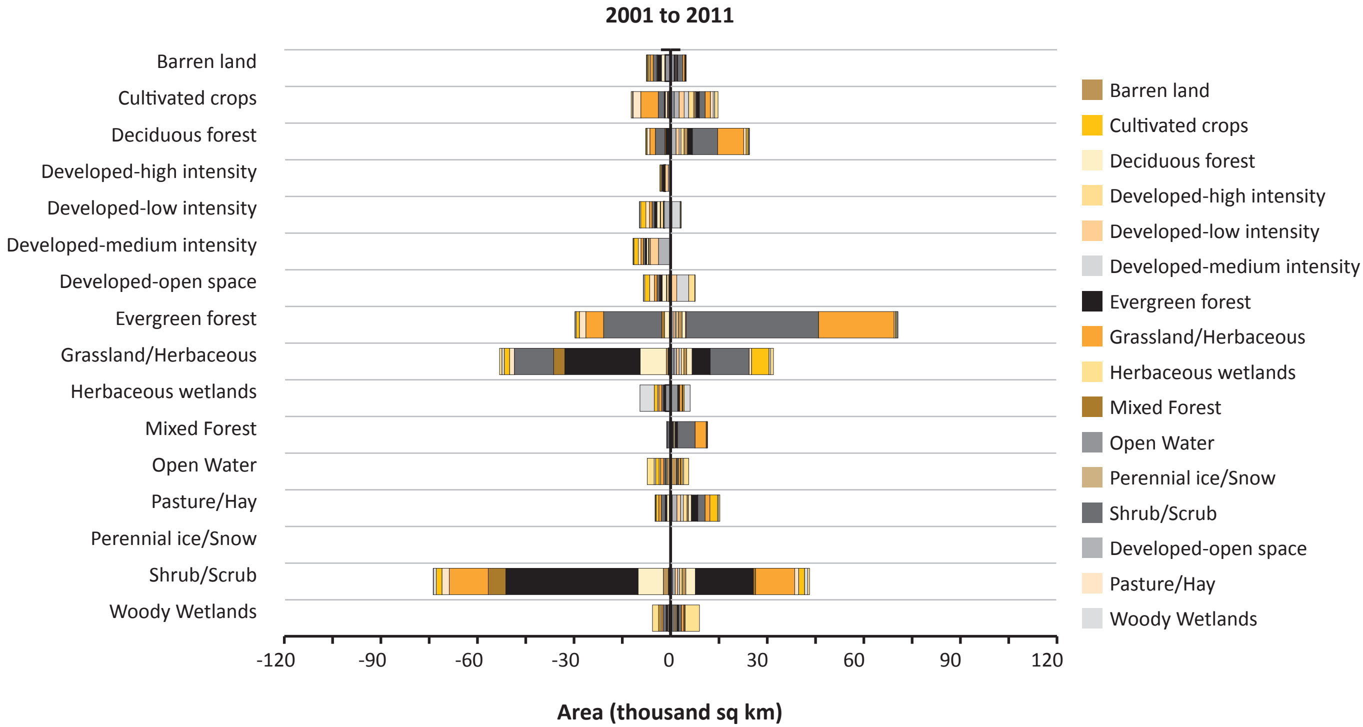
The National Land Cover Database 2011 (NLCD 2011) is the most recent national land-cover product created by the MRLC Consortium (**Figure 2.2.6**). The NLCD 2011 provides, for the first time, the capability to assess wall-to-wall, spatially explicit, national land cover changes and trends across the US for 2001–2011. As with two previous NLCD land cover products, NLCD 2011 keeps the same 16-class land cover classification that has been applied consistently across the US at a spatial resolution of 30 meters. The NLCD

Figure 2.2.6: US land cover, 2011



Source: NLDC 2011

Figure 2.2.7: US land-cover change, 2001–2011



Source: Adapted from Homer *et al.* 2015

2011 is based primarily on a decision-tree classification of *circa* 2011 Landsat satellite data. Details of the construction of the NLCD 2011 are in Homer *et al.* (2015).

Homer *et al*. (2015) also developed a land cover transition matrix and associated graphics from the NLCD products that shows change from 2001 to 2011 (**Figure 2.2.7**). The results show that most areas where there were tree-cover losses showed up as shrub or herbaceous cover gains, while most of the shrub- or herbaceous-cover losses showed up as gains to one of the tree cover types. The vast majority of these shifts back and forth between tree-cover and shrub or herbaceous cover are normal temporary changes in tree cover associated with active forest management. For example, if tree cover drops below 25 per cent , such as through a partial cutting to secure natural regeneration of a new stand, satellite imagery can no longer detect trees as the dominant land cover, and image classification then most often shifts to shrub or herbaceous cover. When the young, newly established trees—whether naturally regenerated from seeds falling from the remaining trees or from seedlings planted—grow tall enough and their crowns expand enough to again provide more than 25 per cent tree cover, then image classification shifts back from shrub or herbaceous cover to tree cover. This shift back and forth normally takes 10 years in southern forests and 15-20 years in northern and western forests. Some analysts (Hansen *et al.* 2010) have mistakenly concluded from two sets of imagery only five years apart that 'deforestation' had occurred, and this has led to exaggerated reports (Rice 2010). That term should only be used when a permanent shift from tree cover to non-tree cover has occurred and is documented over a longer time series of earth observations (Reams *et al*. 2010). Similarly, the term 'afforestation' should be reserved for situations where there is a permanent shift to tree cover from herbaceous or shrub cover.

The figures also show that transitions between cultivated crops and pasture are much smaller than the tree-cover changes. There are some changes back and forth between pasture, that is more intensively managed grass cover, and herbaceous, unmanaged grass cover, while some herbaceous and pasturelands move into and out of cultivation. Interestingly, there is a significant segment of red on the loss side of the cultivated crops category, indicating loss of cropland to development. That red segment appears larger than the loss of tree-covered land to development, and the transition matrix data confirm that it is – a loss of 3.84 million hectares, – 0.47 per cent, of cultivated cropland and pasture to development between 2001 and 2011 compared to the loss of 2.33 million hectares, – 0.25 per cent, of tree-covered land to development. What is also clear is that in the developed-land categories, there was also a significant movement of what had been open space or low density development to more intensely developed areas in 2011. This set of transitions in land cover to developed land reinforces the messages discussed in the land-use section. An increasing percentage of the US's population resides in developed areas which are growing in size at the expense of other land-cover types, while also increasing in development intensity.

US grazing land cover and cover change

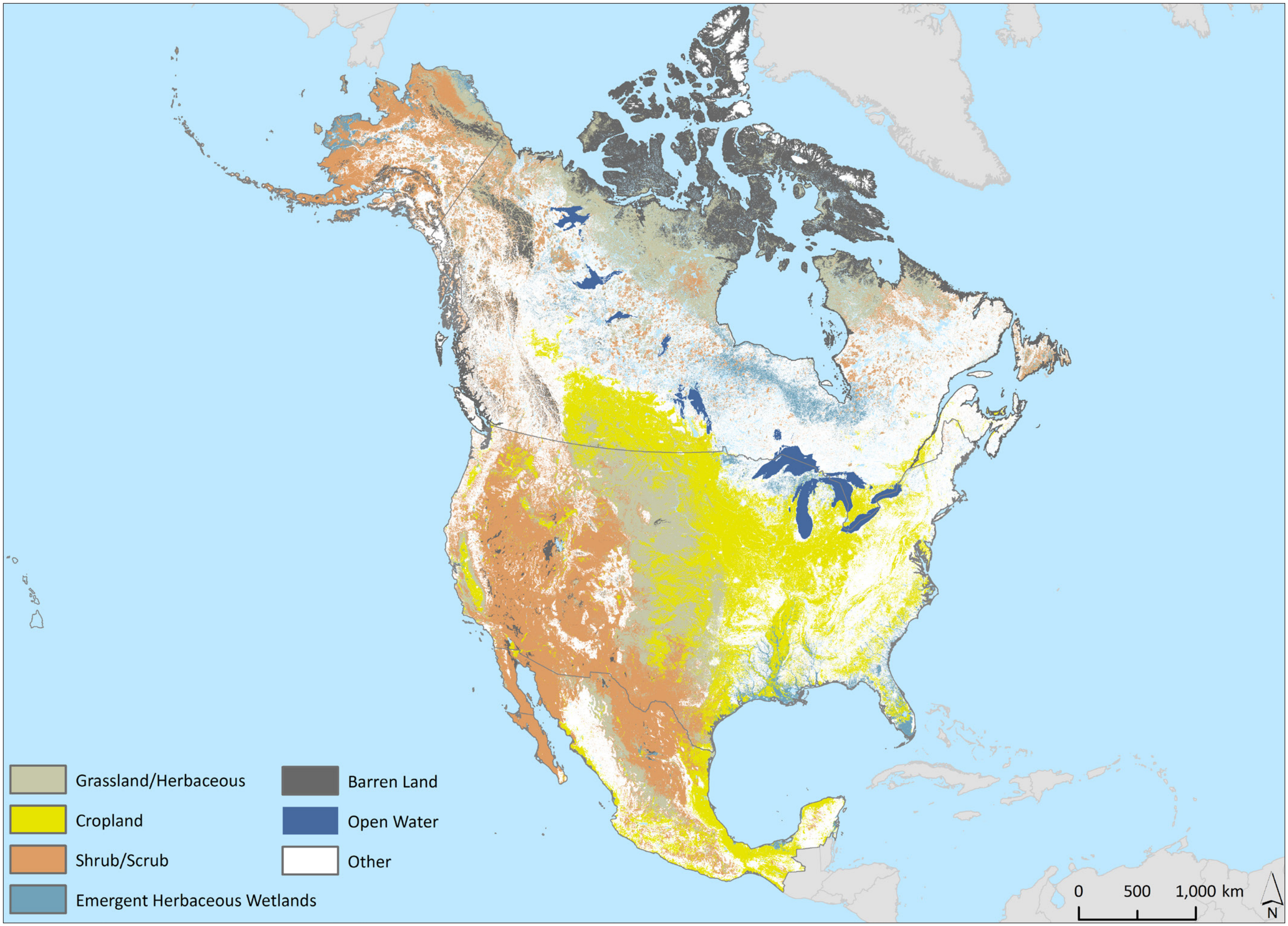
The National Land Cover Dataset (NLCD) databases for 2001 and 2011 were used to estimate changes in the area of shrubland and grassland by classes of ownership (Reeves and Baggett 2014; **Table 2.2.2**; **Figure 2.2.8**). The research suggests that virtually all the changes occurred on the land of non-federal government owners; ranchers, farmers, and tribal governments.

Drivers of these land-cover changes vary by region. In the Great Plains and Eastern Prairies, market shifts in crop prices, such as the increasing value of maize for producing ethanol, and beef prices, played a significant role. Farmers responded to these market signals by bringing grasslands and shrublands under cultivation. Another factor important in the Great Plains and Interior West was the increase in energy development for oil and gas production. Conversely, the shrublands of the Interior West showed the least decline. This is the area where a federal-private partnership is devoted to improving habitat for species such as the greater sage grouse (*Centrocercus urophasianus*).

Reeves and Baggett (2014) analyzed the degradation of grasslands and shrublands in the northern and southern Great Plains, using a process that evaluated satellite imagery, to seek places with significant reductions in productive capacity, estimated by the Normalized Difference Vegetation Index (NDVI). Imagery from 2000 was used as a baseline for comparison with imagery from 2012. They found very little change in land cover since 2000, leading them to conclude that most of the degradation still observable across the landscape occurred prior to 2000. Further, they concluded that land management policies and practices in these regions were probably not contributing to further degradation, although they could not determine whether the policies and practices were supporting recovery.

When the analysis was extended to other western rangelands to assess the impacts of recent droughts, they concluded that northern Texas, eastern New Mexico, and central California have seen the strongest declines in vegetation abundance and productivity. About 16.5 million hectares—15 per cent of all rangelands—have exhibited declining trends in vegetation abundance since 2000. In contrast, increased vegetation productivity was found in the northern Great Plains. The best explanations for these changes are that climate change is extending the growing season in the northern Great Plains while reducing net primary productivity in the southwestern US due to lower precipitation and increased evapotranspiration. If the future brings increased frequency of droughts and fewer years of above-normal precipitation,

Figure 2.2.8: US shrubland, grassland, and pasture cover distribution, 2011



Source: National Land Cover Dataset 2011

then the longer-term productivity of stressed rangelands in the southwest may be permanently reduced.

2.2.4 Land fragmentation

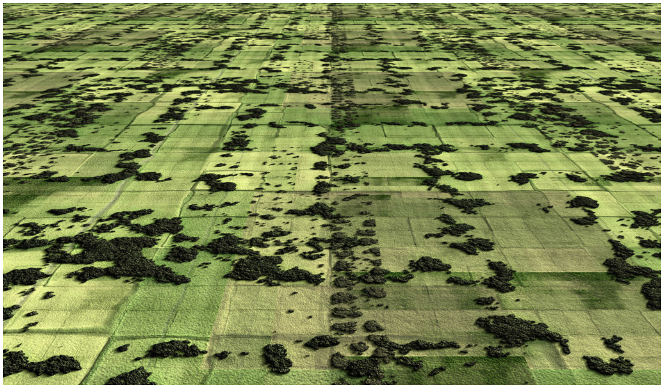
Land fragmentation is a spatial term referring to discontinuous patterns of land-use and land cover resulting from both natural processes and human interventions. Two perspectives are analysed in this North American assessment report: the first focuses on how land cover or land-use patterns affect ecological processes: fragmentation from an 'intactness' perspective. The second focuses on how land cover or land-use changes are affected by changes in land ownership: fragmentation through sub-division, also known as 'parcelization' (see also **Box 2.2.1**).

Fragmentation is a significant threat to endemic species throughout North America. Across the Canadian prairie grasslands, for example, 44 per cent of species' populations have been lost since the 1970s. The edge effects–changes in species' population or community structures that occur at the boundary of two habitats–from fragmented habitat patches play an important role in this decline. For instance, grassland birds avoid nesting close to these edges; so the more edges, the fewer nests. While most of native grasslands' decline occurred before the 1930s due to conversion to agricultural land, further alteration and degradation continues with the smaller patches most affected (Roch and Jaeger 2014).

The types and quantities of ecological values created by natural landscapes often depend on the spatial patterns of land cover and land-use (Laurance 2008; Harper *et al*. 2005; Forman and Alexander 1998). For example, King and DeGraaf (2000) found that different spatial patterns in forest cover influenced bird diversity and nesting success. Flather *et al*. (2009) noted that the distribution and abundance patterns of species vary in time and space and, while these patterns are affected by ecological factors, human manipulation is influencing land cover and use at accelerating rates. Radeloff *et al.* (2010) found that urban area expansion in the US may severely limit the ability of protected areas to function as effective biodiversity conservators. Thus, spatial-temporal trends in land cover and land-use are often taken as leading indicators of subordinate ecological conditions and the diversity, quantities, and values of the services provided by the ecosystems (MA 2005).

Fragmentation and intactness of ecosystems

Fragmentation of land cover into smaller pieces changes ecological processes and alters biological diversity (see Section 2.3.5: Biota). Analysing fragmentation is scale-dependent. Much of the earlier fragmentation work in the late 20th century was at very small spatial scales—relevant to individual ecological processes, but of little use for understanding dynamics at the landscape level. In the past 15 years, technological advances in digital imagery and computing speeds have combined to enable major breakthroughs in analyses.



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Recent analysis by Riitters (2011) showed the relative intactness of tree, grassland, and shrubland cover regionally and nationally across the US. It defined area density as the proportion of a fixed-area neighbourhood around a sample point. For example, for a 16-hectare neighbourhood around a sample point, an area density (p) of 0.6 for grassland means that 60 per cent of the land cover was grasses. Riitters (2011) scaled area density into seven classes, drew samples from the national land-cover dataset and analysed the data at multiple spatial scales (**Table 2.2.3**).

Riitters showed that between 2001 and 2006, the coterminous US had a net loss of 1.2 per cent of its total forest cover. In comparison, there was a net loss of interior forest of 4.3 per cent over the same period. Forest cover losses tended to occur in or near interior forests, while forest cover gains did not tend to create new interior forest. From a global perspective, Haddad *et al*. (2015) found that habitat fragmentation is widespread globally and is increasing – more than 70 per cent of the world's forests are now within 1 km of the forest edge – and that the negative impacts of fragmentation are even stronger and more persistent than previously thought. These include changes in biodiversity and ecosystem function, and they may occur immediately or after a delay of several years.

Table 2.2.3: US land cover percentages†

Area density class	Definition	Tree cover (per cent)	Grassland cover (per cent)	Shrubland cover (per cent)
Intact	(p=1.0)	8.1	3.2	9.6
Interior	(0.9 ≤ p < 1.0)	7.1	2.4	4.5
Dominant	(0.6 ≤ p < 0.9)	11.6	4.8	7.7
Transitional	(0.4 ≤ p < 0.6)	6.5	3.7	5.0
Patchy	(0.1 ≤ p < 0.4)	12.3	10.9	11.5
Rare	(0.0 ≤ p< 0.1)	8.6	12.1	10.7
None	(p = 0.0)	46.0	62.9	51.1

† US land cover percentages by Riitters' area density classes for 16-hectare cells, summarized at the national level. Interpretation example: Tree cover is 'Dominant' or better (p ≥ 0.6) in 26.8 per cent of the 16-hectare cells sampled across US; result obtained by summing the per cent tree covers for the 'Intact' (8.1 per cent), 'Interior' (7.1 per cent) and 'Dominant' (11.6 per cent) tree cover categories.
Source: Riitters 2011

Box 2.2.1: US ownership patterns for forested lands and fragmentation

Ownership patterns for forested lands in the United States have implications for land management. Fifty-six per cent of the 30 million hectares of forest land in the US is privately owned; 62 per cent of which is owned by families and individuals. Privately owned forest lands are largely found in the eastern US.

Over the last 30 years there has been an increasing trend towards the parcelization of privately owned forest lands – dividing larger parcels of forest and selling smaller and smaller parcels to an increasing number of private forest landowners (Butler 2008). Of the 10.4 million owners today, one-quarter have owned their forest less than a decade and are relatively new to forest ownership and have limited experience in forest management. Moreover, less than eight per cent of all private forest landowners have a management plan (Oswalt and Smith 2015). Recent government policies that now require small landowners to have a written management plan prepared in partnership with a professional forester, to qualify for certain financial incentive programmes are helping to educate landowners and improve their decision-making. From a landscape perspective, an increased number of forest management plans may improve the likelihood for a more sustainable provisioning of ecosystem services.

Finally, the relatively advanced age distribution of family farm and forest owners has significant implications for inter-generational land ownership transfers that increase the uncertainty about long-term commitments to sustainable management. Taken together, these factors may make parcelization a tougher problem to solve than intactness fragmentation, but both need to be addressed to achieve sustainability at the landscape scale.

Fragmentation at the wildland-urban interface

One driver of habitat fragmentation in North America is the expansion of settled areas. From 1945 to 2007, the US population nearly doubled, but the urban land area increased at almost twice the rate of population growth (Nickerson *et al*. 2011). Between 1940 and 2000, 28 million housing units were built within 50 km of protected areas; 940 000 units were built within national forests (Radeloff *et al*. 2010). Much of this growth occurred where housing is now dense enough and close enough to wildlands – forests, grasslands, shrub lands, and wetlands – to have ecological consequences. This phenomenon is known as the wildland-urban interface (WUI) (Martinuzzi *et al*. 2015).

As of 2010, the WUI of the conterminous US included about 44 million houses, equivalent to one in every three houses in the country (Martinuzzi *et al*. 2015). Not only are the likelihood of wildfires and damage higher in the WUI (Syphard *et al*. 2009), the WUI also has more invasive alien plants (Gavier-Pizarro *et al*. 2010), more pets that disturb or prey on wildlife (Lepczyk *et al.* 2004), and lower quality water in streams due to contaminated storm water from pavements and lawns (Brabec *et al.* 2002). The increased reliance on septic tanks for waste treatment in the WUI can pose risks for groundwater contamination over time. Radeloff *et al.* (2010) noted that if long-term trends continue, another 17 million housing units will be built within 50 km of protected areas by 2030; 1 million within 1 km, greatly diminishing their conservation value. They concluded that housing growth poses the main threat to protected areas in the United States whereas deforestation is the main threat in developing countries. Therefore, analyzing where WUI occurs and related trends over time can shed light on the location and intensity of the consequences of development for natural resources and impacts on intactness of ecosystems and subsequent threats to sustainable provision of ecosystem services.

As urban centers grow, so do suburban and peri-urban areas. Land and housing prices rise as development intensifies, prompting real estate developers and middle-class home owners to buy further out where land prices are lower and homes are more affordable. This development pattern requires more physical infrastructure and expanded social infrastructure, all of which disrupt intactness of natural landscapes and affect wildlife populations. Rural settings, including woodlands, are also scenic and many people prefer them over urban centers as places to live, raise families and spend their leisure time. These lifestyle preferences also influence WUI expansion.

Whether economic or social preferences are the drivers, expanded development in rural settings has an impact. One of the primary set of consequences arises from roadbuilding and expansion of shopping centers. Roads and parking lots fragment intact natural ecosystems. Their impervious surfaces create storm water runoff, often contaminated with oily residues, and require drainage structures to conduct the water into roadside ecosystems and streams. In colder climates, icy and snowy roads are often treated with chemicals which also wind up in roadside ecosystems. Adjoining utility corridors provide overhead wires where birds commonly perch and defecate, spreading seeds of weeds and other species alien to the natural area. Deer-vehicle collisions have risen 50 per cent over the past several decades as urban sprawl has encroached further into deer country (Huijser 2008). In 2000, there were over one million collisions reported in North America between vehicles and deer. Insurance experts believe that the reported collisions are perhaps only 25 – 35 per cent of the actual total. In 2000, these reported collisions caused 225 human fatalities, over 10 000 personal injuries, and over USD 1 billion in property damage. Federal, provincial and state governments, insurance companies, and drivers spend over USD 3 billion annually to reduce or manage the increasing number of deer-vehicle collisions. Beyond deer collisions, there are innumerable collisions with smaller animals.

Beyond the ecological consequences caused by roadways and utility corridors, there are other impacts. For example, public utilities and social services, such as schools, are costlier to provide in low-density development settings (Kramer 2013). In 2007, Baltimore County, Maryland issued the first-of-its-kind county-level "State of Our Forests" report (Outen and Hirsch 2007). Based on the Montréal Process criteria and indicators applied at the sub-state level, this report led the county government to shift its focus from encouraging additional development in peri-urban areas—with its higher costs of providing public utilities and education—to re-developing existing urban areas.

Many of the existing urban areas were first developed over a century ago and in recent decades had experienced economic and social declines—increasing numbers of rundown and vacant buildings. But these developed areas had intact infrastructure—transportation and public utilities, shopping areas, and education and medical facilities. Reinvesting in existing areas, including updating infrastructure, can enhance quality of life and renew economic development at lower cost than fostering more peri-urban development.

The WUI issue presents both land-use and land-cover challenges. In many settings where homes are built in what was formerly productive forest, much of the tree cover is retained because it adds value to the developed property. A proportion of the ecological services, such as sequestering atmospheric carbon or regulating water supply and quality, that the trees formerly provided in forestland continue to be provided by the remaining trees in the newly developed areas. Quantifying changes in ecosystem services resulting from land-use changes remains difficult and not well-understood. Scientific advances on these questions are needed so policy makers can better understand the effects of their development decisions.

2.2.5 Climate change interactions with agriculture and forest land uses

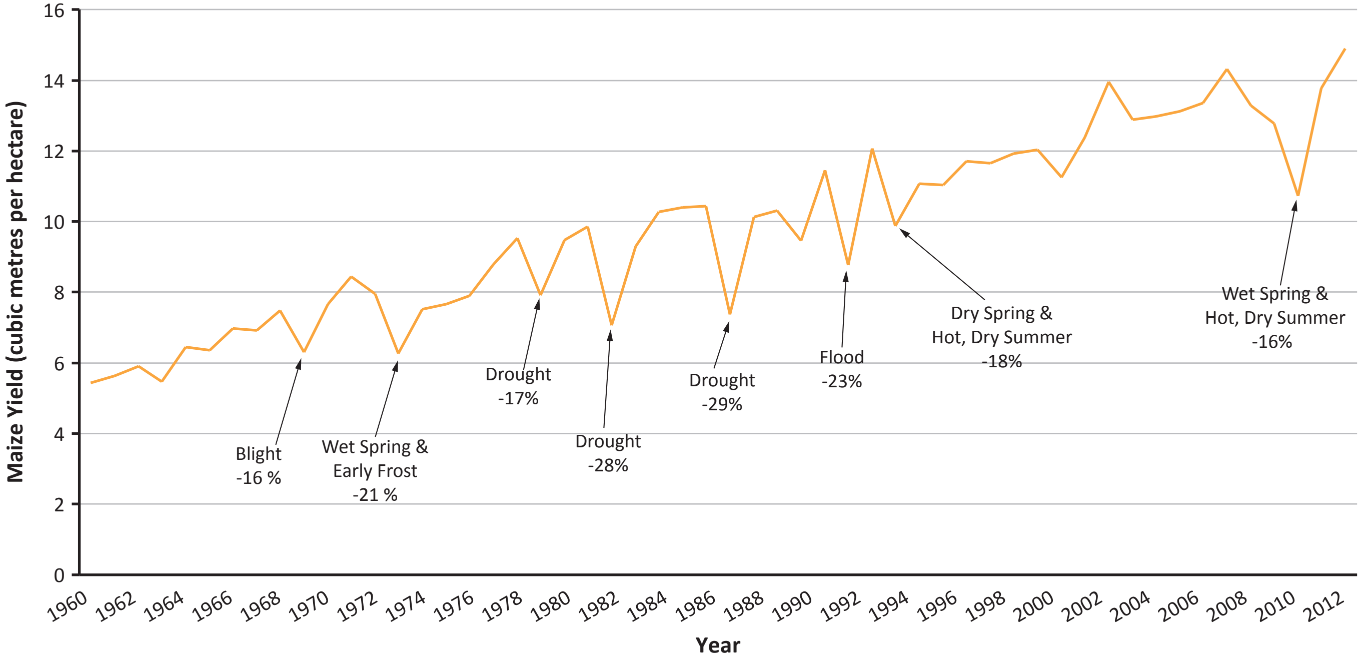
Crops grown in North America are critical for food supplies domestically and around the world. Canadian and US farmers produce more than one-third of the maize and soybeans grown globally, they have over one-third of the global wheat export markets, and they produce nearly one-third of global roundwood harvests. Extreme conditions of temperature and precipitation and the frequency and intensity of other climate-related events have significant impacts on crop yields in North America (**Figure 2.2.9**).

The 1993 flood affected over 1 million km^2 and caused USD 15 billion in damages; half of that was the value of crops lost that year (NOAA 1994). As California enters the fourth year of a drought and millions of hectares in Saskatchewan and Manitoba go unseeded due to excess moisture or flooding (AAFC 2015), there is a growing sense of climate change-induced fragility in North America. The increasing incidence of extreme events and erratic seasonality is exacerbating the adverse impacts of climate change.

Forests are not immune to climate changes either. Evidence is already clear in forest inventories that some tree species are "on the move" (see US Forest Atlas). Iverson *et al*. (2007) found that the species range of nearly half the 134 eastern species modeled will move, some up to 800 km northeasterly in the hottest scenario and highest emissions trajectory. The models suggest a retreat of the spruce-fir zone and an advance of the southern oaks and pines. In reaction to these scientific findings, foresters are already planting some species normally found in warmer places farther north than ever before. Further, natural stand conditions are changing, resulting in species changes—disappearing in some areas and emerging in other places where they haven't been previously. Finally, the past three decades of wildfire history clearly demonstrate that conditions are different today than before 1980. Fire seasons are longer and more land area is burning despite the valiant efforts of wildfire fighters.

More detailed discussion on regional impacts, vulnerability and adaptation to climate change, including in the agricultural sector, is found in Section 2.8 of this assessment (see Climate change). Climate change mitigation responses related to sustainable land management, including crop production and forest management practice, can be found in Chapter 3.

Figure 2.2.9: Maize: US annual average yield (1960-2012) and major climatic events in maize production areas and associated percentage yield reductions below prior year



Sources: USDA 2015 and NOAA 2016

The El Portal Wildfire raging across Yosemite National Park and neighboring Stanislaus National Forest in the July 2014. The fire eventually destroyed nearly 1 900 hectares and caused damages totaling USD 10.6 million.

2.3 Biota – biodiversity and ecosystem services

2.3.1 Introduction

Biodiversity can be defined at three levels, in line with the United Nations Convention on Biological Diversity (CBD): the genetic level, the species level and the ecosystem level. To sustain biodiversity, it must be maintained within and among both species and ecosystems. North America is home to rich biodiversity and a confluence of different ecosystems reflecting its geography, geology, natural history and climate; in fact North America is home to more biodiversity than is widely assumed (Noss *et al*. 2015). At all three levels there has been biodiversity loss and change as the human imprint of development has deepened through industrialization, agricultural intensification, resource extraction, urbanization, the spread of invasive species, fragmentation of habitat, and climate change. At the same time, public awareness of biodiversity-related issues is at an all-time high, and governments at national, state/provincial and municipal levels have implemented a wide variety of recovery and mitigation programmes.

Increasing evidence suggests that biodiversity plays a key role in the provision of ecosystem services, and that threats to biodiversity are also substantive threats to human health, food security and cultural well-being (WHO-CBD 2015; Horwitz *et al*. 2015). Ecosystem services benefit human populations by supplying key ingredients for survival, and are typically divided into four broad categories: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits. North America is home to all of the major categories of ecosystems covered in

Key messages: Biota

North America is home to very rich biodiversity and a confluence of different ecosystems reflecting its geography, geology, natural history and climate.

- An impressive network of well-managed protected areas across North America is in place and is helping to conserve biological diversity.
- While progress has been made to improve the conservation status of many individual species, much biodiversity is at risk in North America, with increasing pressures from land use change, invasive species, climate change, and pollution affecting species, both on land and in the coastal marine environment.
- Resource extraction, particularly for energy production, has been a major driver of land-use change across North America, and restoration efforts are important for both the regeneration of wild spaces and the survival of endangered species.
- At the same time, public awareness of biodiversity-related issues is at an all-time high, and governments at national, state/provincial and municipal levels have implemented a wide variety of recovery and mitigation programmes.
- Regulatory approaches aimed at habitat protection show promise and biodiversity science is very advanced in the region. Continued efforts to integrate traditional ecological knowledge will further benefit conservation efforts.

the landmark collaborative 2005 Millennium Ecosystem Assessment: marine, coastal, inland water, forest, dryland, island, mountain, polar, cultivated (including agricultural) and – often overlooked but increasingly important – urban ecosystems (MA 2005). North America is perhaps unique in its diversity of ecosystems, and Canadian and American citizens have benefitted enormously from this diversity because of the range of ecosystem services they provide.

2.3.2 Species: a broad overview

Although successful recovery programmes have been established for many species, North American biodiversity is on the decline. In Canada, for example, mainly because of habitat degradation and loss, 20 per cent of native amphibians – frogs, toads and salamanders – are considered at risk of extinction. Declines in several amphibian populations since the mid-1990s have been documented in the Great Lakes Basin and the St. Lawrence River corridor; trends for western Canada are not as well documented (Federal, Provincial, Territorial Governments of Canada 2010). A study by the US Geological Survey (USGS) released in 2013 indicated that amphibian populations are declining at *"precipitous rates… from the swamps in Louisiana and Florida to the high mountains of the Sierra and Rockies"* (Adams *et al*. 2013). Similar concerns have been raised about pollinators threatened by habitat loss and fragmentation, pathogens, and the improper use of pesticides, in line with global trends (FWS 2015; Archer *et al*. 2014; Godfray *et al*. 2014; Vanbergen 2014; Potts *et al*. 2010). Pollinator decline has implications far beyond species loss, since pollinators play a key role in many managed and natural ecosystems.

Some recently noted extinctions are in fact less contemporary. In mid-July 2015 the US Fish and Wildlife Service recommended the delisting of the eastern cougar (*Puma concolor couguar*) from the endangered species list, in effect declaring it extinct. The eastern cougar subspecies was listed as endangered in 1973. Accounts suggest, however, that most eastern cougars disappeared in the 1800s as European immigrants killed cougars in efforts to protect themselves and their livestock, forests were converted to agricultural use, and white-tailed deer (*Odocoileus virginianus*), the cougar's primary prey, nearly went extinct in eastern North America. The last records of sighted eastern cougars are believed to be in Maine (1938) and New Brunswick (1932). The delisting is a reminder of the very real consequences of both overhunting and habitat destruction; and the endangered Florida panther may not be far behind, despite successful genetic restoration efforts (Johnson *et al*. 2010).

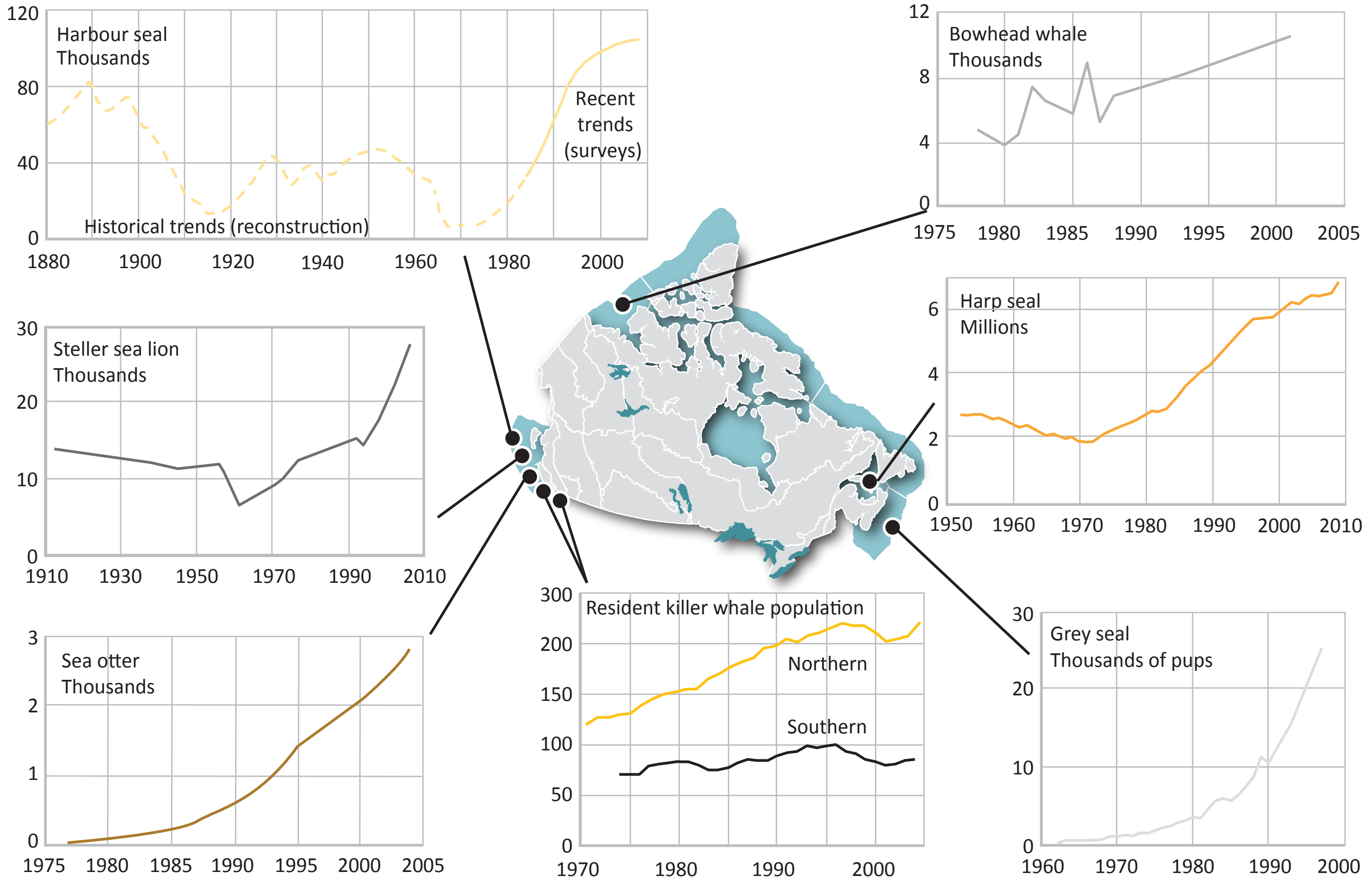
However, there is also a myriad of successful recoveries that are worth emphasizing. The most heralded case may be the American bald eagle (*Haliaeetus leucocephalus*), once considered on the brink of extinction, mainly because of persistent organic pollutants such as dichlorodiphenyltrichloroethane (DDT). Although there are many other causes predating the introduction of DDT, including the removal of important winter foods and habitat change, it is unlikely that this iconic species would still exist today had it not been for continent-wide bans on the use of DDT to control marshland mosquitoes (Gerrard and Bortolotti 2014) and other insects. The recoveries of the grey whale (*Eschrichtius robustus*) from commercial whaling, and of several subspecies of seal, are other examples of the effectiveness of hunting restrictions. **Figure 2.3.1** provides more on other species that have made noticeable recoveries in the Canadian context.

2.3.3 International agreements

The CBD provides an overall framework for addressing biodiversity issues, including species loss, at the international level. All UN member states except the US are Parties to the CBD. Its Strategic Plan 2011–2020 and the associated Aichi Biodiversity Targets provide some very clear targets for reversing losses to species, ecosystems and genetic resources.

Other agreements address specific species or specific threats. For example, there has been some debate on the status of the polar bear (*Ursus maritimus*) in different Arctic countries, including the US and Canada. While the polar bear

Figure 2.3.1: Marine mammals in Canada



Marine mammal populations in North America are recovering from past over-harvesting, including grey seals in the Scotian Shelf and Gulf of St. Lawrence, harp seals in the Gulf of Maine and Scotian Shelf, western Arctic bowhead whales (*Balaena mysticetus*) in the Beaufort Sea, Stellar sea lions (*Eumetopias jubatus*), sea otters (*Enhydra lutris*), and the Pacific harbour seal (*Phoca vitulina*). Resident killer whale (*Orcinus orca*) populations off the coasts of Vancouver Island have also recovered from previous commercial overexploitation but have begun to decline in recent years, possibly related to declines in Chinook salmon (*Oncorhynchus tshawytscha*), an important food source.
Source: Federal Provincial, Territorial Governments of Canada 2010

range states noted that over-harvest was occurring in some regions of the Arctic prior to signature of the 1973 Agreement on the Conservation of Polar Bears, management systems have since been put in place and the harvest is sustainable in most sub-populations across the Arctic (IUCN 2015). The range states agree that the most significant long-term threat to polar bears is climate change. In 2008, the US listed the polar bear as threatened under their Endangered Species Act, noting predicted declines in polar bears over the foreseeable future. Canada declined this move, though it remains (since 2008) listed as a species of "special concern".

All Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) share a common goal of preventing species extinction caused by international trade. However, differing positions are common because the best strategy to protect a species is not always clear, especially when human lives or livelihoods are affected by species trade, or for high-value species in trade. For example, there are differences of opinion on whether the best way to protect elephants from being illegally killed for their ivory is to prohibit all trade in ivory, or to allow controlled legal ivory trade that will feed the demand for ivory and lower illegal market demand. The US, for its part, has championed efforts to reduce the demand for ivory by imposing tight national controls on its trade, and has been a leader in efforts to combat illegal wildlife trade. Controversies at CITES conferences include the proposed Appendix I listing of the Atlantic bluefin tuna (*Thunnus thynnus*), which Canada refused to support despite repeated efforts by many states. Indeed Canada helped persuade the International Commission on the Conservation of Atlantic Tuna to raise quotas in 2014 (Galloway 2014).

There is much room for continental collaboration on species diversity. For example, Canada and the US share many migratory species, such as the monarch butterfly (*Danaus plexippus*), the grey whale, and many species of birds, and this has often served as a catalyst for political action and policy coordination; it is increasingly evident that habitat protection is necessary to ensure the survival of many of these species.

While there is room for improving policy coherence and collaboration between Canada and the US, there are several important bilateral and trilateral agreements on shared species and common biodiversity issues in North America, including the Migratory Birds Convention originally signed in 1916 between Canada and the US (Olive 2014; Waples 2013). This Convention remains an important and active mechanism to protect North American migratory species. Other examples of effective North American collaborative mechanisms include the Commission for Environment Cooperation, which has projects on the protection of habitats (such as grasslands) and species (such as monarch butterflies); the Trilateral Committee for Wildlife and Ecosystem Conservation and Management, which meets annually to address shared interests related to species conservation and shared issues; and the North American Bird Conservation Initiative. There has also been considerable progress in the establishment of transnational networking and scientific collaboration between the two countries (Temby and Stoett 2015).

2.3.4 Key drivers

Urbanization

Urban sprawl is one of the greatest threats to biodiversity in many parts of North America; this is reducing natural habitat in some areas and agricultural biodiversity in others. However, smarter and greener cities are on the horizon: the integration of green spaces, rooftop gardens, urban pollination programmes and other innovations are decreasing the ecological footprint of urban areas and conserving urban biodiversity, which is an often-neglected aspect of ecology. Many cities are newly committed to the theme of resilience, largely as a response to threats associated with climate change. The Rockefeller Foundation's 100 Resilient Cities Challenge, for example, now includes commitments from 18 North American cities (including biodiversity-related commitments), and it is now increasingly accepted that the presence of urban biodiversity enhances human physical and mental health and can meaningfully contribute to human nutrition (Horwitz *et al*. 2015; Hunter 2015; Alcock 2014; Beyer 2014). Evidence suggests that restoring ecosystem services in urban areas also results in demonstrable concrete economic benefits (Elmquist 2015; Goddard *et al.* 2010).

Resource extraction and energy production

Resource extraction, particularly for energy production, has been a major driver of land-use change across North America, and restoration efforts are vital for both the regeneration of wild spaces and the survival of endangered species.

Forestry retains its status as a major employer in both Canada and the US. Although clearcutting is less common, there are still significant threats to biodiversity associated with large-scale forestry operations. In many cases, selective logging and legislation has protected wild species at risk, such as the spotted owl (*Strix occidentalis*), but at costs to the industry and logging communities.

Increased demand for biofuel in Europe has made the US the world's largest exporter of wood pellets. The systemic removal of small sections of the boreal forests of Alberta and Manitoba for the extraction of oil sands has been perhaps the most notable land-use change in North America over the past decade, though this has slowed in recent years due to falling oil prices and the persistence of forest fires. Invasive species, such as the mountain pine beetle (*Dendroctonus ponderosae*), present another threat to forest ecosystems and biodiversity (see Section 2.8; **Box 2.8.2**). Overall, *"Canada's 348 million hectares of forest lands represent about 9 per cent of the world's forest cover, but account for only 0.3 per cent of global deforestation"* (NRCanada 2015).

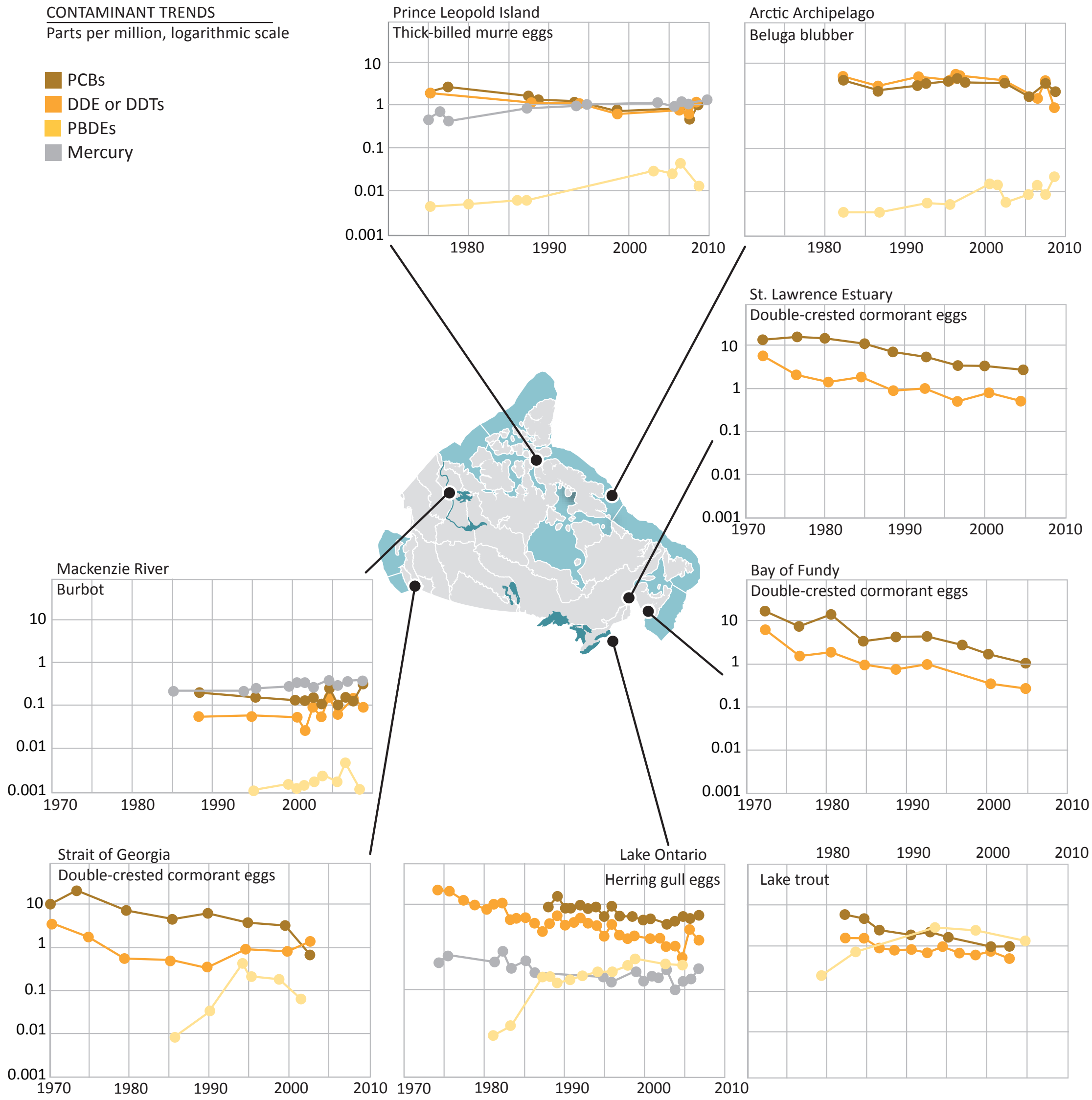
Although some forms of energy generation have a considerably greater impact than others, especially when the compounding effects of climate change are considered, all forms of centralized energy production have an effect on biodiversity, wildlife, ecosystems and surrounding communities (Fthenakis and Kim 2009): oil sands production impacts boreal forests and rivers; hydraulic fracking infrastructure, including wells can disrupt local ecosystem services including water provision; mountain-top coal mining harms fragile ecosystems; offshore oil and gas drilling can threaten marine life; hydropower and large-dam construction contributes to reservoir-linked displacement; wind farms can harm birds (Sovacool 2009); and solar farms can fragment habitat. The creation of power lines and the construction of new roads to sites, essential for most forms of energy production, cause land and habitat fragmentation. But, increasingly, citizens are presented with an array of personal choices regarding their energy sources, and communities are making collective decisions favouring less intrusive energy projects.

Contaminants

Apart from microplastic contamination (see **Figure 2.3.2**), concentrations of legacy contaminants in terrestrial, freshwater and marine systems have generally declined over the past 10–40 years, though mercury levels are increasing in some wildlife in some areas (Braune *et al*. 2015). Fortunately, levels of legacy contaminants – banned or restricted chemicals such as polychlorinated biphenyls (PCBs) – have declined in wildlife in the Strait of Georgia, the St Lawrence Estuary, the Great Lakes, the Bay of Fundy and the Arctic since the 1970s, although rates of decline in some areas have slowed in recent years.

The recovery of peregrine falcons (*Falco peregrinus*) and American bald eagles, after the banning of DDT demonstrates that some species can rebound after the contaminant stress has been lifted. Novel flame retardants and polybrominated diphenyl ethers (PBDEs) are examples of emerging contaminants which have more recently been found to spread through and accumulate in ecosystems. Levels of PBDEs have increased since the 1980s in fish, birds, whales and polar bears (Wolschke *et al.* 2015). Contaminants can directly affect wildlife health and reproduction and increase vulnerability to other stressors.

Figure 2.3.2: Contaminant trends (parts per million on a logarithmic scale), 1970–2010



The charts show a range of trends and levels of two legacy contaminants (PCBs and DDT), mercury, and an emerging contaminant (PBDEs) in wildlife. Amounts and trends are partly related to proximity to contaminant sources and partly to other factors that influence an animal's exposure to and uptake of contaminants, including position in the food web. Magnitudes of contaminant levels should be compared from chart to chart only in general terms – datasets are not all comparable in the types of tissues sampled and in analysis and data reporting methods. Note: DDE is a breakdown product of DDT.
Source: Adapted from Federal, Provincial, Territorial Governments of Canada 2010

2.3.5 Key stressors

Invasive species

Invasive alien species are generally considered the second largest threat to biodiversity after land-use change; beyond predation, a dominant non-native species can seriously alter habitat of others, driving some close to extinction and threatening human economies and ecosystem health (Lodge *et al*. 2006; Pimentel *et al*. 2005). Both intentional and incidental introductions of non-native species into non-native ranges are a by-product of anthropogenic activities. In North America, driven mainly by economic factors (Keller and Perrings 2010), non-native species have been introduced into the Great Lakes Basin at an increasing rate, exceeding one per year between 1959 and 1999 (Dettmers *et al*. 2008).

The population expansion and ecological effects of Dreissenid mussels (zebra mussel, *Dreissena polymorpha*, and quagga mussel, *D. bugensis*) drastically changed the ecosystem in the Great Lakes and caused considerable economic damage to water systems. This particular trend shows no signs of abatement as new alien species continue to be introduced every 9–12 months (Hansen 2010). Notable pathways of introduction of aquatic biota include trade routes, such as the Erie Canal and St. Lawrence Seaway; ballast water releases from shipping; accidental introductions from fish hatcheries; the aquarium trade and live fish markets; the construction of roads and railways for trade and transport; and the culture of non-native bait fish. Meanwhile the US government is spending billions of dollars to prevent the spread of the voracious Asian carp, which have travelled north up the Mississippi River towards Lake Erie. In the West, the infestation of native mountain pine beetle over the last decade was of unprecedented intensity, damaging more than 163 000 square kilometres of forest (Safranyik *et al*. 2010). This expansion has had a tremendous impact on the forestry industry in Canada and the US and reflects the fact that not all invasive species are from distant lands, but due to climate change and other drivers, are encroaching on new areas where they face no natural predators.

Invasive non-native plants are one of the greatest threats to Canada's croplands, rangelands and natural areas. They degrade productivity and biological diversity; they are responsible for significant economic loss, and they affect trade with other countries. Approximately 1 229 (24 per cent) of the 5 087 known plants in Canada are not native. Of these, 486 are considered weedy or invasive. Great strides in the prevention, eradication, and control of invasive plants have been made, and the North American Plant Protection Organization, which derives its authority from the Food and Agriculture Organization of the United Nations (FAO), and a complex network of professional organizations, has worked to limit the spread of popular but invasive plants. Often the result of careless or ill-informed ornamental landscaping, they have also found their way through various trade routes, incidental releases of seeds and intended introductions for agriculture and ornamental horticulture. Well-known invasive plants in North America include various forms of kudzu (*Pueraria spp.*), knotweed (*Fallopia japonica*), the giant hogweed (*Heracleum mantegazzianum*), Dalmatian toadflax (*Linaria dalmatica*), English holly (*Ilex aquifolium*), gorse (*Ulex spp*.), the common water hyacinth (*Eichhornia crassipes*), hydrilla (*Hydrilla verticillata*) and, perhaps most commonly, purple loosestrife *(Lythrum salicaria*). However, it is important to note that invasive alien species do not necessarily destroy ecosystems, but alter them, making it more difficult for other species to co-exist, and in some cases, reduce the human benefits derived from ecosystem services.

Human, livestock and wildlife health may also be threatened by the link between invasive pathogens and the zoonotic and vector-borne infectious diseases they may transmit, such as West Nile or Lyme disease, in humans. In North America, the One Health Approach, which links ecosystem health with human health, is gaining traction and offers a more comprehensive approach to such environmental and anthropogenic triggers driving disease (Karesh *et al*. 2015).

Red lionfish (*Pterois volitans*) in its native range near Gilli Banta Island.

Chinese mitten crab (*Erocheir sinensis*) a marine invasive species.
© Alexander Vasenin

Invasive marine species

In marine ecosystems, a small percentage of species become a serious problem, having major impacts on biodiversity, ecosystems, fisheries, health and economics (Ruiz *et al*. 1997). Marine areas that are already stressed by pollution or that are naturally low in biodiversity appear to be more vulnerable to invasions. As demonstrated by Cohen and Carlton (1998), San Francisco Bay appears to be a particular hotspot for invasions. Which species survive in a new location and which may cause problems, however, cannot easily be predicted – a phenomenon that Carlton and Geller (1993) refer to as "ecological roulette."

Lionfish (*Pterois volitans*), native to the Indo-Pacific and available in the tropical fish trade, were seen in the early 1990s on the Florida coast, and were thought to have been released from aquaria. With no natural predators they are now ubiquitous in nearly all marine habitats in the Atlantic along the southeast US Atlantic coast, the Gulf of Mexico, the Caribbean and on to South America. As shown by Albins (2013), in many areas their densities have surpassed some native reef fish, and they grow larger and more abundant in invaded areas than in their native range; in some areas they now comprise almost half of the total biomass of predators.

They disrupt the structure and function of reef communities and impair commercial fishing and tourism. Since lionfish are ecologically and environmentally damaging, outreach and management strategies have been designed to reduce their populations. Fishing and spearfishing tournaments have been organized, which include education about biology, ecology, impacts, collecting and handling techniques. Lionfish are a desirable dish for many, and populations can be reduced if more people begin eating them (The North Carolina Sea Grant, Coastwatch, published lionfish recipes in their autumn 2013 issue). Markets for juveniles are being developed for the aquarium trade. Puerto Rico exports 200 to 300 juveniles per week to the US aquarium trade, and Florida Keys collectors also remove and sell juveniles. Since developing a market creates pressure to maintain the species as an economic resource, projects aimed at controlling invasive species through human consumption should be examined for both benefits and potential problems.

The green crab (*Carcinus maenas*) is native to Europe and northwest Africa, where it lives on rocky shores, pebble beaches, mud flats and tidal marshes with a wide range of salinity and temperature. It arrived on the US Atlantic coast in the 1800s, probably on ship hulls, and settled from New

Jersey to Cape Cod. Later the crab began moving north, and its arrival in Maine coincided with dramatic declines in the soft clam fishery. Green crabs are a major predator of bivalves, can crack open clams and mussels faster than other crabs, and can out-compete native crabs for food. A second major invasion occurred in 1989 in San Francisco Bay, where the crabs probably arrived as larvae in ballast water or in seagrass or kelp used in shipments of lobsters and bait worms. Grosholz and Ruiz (1995) documented their spread and effects, including losses of up to half of the Manila clams (*Venerupis philippinarum*) in California. As the species continues to move north it is a concern for Dungeness crab (*Metacarcinus magister*), oyster and clam fisheries in the Pacific Northwest.

The Chinese mitten crab (*Erocheir sinensis*), native to Korea and China, is believed to have been accidentally released in the early 1900s in Germany and spread into many European rivers and estuaries, where it feeds on native species and burrows into river banks, often leading to their collapse. It became established on the North American west coast in the 1990s, and is considered a threat to native invertebrates, to the structure of freshwater and estuarine communities, and to some commercial fisheries.

Tunicates (sea squirts) attach to hard substrates, including artificial structures like floating docks and pilings. Some (*Botryllus schlosseri* and *Botrylloides violaceus*) settle on eel grass blades and reduce light penetration, thereby reducing growth and survival of the grasses, which are important habitats for numerous animals. The carpet sea squirt (*Didemnum vexillum)*, which reproduces rapidly and spreads easily, has invaded and overgrown marine communities in New England and mid-Atlantic coasts, as summarized by Lambert (2009).

While the common reed, *Phragmites australis*, is native to North America, a new genetic strain from Europe is a major invader in east coast brackish and freshwater marshes. It out-competes native plants, replacing diverse plant assemblages in freshwater and brackish wetlands. Detritus from Phragmites enters food webs the same way as the detritus from the native Spartina, so it has a similar trophic function. The Atlantic cordgrass (*Spartina alterniflora*), native to the east coast of the US, has been planted elsewhere for coastal protection, but when moved to the west coast it became invasive (Daehler and Strong 1996). It is changing tidal mudflats into dense vegetation, affecting migratory waterfowl, shorebirds and wading birds that forage in the open mudflats. In San Francisco Bay, it has hybridized with native Spartina species. Trends in invasive aquatic species are upwards in the Great Lakes (National Academy of Sciences 2008), Gulf of Maine (Pappal 2010), in freshwater habitats in Rhode Island (Watershed Counts 2014) and elsewhere.

Urban encroachment

Habitat fragmentation was discussed in the previous section on land-use change. The encroachment of urban space into ecosystems remains a key stressor on biota in North America. Radeloff *et al*. (2010) found that in the United States, between 1940 and 2000, 28 million housing units were built within 50 km of protected areas, and 940 000 were built within national forests. Housing growth rates during the 1990s within 1 km of protected areas (20 per cent per decade) outpaced the national average (13 per cent). If long-term trends continue, another 17 million housing units will be built within 50 km of protected areas by 2030 (1 million within 1 km), greatly diminishing their conservation value. US protected areas are increasingly isolated, and housing development in their surroundings is decreasing their effective size; some national forests are even threatened by habitat loss within their administrative boundaries.

Recent work by Flather (2015) looked at songbird species richness and abundance at the interface between protected areas and housing developments. He found that housing developments immediately outside the perimeter of a protected area had an impact on species richness and abundance within the protected area, especially in the perimeter zone. His findings suggest that conservation policy and decision makers seeking to create protected areas to preserve species richness and diversity need to create protected areas large enough so that the edge effects of adjoining land uses do not compromise desired conservation objectives.

Rittenhouse and others (2012) found that changes in species richness and abundance for birds were mainly associated with changes in non-dominant types of land cover, for example grassland or shrubland habitats within an area dominated by forests, or forest patches within an extensive area of grasslands. But in many ecoregions, different types of land cover were associated with species richness than were associated with abundance. Conversion of natural to anthropogenic land cover was more strongly associated with changes in bird species richness and abundance than persistence of natural land cover in nearly all ecoregions. In addition, different co-variates were more strongly associated with species richness than with abundance in 11 of 17 ecoregions; that is, different parameters affected richness rather than abundance. Loss of grassland and shrubland patches affected bird species richness and abundance in forested ecoregions. Loss of wetlands was associated with bird abundance in forested ecoregions. These findings highlight the value of understanding changes in non-dominant land-cover types within a landscape and their association with bird diversity. These results were also consistent with similar findings by Pidgeon *et al*. (2007) regarding expansions of housing development and findings by Radeloff *et al*. (2010), who studied the expansion of developed areas in the wildland-urban interface.

Climate change

All the above and below trends take shape within the context of an increasingly pervasive driver: climate change, caused primarily by anthropogenic emissions of greenhouse gases. Climate change alters habitat, temperature, and phenology, and thus has a direct impact on biodiversity. Scientific evidence for climate-related species migrations emerged in the early 2000s (Walter *et al.* 2001). The biggest concern is that species are in effect losing habitat; this has been predicted for more than half of American bird species (National Audubon Society 2015; Langham *et al*. 2015; Schuetz *et al*. 2015) as migration patterns are being disrupted, and simulations have predicted similar changes in forest composition as the tree lines move north (Scheller and Mladenoff 2005), although it will be more difficult for trees to migrate (Iverson and Schwartz 2004). Chen *et al*. (2011) provide a general model on range shifts of species at least partially induced by climate change.Stewart *et al* .(2015) created a model to assess the potential risk posed to pikas (Ochotonidae) and other climate-sensitive mammals by climate change. Their model matched previous findings and predicted high levels of extirpation of pikas in study sites across California, with the size of areas of rocky debris and summer temperatures being the best predictors of range.

Wildfires exacerbated by prolonged drought on the West Coast have also driven species into new geographic territories; coastal flooding will have a similar effect. Concerns have also been raised about the tropicalization of marine ecosystems, increasing the range of invasive species such as lionfish, in addition to the threats posed by ocean acidification and warming on coral, which cannot migrate and suffer from related ocean acidification and temperature shift events.

Problem areas related to these emerging concerns include changes in the population ranges and dynamics of invasive alien species. This is perhaps the most noteworthy concern, as has been seen with the spread of the mountain pine beetle on the west coast and the alien invasive zebra mussel (*Dreissena polymorpha*) in the Great Lakes region. Higher temperatures and shorter winters lengthen the breeding window of such species and allow them to spread to different regions, where they have fewer or no natural predators. Medical practitioners and veterinarians will also have to be aware of the climate-assisted migration of species posing dangers to humans and livestock. Wildlife diseases caused by non-native pathogens, such as West Nile virus, have killed thousands of birds and potentially threaten many different wildlife species. The link between domesticated and wild animals is important as well: for example, respiratory diseases found in domestic sheep have been linked to population declines of the threatened bighorn sheep (*Ovis Canadensis*) (Wehausen *et al*. 2011).

The long-term impact of climate change in freshwater areas is largely unknown, but indications are that it will have a serious impact on fisheries, the Great Lakes, water provision, and the introduction rate of aquatic invasive species (Kling *et al*. 2003). However, warmer temperatures will also increase biodiversity in many areas, especially in the North; it is the loss of native species in the process that is of primary concern. Higher temperatures are also changing the northern natural landscape as ice melts and methane is released from permafrost, changing frozen peatland ecosystems to wetlands, affecting species and food webs.

2.3.6 Selected key impacts

Grasslands

Another ecosystem facing challenges in North America is grassland, which is essential habitat for several endemic species – such as the pronghorn antelope (*Antilocapra americana*), swift fox (*Vulpes velox*), black-footed ferret (*Mustela nigripes*), black-tailed prairie dog (*Cynomys ludovicianus*), ferruginous hawk (*Buteo regalis*), and greater sage grouse (*Centrocercus urophasianus*) – and, since grasses prevent erosion, is a perfect natural landscape for farming wheat, rye and oats. In North America, the prairies extend throughout the Great Plains area, covering much of the US states of North Dakota, South Dakota, Montana, Nebraska, Kansas, Oklahoma, Texas, Wyoming, Colorado and New Mexico, and the Canadian provinces of Alberta, Manitoba and Saskatchewan. Other forms of grassland ecosystem exist in other North American regions. They have all been subjected to extensive land fragmentation over the past century (Roch and Jaegger 2014).

Grassland losses are significant, even in relation to other major biomes in North America. Most loss in Canada occurred before the 1930s as a result of conversion to cropland. Estimates of total loss prior to the 1990s include 97 per cent of tallgrass/savannah in southern Ontario, 70 per cent of prairie grasslands, by far the largest of Canada's grasslands, and 19 per cent of bunchgrass/sagebrush in British Columbia (Federal, Provincial, Territorial Governments of Canada 2010).

Grassland health has also suffered. Over the long term, changes in natural disturbance regimes due to factors such as fire suppression and confined cattle grazing have had negative impacts on grasslands. Sound stewardship practices in some areas are helping to address the problem. Other stressors include invasive non-native species, forest encroachment, fragmentation, and intensification of agriculture. One group of scientists has concluded that the *"combination of environmental change and diversity loss increases the risk of abrupt and potentially irreversible ecosystem collapse"* and they *"demonstrate this relationship in a degraded but species-rich pyrogenic grassland in which the combined effects of fire suppression, invasion and trophic collapse have created a species-poor grassland that is highly productive, resilient to yearly climatic fluctuations, and resistant to invasion, but vulnerable to rapid collapse after the re-introduction of fire"* (MacDougall *et al*. 2013).

An effort to revive grasslands and support what has been called the 'Buffalo Commons' would convert roughly 360 000 square kilometres of farmland back into native prairie grassland throughout the Great Plains region; this proposal has generated much animated discussion (Popper and Popper 2006). Nonetheless, water shortages, the privatization of prairie lands, the conversion of crops for biofuel (Fargione *et al*. 2009) and other stressors and challenges are on the rise, not decline. The Commission for Environmental Cooperation (Canada, Mexico and the US) has helped organize a Regional Grassland Conservation Alliance for further stakeholder discussion and policy planning.

Salt marshes

Salt marshes, among the world's most productive ecosystems, are inter-tidal coastal ecosystems that are regularly flooded with salt or brackish water, and are dominated by salt-tolerant grasses, herbs and low shrubs. Their stability is mainly controlled by the relative rates of sediment accretion and coastal submergence. Salt marshes stabilize shorelines, serving as natural barriers to coastal flooding, shoreline erosion and wave and storm damage (Costanza *et al*. 2008) as well as removing sediment, nutrients, and other contaminants from runoff and riverine discharge (Gedan *et al*. 2009) – providing more ecosystem services than other coastal environments (UNEP 2006). They also play a large role in the aquatic food web and the delivery of nutrients to coastal waters. They serve as critical habitat for various life stages of coastal fisheries that account for a significant part of the world's fish catch – many of the commercial fish species of the US east coast utilize salt marshes at some time in their life cycle. In addition to providing habitat for juvenile fishes, crabs and shrimp, birds use them as stopovers during migrations, and some birds over-winter in the marshes. Additionally, they play a major role in the global carbon cycle, storing carbon in their sediments, thereby preventing it from re-entering the atmosphere and contributing to global warming (Chmura *et al*. 2003).

For centuries, coastal marshes have been filled in for urban or agricultural development or used as municipal waste dumps. They have been drained, diked, ditched, grazed and harvested, sprayed for mosquito control, and invaded by non-native species. Key threats are land reclamation, coastal development, dredging, sea level rise and eutrophication, all reducing their capacity to provide critical ecosystem services and habitats for numerous species.

Sea-level rise is the largest climate-related threat to salt water marshes. While some marshes can adapt, others, especially ones cut off from sediment delivery by levees and sea walls, cannot (Day *et al*. 1995). Subsidence, which contributes to relative sea level rise in some regions, is an additional stressor. Impacts depend upon accretion and subsidence rates as well as the marsh's ability to migrate inland – coastal squeeze describes the inability of marshes to move inland due to barriers such as paved areas. Current loss of salt marshes is estimated at 1–2 per cent per year (Bridgham *et al*. 2006) making them one of the fastest disappearing ecosystems worldwide. Massachusetts, US, has lost 41 per cent of its salt marshes since the American Revolution, with a loss of 81 per cent in Boston (Bromberg and Bertness 2005), while today Louisiana is said to lose an area of marsh the size of a football field every hour.

Marine biodiversity

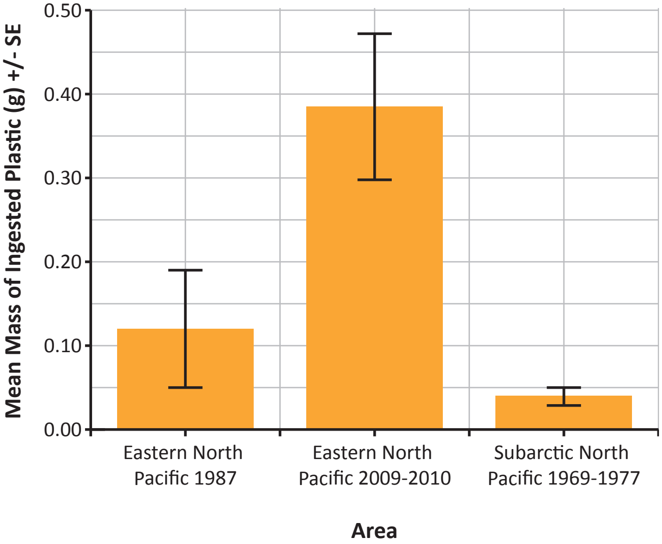
North America's marine biodiversity faces significant threats, although recent initiatives have resulted in comparatively large areas dedicated to conservation. Monitoring continues of the impact of high-profile disasters such as the BP 2010 oil spill in the Gulf of Mexico, which had a deleterious impact on wildlife such as turtles, squid and shrimp. But most drivers of biodiversity loss in marine areas, including marine mammals and birds, are less sudden but equally damaging. The 2015 *Living Blue Planet Report* (WWF 2015) indicates that global populations of marine vertebrates declined by 49 per cent between 1970 and 2012, with some fish species declining by almost 75 per cent. The report shows steep declines in coral reefs, mangroves and seagrasses that support marine food webs and provide valuable services to people. The biggest drivers of these declining trends are from human activities: overfishing, habitat destruction and climate change. The report also suggests solutions and opportunities to improve the situation by protecting critical marine habitats, managing fish stocks more sustainably, improving fishing practices, and redirecting funds to support these initiatives.

Marine protected areas (MPAs) with limited fishing are one possible mechanism for protecting diversity. Caselle (2015), studying the reserves in the Channel Islands off the coast of California, found that after the first five years of protection, fish species targeted by fishermen had both greater density, measured in numbers of fish per area, and biomass, measured in total weight per area, inside MPAs compared with reference sites outside, and this was still true in 2013. In addition, fish stocks outside the MPAs increased over time, although more slowly. It is not known if the population increases outside the MPAs are due to reduced fishing pressure, spill-over from MPAs, favourable environmental conditions or a combination of all three.

An emerging threat to marine biodiversity is the accumulation of plastics in oceans, lakes, and rivers. While this problem has been acknowledged for many years in the context of the oceans, recent findings indicate disturbing levels of plastic microbeads in the Great Lakes and St. Lawrence Basin (Provencher 2014; Johnston 2013). Remote Arctic sea ice has already been found to contain high concentrations of microplastics, and the extent to which melting ice will release anthropogenic particulates into the ocean is not yet fully known (Obbard 2014). Microplastics have entered the food chain; they are regularly ingested by fish, birds (**Figure 2.3.3**) and marine mammals, and toxic bioaccumulation and, in some cases asphyxiation and starvation, often result. Microplastics emerge from a variety of sources, including microfibres from clothing put through washing machines, microbeads in body wash, shampoo, and toothpaste, the photodegradation of plastic bags, debris from car tires, and others. After several states, including Illinois, New Jersey, Wisconsin and California, moved towards phasing in a ban on microbeads in personal care products, the US government passed a law in late 2015 banning them nationwide, and the Canadian government appears prepared to take similar action. In the meantime, several large cosmetics firms have voluntarily declared they will stop using them in their products (See also discussion of marine plastics in sections 2.5.4 and 2.6.1).

Fertilizers from agriculture, phosphates from detergents and industry, and sewage from towns and cities add nutrients to aquatic systems, sometimes causing algal blooms. In recent years, algal blooms have been reported in lakes, reservoirs, ponds, rivers, swamps and estuaries in both Canada and the US. Some past successes in nutrient reductions, particularly in the Great Lakes, are now being reversed as nonpoint source runoff from growing population increases. Over the past 16 years, nitrogen has increased in 28 per cent of water bodies sampled and decreased in 12 per cent, while phosphorus has increased in 21 per cent and decreased in 29 per cent. Although harmful marine algal blooms occur naturally, they appear to be increasing in their prevalence and impacts, especially in the oceans off North America's coasts (Lewitus *et al*. 2012). In the summer of 2015, for example, a record-breaking toxic algal bloom spread from the Aleutian Islands to southern California, threatening wildlife and forcing some fisheries to close; unusually warm ocean temperatures are suspected.

Figure 2.3.3: Plastics ingested by seabirds, 1969–2011



Plastics found in the digestive tracts of dead northern fulmars (*Fulmarus glacialis*) in the North Pacific, Canada 2011.
Source: Avery-Gomm *et al*. 2012

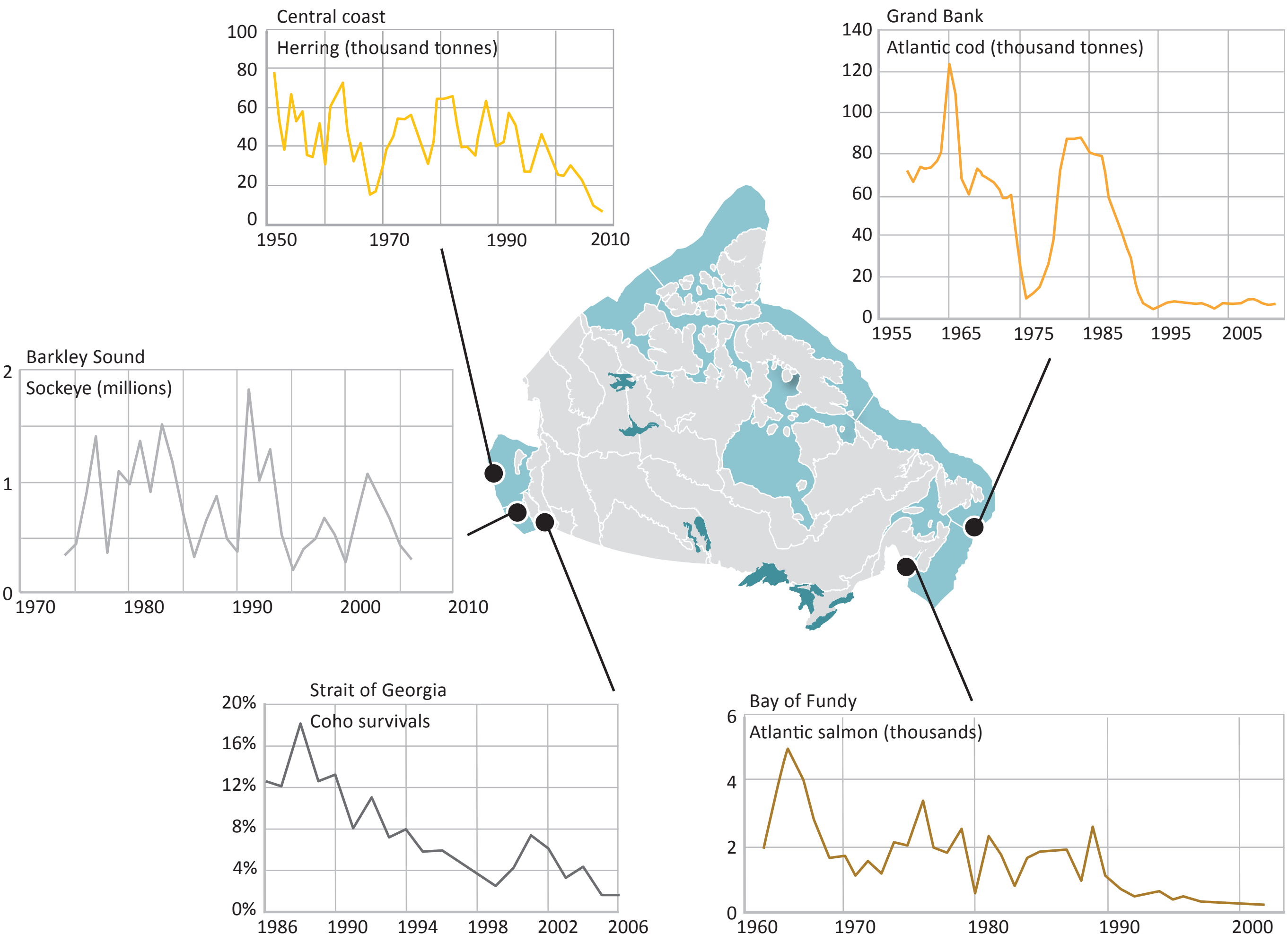
Overexploitation, combined with other stressors such as increased temperature, decreased salinity, and increased acidity, have contributed to declines in some fish stocks in both oceans and the large northern bays. "*Declining stocks include groundfish, such as Atlantic and Pacific cod, lingcod and rockfish, pelagic fish such as herring and capelin, and anadromous fish such as coho, Chinook salmon, Atlantic salmon, and Arctic char. Management measures designed to reverse longterm fisheries declines have been largely unsuccessful. Depending on the fishery, rebounds have been hampered by large-scale oceanographic regime shifts, loss of spawning and rearing habitat, and contaminants*" (DFO 2010). Some fisheries are in recovery mode, such as turbot (*Scophthalmus maximus*), sablefish (*Anoplopoma fimbria*) and Pacific sardine (*Sardinops ocellatus*) in the West Coast

Vancouver Island Ecozone, and pink and chum salmon (*Oncorhynchus gorbuscha* and *Oncorhynchus keta*) in the Strait of Georgia.

Marine fisheries

In the US the National Marine Fisheries Service (NMFS), a division of the National Oceanic and Atmospheric Administration (NOAA), is responsible for the stewardship of the nation's living marine resources and their habitat within the Exclusive Economic Zone (200 nautical miles or 370 km from the coastline). NMFS assesses and predicts the status of fish stocks, and conserves and manages marine fisheries to promote sustainability and prevent overfishing, declining

Figure 2.3.4: Trends in selected fish species, 1950–2010



Source: Federal, Provincial and Territorial Governments of Canada 2010 species, and degraded habitats. Eight regional fisheries management councils set the catch limits for particular species. Coastal states generally manage fisheries within near-shore state waters. The 2006 amendments to the Magnuson-Stevens Fishery Conservation and Management Act provided new guidance on programmes addressing fishery conservation and reduction of overcapacity. Provisions mandating catch limits and catch accountability have improved fish stocks. Even though seafood consumption is increasing in the US on a per capita basis, NMFS data indicate that over 80 per cent of the nation's fish stocks are already at sustainable levels, with some yearly variation (NOAA 2007).

Fishing is affected by fluctuations in fish abundance. Fisheries managers require high-quality observations and well-supported predictions about species status and abundance; biological, economic and social science data are needed to set catch limits. Concerns arise if the data are insufficient for managing marine fisheries sustainably. Understanding and modeling fisheries and ecosystems at an acceptable level of certainty requires a broader understanding of ecology than has been addressed by traditional, single-species fishery management. Ecosystem research and analyses is forming the basis for new analytical models and assessments of ecosystem status to predict impacts of various fishing strategies. Ecosystem-Based Management assessments include habitat protection and multi-species interactions. For example, attention is being directed towards the status of forage fish populations, such as menhaden, that comprise a significant part of the diet of desirable larger fisheries species (MFCN 2015).

In both the US and Canada, there is considerable concern about the failure of Atlantic cod in the Gulf of Maine to recover after the once-plentiful population crashed in the early 1990s. In 2010, the fishery moved to a quota-based "catch share" management system which has been effective on the West Coast and which should have ended overfishing and brought about recovery, but the biomass has continued to decline; it was estimated in 2014 at just 3-4 per cent of sustainable levels. Despite strict catch limits, cod have not rebounded and fishery workers have suffered economic consequences. One reason for the failure to recover is the changing climate. The Gulf of Maine is near the southern limit for cod, and as the water warms, it becomes less suitable. Many juveniles appear to be dying before reaching adulthood. Pershing *et al.* (2015) suggest this could be in part due to an increase in predation on young cod. Warmer waters mean an earlier spring and a later fall, which could result in more migratory predators present in the region for a longer duration each year (Pershing *et al.* 2015).

The domestic aquaculture industry provides only 1.5 per cent of the US seafood supply, while foreign aquaculture contributes an increasing proportion, particularly of shrimp, salmon, tilapia and a variety of mollusks (NOAA 2007). An expanded North American aquaculture sector is desirable but brings with it specific health and environmental risks that need to be addressed, including the spread of diseases to wild fish and increased marine debris.

Freshwater fisheries

Fishing for commerce and sport is very common across North America. Freshwater fish from rivers and lakes is a subsistence food for some North Americans, and the Great Lakes fishery industry generates substantial revenue (it is hard to obtain an accurate estimate of the overall value of the fishery, but it is certainly in the hundreds of millions of dollars range). Pollution, overfishing, and invasive species have dramatically altered the genetic biodiversity of the Great Lakes fish fauna: over the past two centuries 18 native species have been extirpated, and over 61 species are presently considered threatened or endangered (GLFC 2015). Long term threats include the possible introduction of the dreaded and voracious Asian Carp into Lake Superior, the impacts of climate change, and continued accumulation of microplastic and other particles in the food chain. A wide variety of fish are taken from each lake for commercial purposes. For example, NOAA statistics from 2013 indicated that the species in **Table 2.3.1** were successfully landed in Lake Erie, where the threat of Asian carp invasion is most immediate.

Table 2.3.1: Species successfully landed in Lake Erie, 2013

Species name	pounds caught	US dollars
Bigmouth Buffalo	379 084	194 116
Brown Bullhead	50 796	14 623
Burbot	1 119	1 546
Carp	402 925	109 089
Channel Catfish	564 070	225 006
Freshwater drum	526 894	121 183
Gizzard Shad	41 246	8 028
Goldfish	103 685	73 490
Lake Whitefish	63 940	95 729
Minnows	23 735	80 224
Quillback	284 375	83 595
Rockbase	129	0
Smallmouth Bass	111	0
Suckers	28 790	3 613
Walleye	271	925
White Bass	741 959	420 384
White perch	659 216	225 392
Yellow Perch	1 547 199	2 973 980
Total	5 419 544	4 630 923

Source: NOAA 2015c

Recreational fishing is also a major, multi-billion dollar industry across North America, though there are indications interest in this activity is slowly declining, and recreational fishing is generally highly regulated at the state and provincial levels (Arlinghaus *et al*. 2015).

Threats to rivers and lakes, invasive species, and overfishing have put many species of fish at severe risk. According to the US Geological Survey, between 1898 and 2010, 57 North American species and subspecies and three unique populations have gone extinct (3.2 per cent of total known species); the rate of extinction is estimated at 877 times the background extinction rate over geological time (Burkhead 2012). It is clear that determined efforts and extensive policy coordination is necessary to avoid serious negative outcomes in North American fish biodiversity. The Great Lakes Fisheries Commission is an example of such cooperation in action.

2.3.7 Research

North America is clearly a world leader in biodiversity science, reflected in extensive transnational networking. The Quebec Centre for Biodiversity Science, for example, now has more than 110 professional researchers and over 700 graduate students and post-doctoral fellows in its network. Similar networks exist across the continent and help generate well-informed public debate. Modern technology enables very sophisticated mapping of ecosystems, biodiversity, invasive species and other key factors, which can be used for risk analysis, green corridor construction and other imperatives. Big data collections and shared information will not only advance North American efforts but will contribute to global understanding of biodiversity conservation. Citizen science is also highly encouraged in the biodiversity sector, and new mobile phone apps make it easier for people to report wildlife activity and identify invasive species.

Canada continues to host the Secretariat of the CBD, which is the leading UN organization for biodiversity conservation. Many experts hope that the US will join the CBD as a Party to the Convention instead of simply maintaining its current position as an observer. However, some critics argue that there has been reluctance on the part of governments to fully engage in the research and development needed to advance biodiversity and environmental science. For example, much to the dismay of scientists across the country, the Canadian Federal Government withdrew funding for the Experimental Lakes Area in Ontario, one of the few places on Earth where scientists were able to conduct holistic research on lake ecosystems. The Ontario government and the International Institute for Sustainable Development (IISD) are, however, working to maintain the area, and the newly elected Canadian government has promised to make new investments into what is now known as the IISD Experimental Lakes Area (**Box 2.6.1**).

2.3.8 Conclusion

While biodiversity conservation remains a serious challenge in the North American context, there are many positive developments that give ample cause for hope. Public awareness is high, and the level of scientific expertise is perhaps unparalleled.

There is a growing recognition that a holistic approach to environmental and human health is necessary, reflected in developments such as the One Health Approach. The number and size of protected areas is on the increase. Organic farming and urban agriculture are both expanding, opening new space for incentive-based government policies.

However, extinction is on the horizon for many species as contaminants, land-use change, invasive species, and altered climatic conditions continue to take their toll on indigenous flora and fauna. There are genuine concerns that the ecosystem services currently taken for granted, such as natural waste processing and the provision of natural remedies, could reach pressure thresholds in the future, especially if urban infrastructure is not considerably updated and improved for efficiency and effectiveness. Though there are a few promising exceptions, the need for reduced fragmentation of habitats and greater connectivity between protected areas is not being met. Adjustments to North American lifestyle and production methods are necessary, part of the bigger picture of moving towards a post-industrial economy and society.

2.4 Freshwater

2.4.1 Introduction to water issues in North America

North America contains 13.2 per cent of global renewable freshwater resources (FAO 2014). Most communities in North America are generally recognized as having safe and reliable access to water at an affordable cost, with some exceptions, including in rural areas and on certain tribal lands in the US. However, water security in the US and Canada is quite high currently, due to the infrastructure and treatment available to mitigate the effects of variable water flows and pollution (Vörösmarty *et al*. 2010). The relatively high quality of water in North America contributes to relatively good public health, and North Americans have some of the lowest rates of water-borne disease in the world. There are some areas of the region for which safe and reliable sources of drinking water are threatened, in particular rural communities dependent on shallow aquifers that are increasingly contaminated by nitrates, and many of Canada's indigenous communities (Daley *et al.* 2015; CCA 2013, CCA 2014). The long-term sustainable supply of freshwater for irrigation, industry, and municipal uses is also undermined by reliance on groundwater sources that are being depleted and contaminated, and the increasing threat of drought and water scarcity in arid regions.

North America uses substantially more water per person than any other region in the world, although recent trends indicate that water withdrawals are declining even with population and economic growth.The average North American's awareness of water security has been enhanced by media coverage of the drought moving through the US South and West over the last decade. Segments of the agricultural economy, particularly west of the 100th meridian, are dependent on unsustainable withdrawals of water from ancient and slow-to-recharge aquifers and increasingly depleted surface water systems. Depletion of aquifers also reduces the base flow in perennial streams, resulting in the degradation of important freshwater aquatic systems. Quantities and recharge rates of groundwater remain poorly understood, complicating an ability to ensure sustainable use and avoid contamination of this important water source. In the Southwestern US, communities are also highly dependent on reservoir storage that is vulnerable to contamination associated with watershed development and evaporation fueled by climate change.

Projections show that disparities between demand and supply will become more severe with population growth, increasing economic aspirations, and climate change. Similar economic and food security consequences extend globally.

Most of the water quality issues in North America affect aquatic life and recreational uses of surface waters (see

Key messages: Freshwater

Most communities in North America, with some exceptions, are generally recognized as having safe and reliable access to water at an affordable cost.

- Legislation enacted in North America in the early 1970s has led to effective control of point sources of surface water pollution and ensure the delivery of safe drinking water to most communities in the region.
- While drinking water quality is in good condition in general, some drinking water infrastructure is aging and is in need of investment. Negative trends are chiefly the result of degraded infrastructure and weak governance. These isolated water quality incidents threaten human health, in some cases acutely.
- Water security in Canada and the US is generally quite high, due to the infrastructure and treatment available to mitigate the effects of variable water flows and pollution.
- However, the long-term sustainable supply of freshwater for irrigation, industry, and municipal uses is undermined by reliance on groundwater sources that are being depleted and contaminated, and the increasing threat of drought and water scarcity in arid regions.
- In some areas, legacy, persistent, and emerging freshwater contamination problems are perpetuated by historic and ongoing activities, including diffuse nutrient runoff and new industrial activity.
- Freshwater fisheries are well-regulated in the Great Lakes region and are generally controlled across North America, but face challenges due to factors such as climate change, population pressure, and pollution.

Box 2.4.1), although there are also increasing concerns about contamination of groundwater resources associated with the oil and gas industry. Non-point sources remain the largest source of pollutants, especially nutrients, to North American waters and contribute to the degradation of important coastal areas such as the Gulf of Mexico and the Chesapeake Bay.

2.4.2 Water quantity

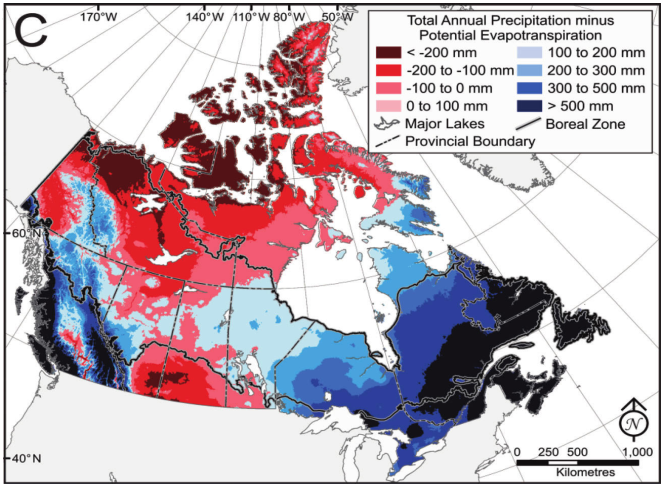
The distribution of freshwater resources across North America is uneven. Generally, the West and far North are quite arid, experiencing more evapotranspiration than precipitation (**Figures 2.4.1a** and **2.4.1b**). The coastal areas of the region are generally wetter, as is much of the eastern half of the region. The water issues faced in North America, therefore, also vary across the region.

Water use and withdrawals

Approximately 500 billion cubic meters of water are withdrawn from North America's rivers, lakes, and groundwater every year (EC 2015d; Maupin *et al*. 2010). North Americans use more water per person than any other region in the world (UNEP 2012). However, North America has made some progress in water use as a result of increases in efficiency, conservation efforts and other sector-specific technological changes.

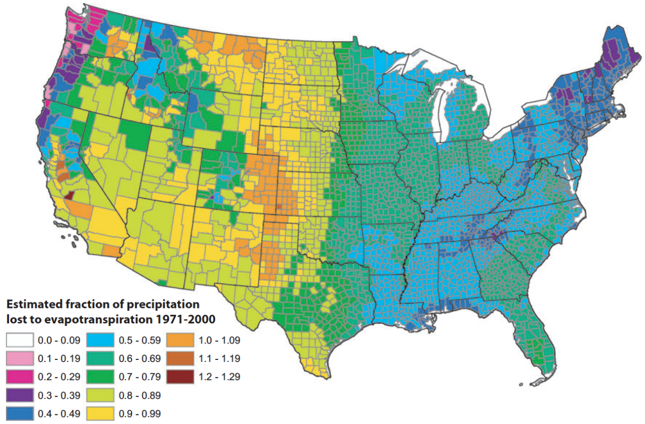
Total water withdrawals in the US declined by 13 per cent between 2005 and 2010, following a relatively stable period between 1985 and 2005, with the largest reductions in water used for thermoelectric power, irrigation, municipal supply and industry (Maupin *et al*. 2010; **Figure 2.4.3**). A similar pattern occurred over the same period in Canada with total

Figure 2.4.1a: Canada, total annual precipitation minus potential evapotranspiration, 1971–2000



Source: Webster *et al.* 2015

Figure 2.4.1b: US, total annual precipitation minus potential evapotranspiration, 1971–2000



Source: Sanford and Selnick 2012

withdrawals declining by 7 per cent (Environment Canada, 2015d; **Figure 2.4.4**). In Canada, much of the reduction was associated with decreases in manufacturing production between 2005 and 2009.

The largest increase in withdrawals in the US, 39 per cent between 2005 and 2010, occurred in the mining sector, including large increases in water use for oil and gas extraction. This trend has continued since 2010 with the recent expansion of hydraulic fracturing (fracking) technology used to drill horizontal wells. Although the total water use required for fracking varies widely across the US, from less than 100 to more than 30 000 cubic metres per well (**Figure 2.4.5**; Gallegos *et al*. 2015; Wade *et al*. 2015), the median water used in drilling horizontal oil and gas wells increased from 670 to more than 15 000 cubic metres per well between 2000 and 2014. Studies by Nicot and Scanlon (2012) quantified water use for fracking in Texas by shale play, and found that it was increasing and was projected to continue to increase until around 2020. However, they suggest that brackish water will replace fresh water over time.

While Canada separates water withdrawal statistics from water consumption, the collection of consumption data in the US is complicated by many factors, including type of use, reporting factors, climate and temporal weather factors and geographic location. The distinction is important because the impacts of consumptive water use – the portion of water use that is not distributed to other economic units and does not return to the environment – are significantly different from the impacts of water withdrawn and returned to the environment. In 2009, Canada's consumptive water use was less than 10 per cent of the total water withdrawn. Significantly, a recent report by the Electric Power Research Institute (March *et al*. 2014) developed new algorithms for predicting freshwater consumption in the thermoelectric power, municipal and agricultural sectors of the US; these sectors account for 90 per cent of the country's freshwater withdrawals. Areas with the largest water consumption volumes include California, the eastern Pacific Northwest, the Lower Colorado Region, and parts of the region overlying the Southern High Plains (Ogallala) Aquifer (New Mexico, Texas, and Oklahoma). The total volume of consumption

Box 2.4.1: Great Lakes water quality index scores in Canada, 2014

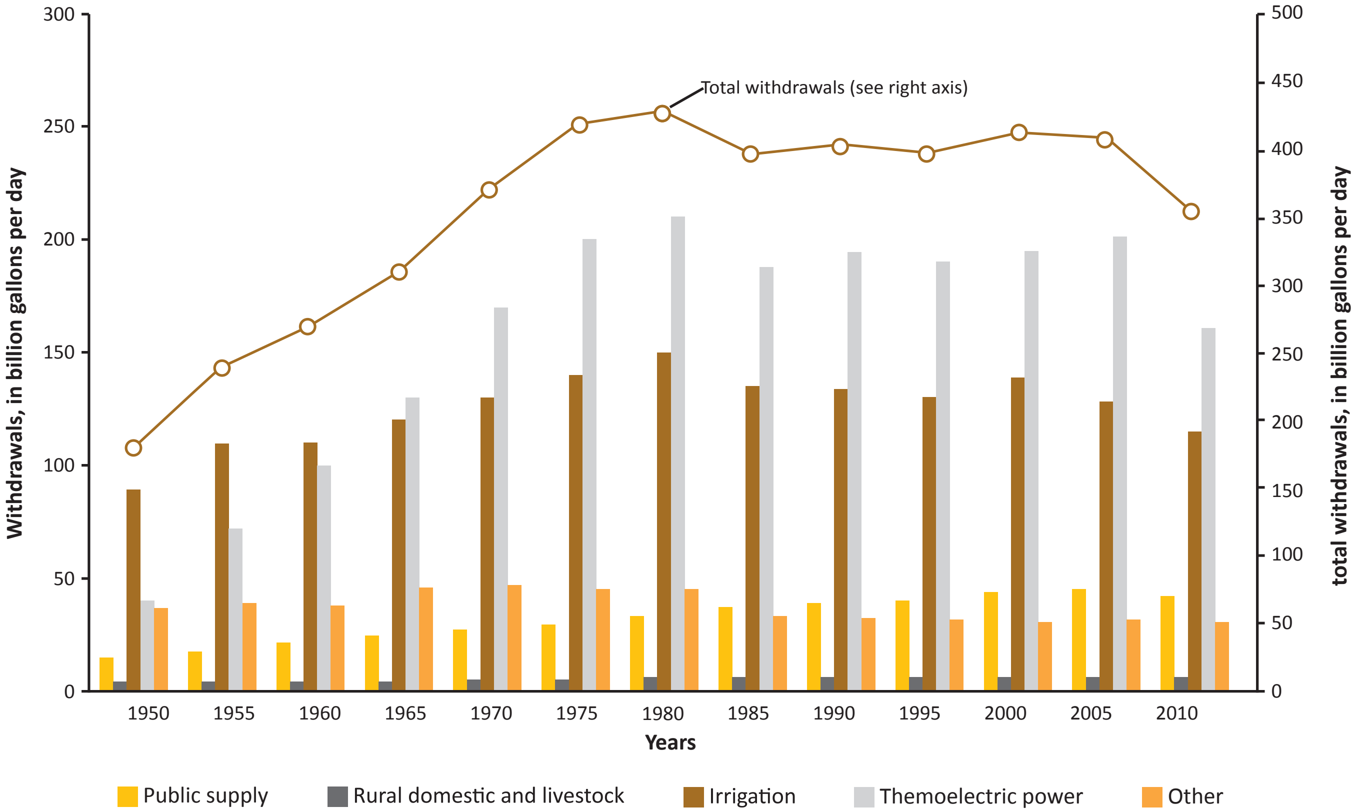
The largest freshwater resources in the region are the Great Lakes, the management of which is shared between Canada and the US. The Boundary Waters Treaty of 1909 provides principles for using the waters shared by Canada and the US, and created the International Joint Commission (IJC) to help prevent and resolve water-resource and environmental disputes between the two countries through processes that seek the common interests of both. Under the treaty, the construction of any project that affects the natural level and flow of water across the boundary must be approved by both the responsible government and the IJC. Alternatively, the two federal governments may reach separate agreements regarding such projects. The treaty also allows the governments to refer issues of concern along the boundary to the commission for investigation and report, but the IJC reports are advisory and not binding on the governments (IJC 2015). The IJC also supports a number of initiatives related to water quality and management, including the Great Lakes Water Quality Agreement 2012 and the International Watershed Initiative. Because of the size of the Great Lakes, reductions in pollutant loading may take years to show measurable improvements in water quality. In addition, the Great Lakes, like many waters in North America, continue to be threatened by legacy pollutants which continue to be detectable in offshore waters of the Great Lakes at low concentrations, despite efforts to reduce them across the watershed. As an indicator of water quality, toxic chemical concentration was considered to be fair but overall trends were undetermined due to a combinations of reduction in the concentrations of some legacy chemicals (e.g., organochlorine compounds) with mixed trends for others (e.g polycyclic aromatic hydrocarbons; current-use pesticides, total mercury) (Environment Canada and US EPA, 2014). Contaminants in fish and waterbirds show varying trends. For example, total mercury concentrations in fish, while still below 1987 Great Lakes Water Quality Agreement guidelines, appear to be increasing in some of the Great Lakes. Conversely, concentrations of penta-PBDEs are above Canadian federal environmental quality guidelines values, but appear to be declining. PCBs in fish are above 1987 Great Lakes Water Quality Agreement guidelines. The concentrations of some banned pesticides and related products (e.g., DDT, DDE) in herring gull eggs are declining relative to their concentrations in the 1970s and 1980s, but some other contaminants show no trend (Environment Canada and US EPA 2014).

Figure 2.4.2: Great Lakes water quality index scores in Canada, 2014

Source: Federal, Provincial Territorial Governments of Canada 2010

State and trends

Figure 2.4.3: US water withdrawals from all sources, 1950–2010

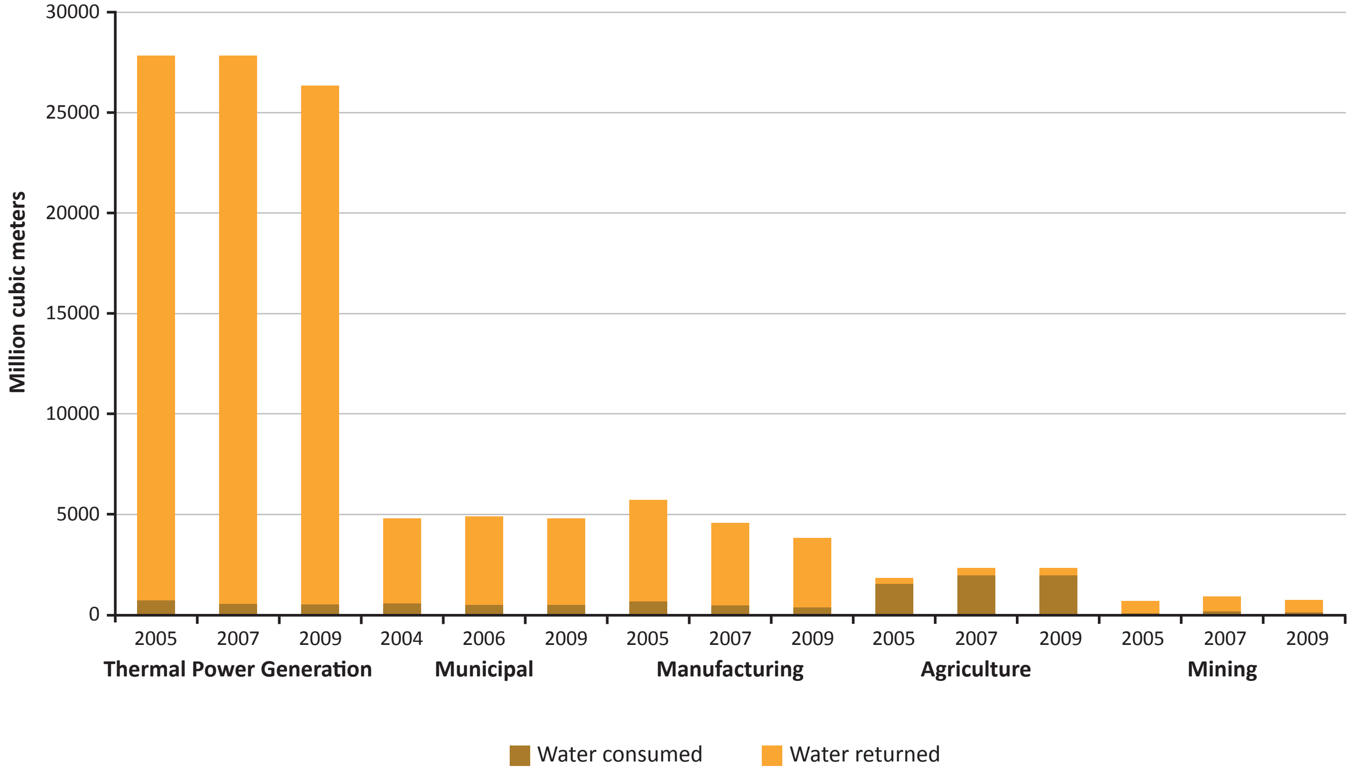


Source: USGS 2012

calculated (**Table 2.4.1**) was 79 800 MGD, 23 per cent of total withdrawals, and may approach 455 million cubic metres per day when irrigation conveyance losses to evaporation are included.

The thermoelectric sector withdraws the largest volume of water in the region. Many power plants constructed before 1980 use a once-through cooling system that is much more water intensive than recirculation or dry cooling systems, that are more common in power plants constructed more recently (US EIA 2014). Most new plants use either recirculation (predominant) or dry cooling instead of once-through cooling. Construction of recirculating systems peaked between 2000 and 2004 (US EIA 2014). These trends, along with shifts to low/no water use renewables, are helping to reduce consumptive water use in power production. An earlier report by Torcellini (NREL 2003) estimated aggregate water evaporated at thermoelectric plants to be between 1.7 litres per kilowatt hour and 68 litres per kilowatt hour, with 7.6 weighted litres per kilowatt hour evaporated, at hydroelectric plants (EPRI 2014). Increases in evaporation for lake-based systems over free-running river systems are considerable, particularly for lakes in arid regions such as Lake Mead and Lake Powell (Torcellini *et al.* 2003). This

Figure 2.4.4: Canada water withdrawals, 2005, 2007 and 2009



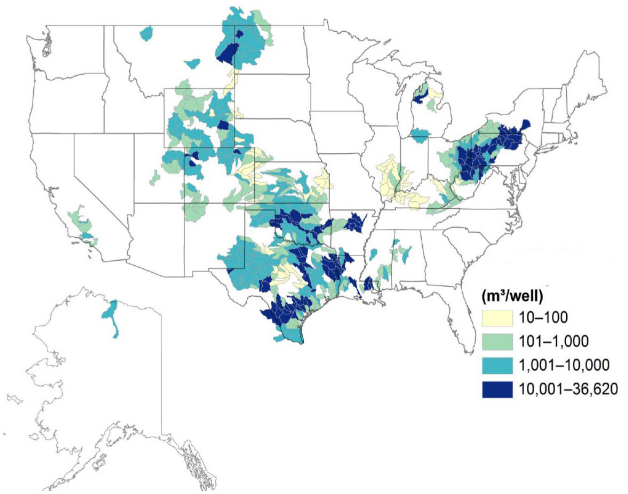
Source: Environment Canada, Canadian Environmental Sustainability Indicators 2012

analysis also did not include the drought occurrences of the last four years in California, Texas and the desert Southwest (approximately from 2011-2015).

The agricultural sector is the largest consumptive user of water. Although irrigation withdrawals declined across the region due to a shift to more water-efficient systems, consumptive use of water in the agricultural sector increased during the same period in Canada and experts believe is likely to have also increased in the US. The use of water-efficient irrigation technologies, for example sprinklers instead of flood irrigation, results in increased consumptive water use because of increases in evapotranspiration-related losses (EC 2015; Water Withdrawal and Consumption by Sector; see **Figure 2.4.6**).

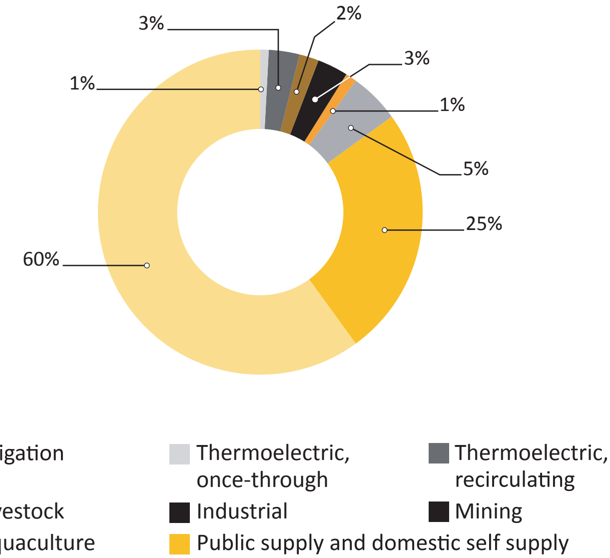
The proportion of water withdrawn from groundwater, compared to surface water, has increased substantially across North America in recent years. The US pumps about 1.32 trillion cubic metres per year of groundwater for drinking, irrigation and industrial uses (Kenny *et al.* 2009 cited in DeSimone *et al.* 2014). Indeed, groundwater provides one-third of the water used for public supply and has increased fourfold since 1955 (DeSimone *et al.* 2014) as

Figure 2.4.5: Fracking water use in the US, 2011–2014



Source: USGS 2016

Figure 2.4.6: US water consumption by sectors, 2005-2009

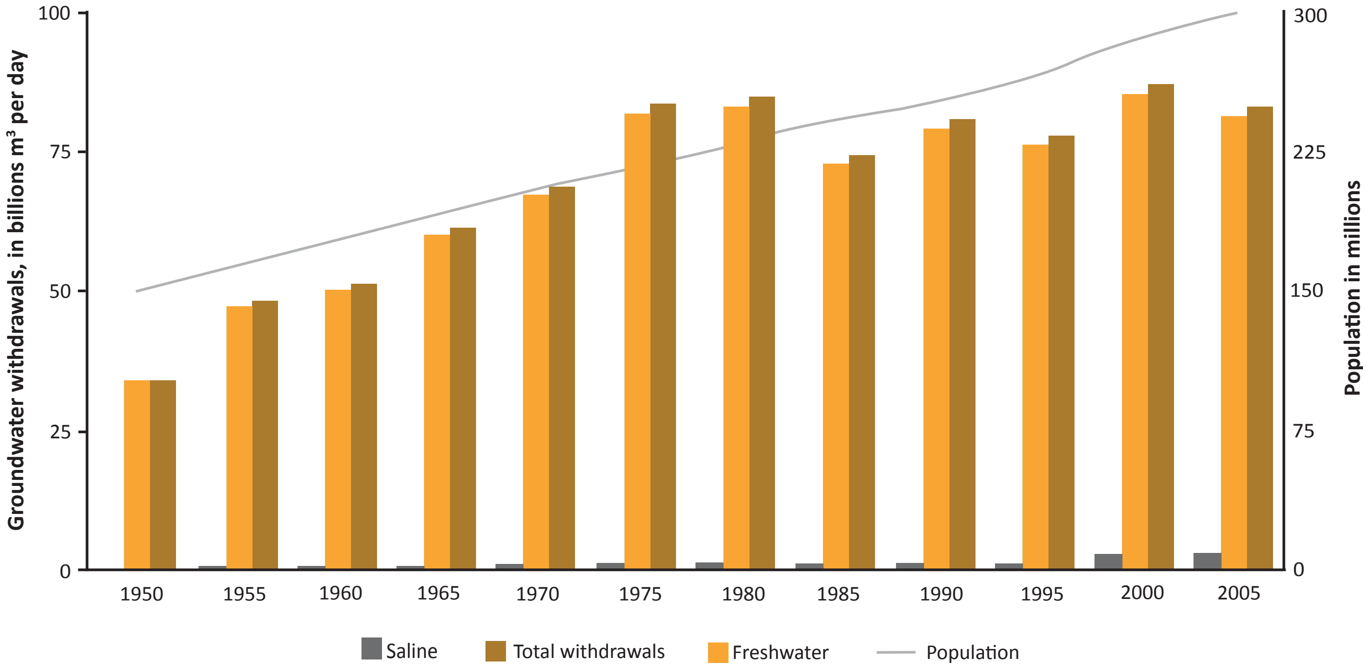


Source: EPRI 2014

Table 2.4.1: Summary of water withdrawals and consumption across all major sectors in the US in 2005

Water use category, 2005	Data source (withdrawal)	Withdrawal (million m³ per day)	Consumption (million m³ per day)	Consumption (withdrawal %)
Public Supply and Domestic Self-Supply	USGS, Kenny *et al*. 2009	213.70	89.91	27.5
Irrigation	USGS, Kenny *et al*. 2009	581.90	216.85	37.3
Thermoelectric, once- through	EPRI 2014	611.90	5.46	0.9
Thermoelectric, recirculating	EPRI 2014	23.60	12.55	53.0
Livestock	USGS, Kenny *et al*. 2009	9.66	5.61	58.0
Industrial	USGS, Kenny *et al*. 2009	76.89	11.53	15.0
Mining	USGS, Kenny *et al*. 2009	10.41	2.81	27.0
Aquaculture	USGS, Kenny *et al*. 2009	36.61	18.31	50.0
Total without irrigation conveyance losses	Calculated, EPRI, 2014	1564.77	363.02	23.2

Figure 2.4.7: US groundwater pumping for public and domestic supply and population, 1950–2005



The volume of groundwater pumped for public supply has quadrupled in the past 60 years, while the population of the US has approximately doubled. Source: Adapted from Kenny *et al.* 2009

well as supplying private homeowners in many rural parts of the country. In Canada, data on the use of groundwater are limited and dated; estimates from the mid-1990s suggest that it accounts for roughly 4 per cent of freshwater use in Canada, about double the share of a decade earlier (CCA 2009). At least 150 million people in the US and 10 million in Canada, nearly half of North America's population, and most of those living in rural areas rely on groundwater for drinking and other household uses (CCA 2009; Kenny *et al.* 2009; DeSimone *et al.* 2014; **Figure 2.4.7**). Large aquifers in some of the most important agricultural regions, including California's Central Valley and throughout the Midwest are declining in level due to extraction exceeding recharge (Famiglietti and Rodell 2013).

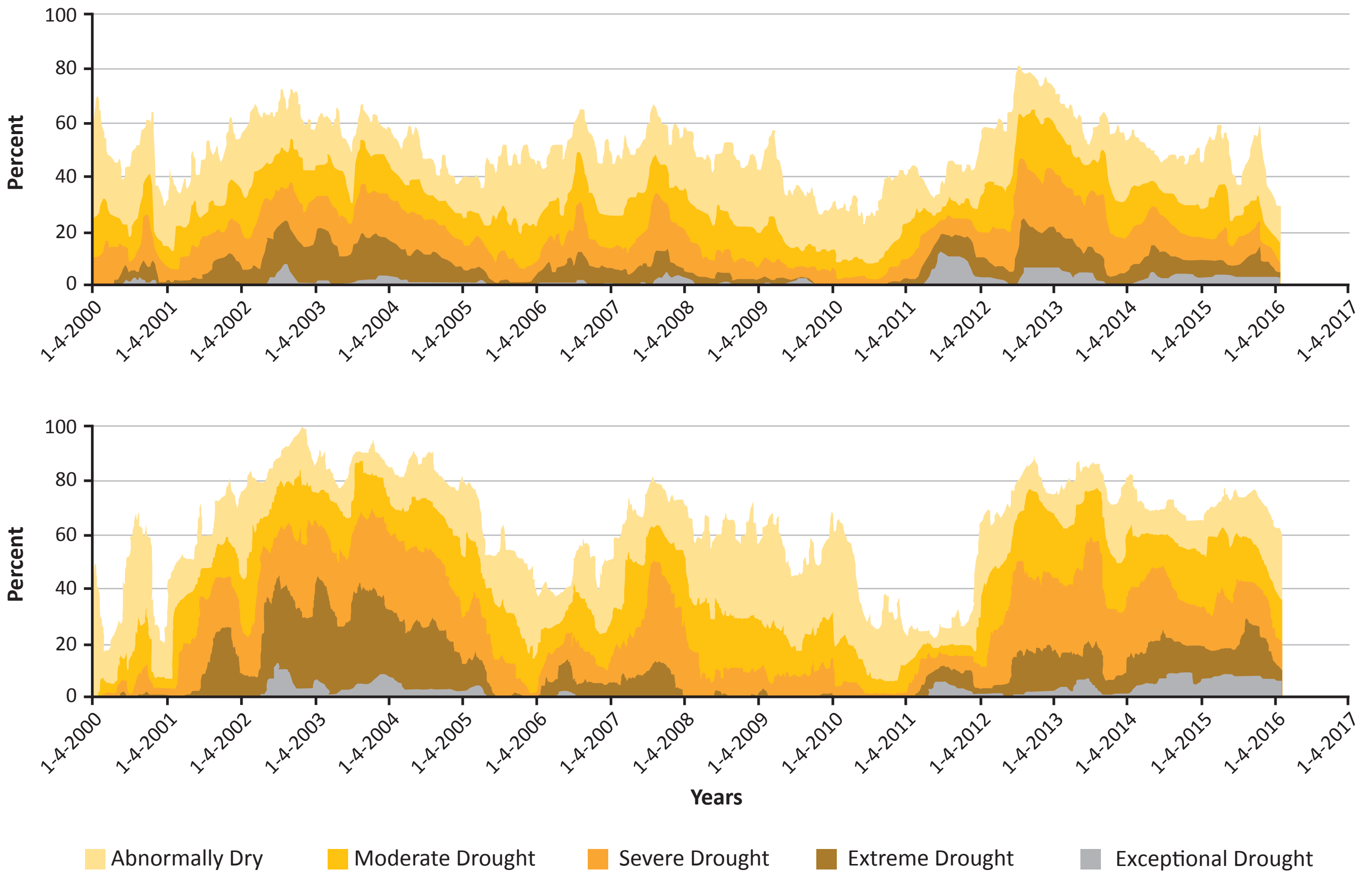
Drought

Water demand exceeds sustainable supply in the arid western areas of North America and, at times, in eastern and central regions of the US, resulting in the mining of aquifers, fragmentation and regulation of most western rivers by dams, and vulnerability of urban and rural communities to drought. Extreme drought has been a recent feature of much of western North America (Howitt *et al.* 2015; **Figures 2.4.8** and **2.4.9**). The human and environmental costs of droughts include the over-extraction of groundwater that has long-term impacts on water-supply resilience and can have long-term negative effects on agricultural production, aquatic and terrestrial ecosystems and economic activity, as well as increasing airborne dust and pollutants, (Borsa 2014;

Garfin *et al*. 2014; Famiglietti 2013; Williams 2010). Extensive drought has also dried reservoirs in California and other parts of the western US, threatening power production, municipal water supplies, groundwater recharge, agriculture and river ecosystems. Concurrent watershed damage, including tree mortality and fires, has further contributed to damage to reservoirs, lakes, river ecosystems and water supplies (McDowell *et al.* 2013; Williams *et al.* 2010).

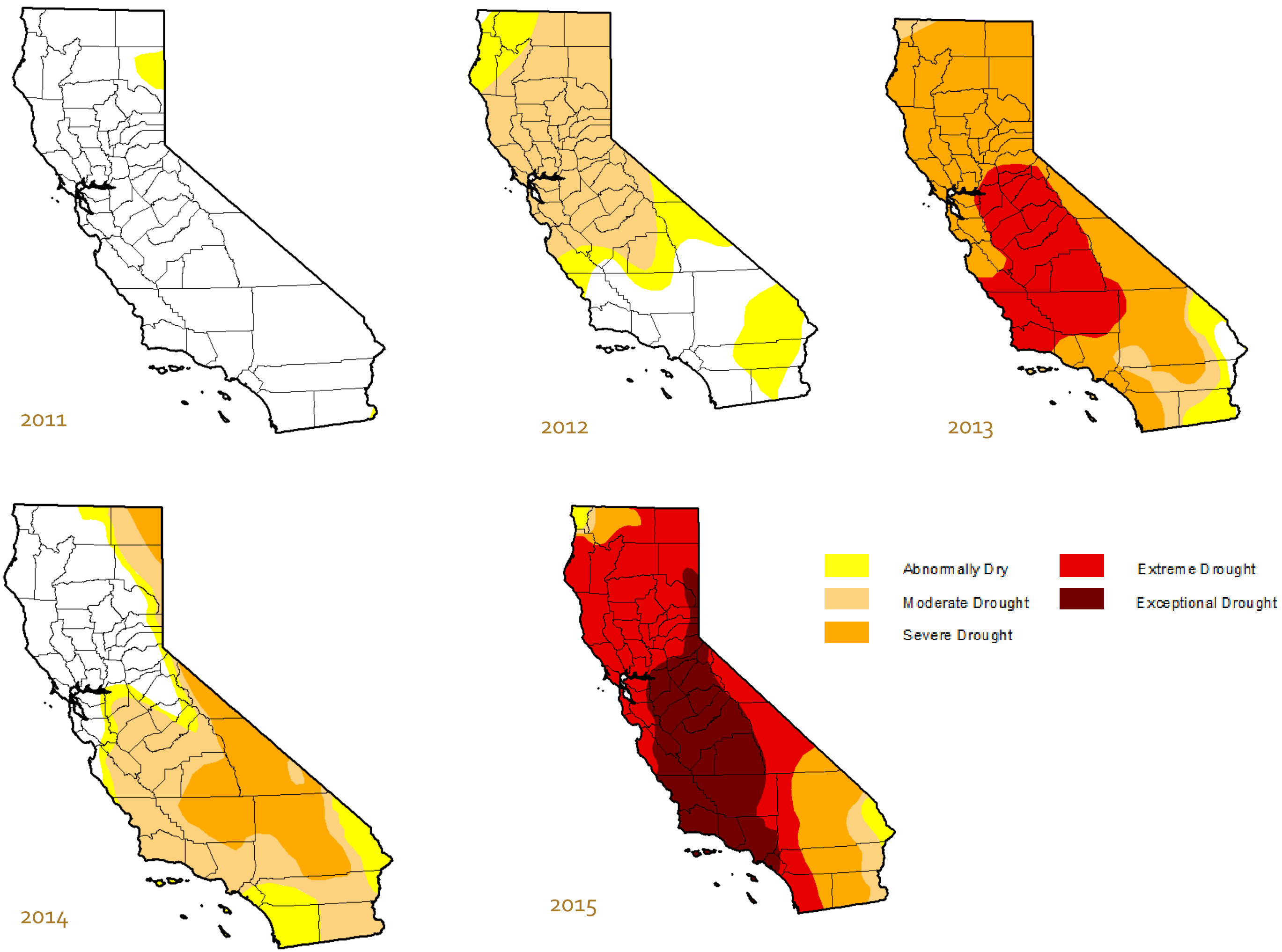
Droughts in western North America are repetitive, and can last for many years, with residents at the low end of the economic spectrum often the hardest hit by impacts (Garfin *et al.* 2014). The current drought is estimated to have cost the Californian economy around USD 2.74 billion, most of which will be incurred by the agricultural sector (Howitt *et al.* 2015). Indeed, some agricultural producers in the US West have begun a shift to less water intensive crops.

Figure 2.4.8: Comparison of droughts across the continental US (top) and in NOAA's climate region (bottom), 2000–2015



Source: National Drought Mitigation Centre 2016

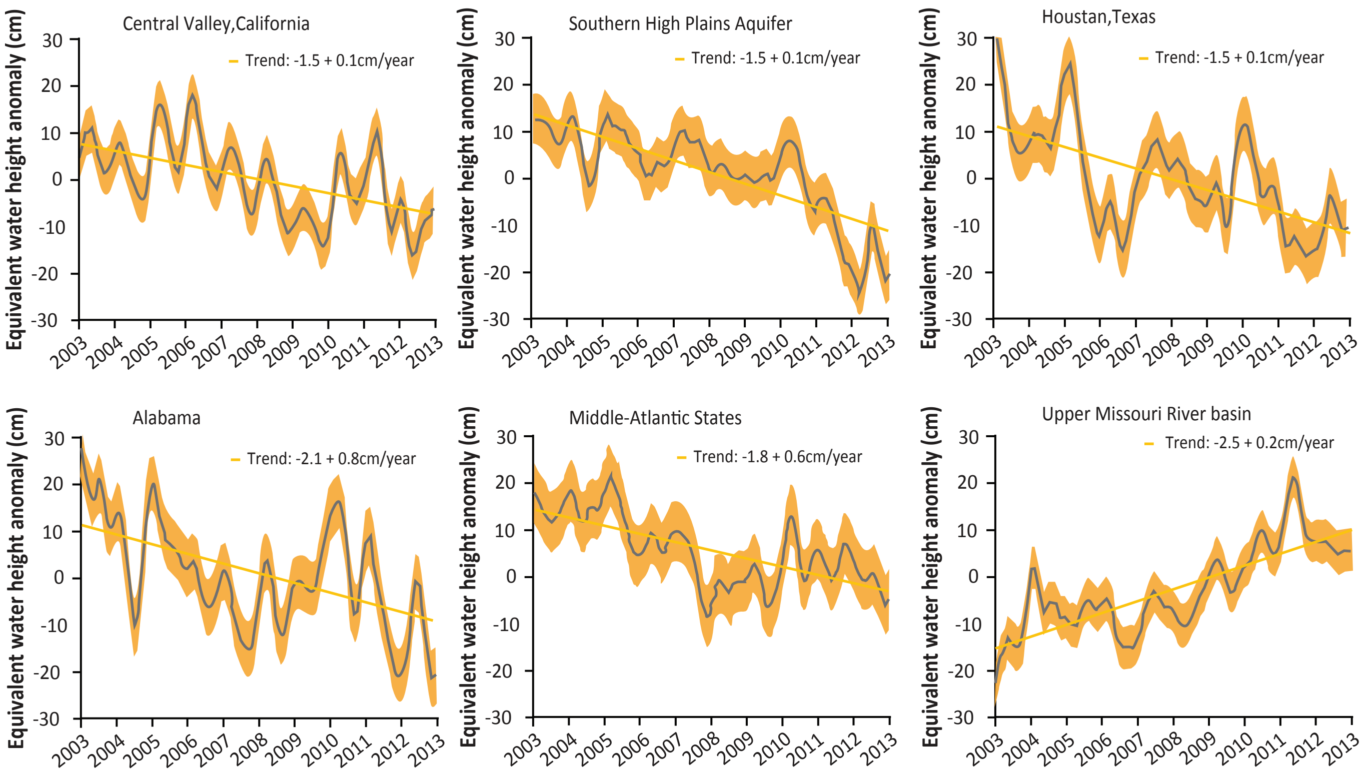
Figure 2.4.9: California's drought level at the first week of January, 2011-2015



Source: National Drought Mitigation Centre 2016

Droughts are projected to increase as a result of climate change associated with increases in temperature, evaporation, and changes in precipitation patterns. Although there may be some areas in which increases in precipitation will lead to increased water availability, in other areas modest increases in precipitation will be offset by decreases in streamflow due to increased temperature. In the most arid parts of the western US, precipitation is projected to

Figure 2.4.10: Changes in US aquifers, 2003 and 2012



Source: Famiglietti and Rodell 2013

decrease while temperature increases, leading to projected reductions in water availability (Jardine *et al*. 2013).

The Colorado River Basin is one of the river systems most threatened by climate change. Flowing from high in the central Rocky Mountains to its delta in Mexico, the 1 400 mile Colorado River provides critical water resources to seven western states. Water in this basin is generally stored in reservoirs during spring runoff and used in late summer and early fall, primarily for irrigation. Climate change threatens to reduce the annual runoff in the basin by 8.5 per cent and transition from a snowfall to a rainfall dominated system. These changes are projected to result in increased evaporation and the need for additional infrastructure to manage winter and spring runoff (Mankin *et al.* 2015).

The Gravity Recovery and Climate Experiment (GRACE) satellite programme led by the National Aeronautics and Space Administration (NASA) has vastly improved its ability to measure net change in aquifers over time and is an excellent example of the use of new data tools and analytics to inform environmental management (Famiglietti and Rodell 2013). GRACE has demonstrated how large aquifers in some of the most critical agricultural regions in North America, including the Central Valley of California and the Southern High Plains (Ogallala), contracted between 2003 and 2012 due to extraction rates that exceed recharge rates (**Figure 2.4.10**; Famiglietti and Rodell 2013).

In Canada in 2009, there was a high threat to water availability in parts of southern Ontario, southern Alberta, southern Saskatchewan, southwestern Manitoba, and the Okanagan Valley in British Columbia. A high threat to water availability means that more than 40 per cent of the water in rivers was withdrawn for human use. The threat was moderate to medium in parts of southern Alberta and southwestern Manitoba, where 10–40 per cent of water in rivers was withdrawn for human use. The threat to water availability was low across the rest of Canada, as less than 10 per cent of water in rivers in those areas was withdrawn for human use (see also **Box 2.4.2**).

2.4.3 Water quality

Water quality in North America has improved substantially since the middle of the last century due to environmental legislation enacted in the 1970s that has largely resulted in control of point sources of pollution. Non-point sources remain the largest source of pollutants, especially nutrients, to North American waters.

In the US, degraded water quality mainly threatens aquatic life and recreational uses of surface water (a discussion of North American drinking water quality can be found in the subsequent section). Nearly half of US waters do not meet standards considered to be protective of aquatic life, and 70 per cent do not meet standards for aquatic life harvesting. Similarly, more than 40 per cent of US waters do not meet recreational-use standards. Although nearly a quarter of US waters protected for public water supplies are considered impaired, many of these waters are not currently used for public supplies but threaten the ability to develop new supplies.

In total, most recent data available indicate that 54 per cent of assessed river kilometres and 68 per cent of assessed lake area in the US are impaired (USEPA 2015g, Watershed Assessment, Tracking, and Environmental Results).

Canadian freshwater quality is reported nationally by Environment Canada on the basis of selected federal and regional monitoring sites, and the status of water quality is determined against an index based on water quality guidelines designed to be protective of aquatic life. Water quality at a monitoring site is considered excellent when its ambient quality never or very rarely exceeds guidelines for any selected parameters. However, the quality and reliability of regional data are not easy to assess, exceedances of various guidelines are not tracked systematically, and the spatial and temporal resolution of monitoring is inadequate for the understanding of patterns of many contaminants (CCA 2013).

Between 2010 and 2012, most monitored sites were reporting fair to good water quality (**Figure 2.4.11**), although quality was generally higher in sites with the least anthropogenic disturbance.

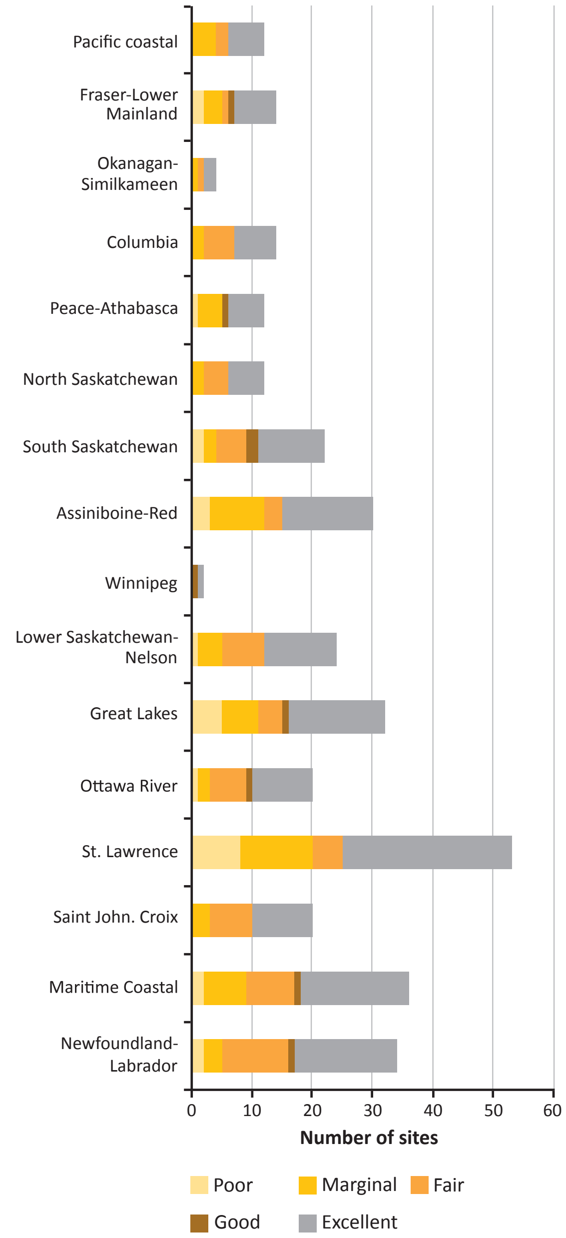
Recent water quality trend data for surface waters in the United States are not available. The last national assessment for rivers and streams in the United States was released in March 2016 and documents changes in water quality between 2004 and 2009. Overall, the amount of stream miles considered to be in good quality for biological conditions declined by 8.9 per cent (from 36.7% to 27.8%) and for phosphorus dropped by 14.3 per cent. However, the per cent of streams with good riparian condition rose over the same period (US EPA 2016).

Nutrients

Nutrient pollution, mainly from non-point sources, remains one of the most significant and intractable pollution issues in North American waters. Non-point sources represent 85 per cent of total nitrogen loads to North American rivers (McCrackin *et al*. 2015; Clair *et al*. 2014; **Table 2.4.2**).

Synthetic fertilizer and agricultural biological nitrogen fixation are the main non-point sources of nitrogen in the major agricultural areas of the US High Plains and Midwest, whereas atmospheric deposition is the most important

Figure 2.4.11: Canada, freshwater quality in drainage regions, 2010–2012



Source: Environment Canada 2014

source on the eastern seaboard and parts of the Southwest (Sobata *et al*. 2013; **Figure 2.4.12**). Most of these non-point sources are generally not regulated under the US Clean Water Act or any Canadian federal or provincial law, with confined feedlot manure and centralized sewage discharges as the exceptions (Clair *et al*. 2014). In total, human-mediated nitrogen inputs represent 34 kg N per hectare per year with the highest loads occurring along the Atlantic Coast and the agricultural areas of the mid-west (**Figure 2.4.12**).

Agricultural runoff is an important source of nutrients to rivers in Canada and the US. Canada also receives a significant amount of atmospheric deposition (see Section 2.1) from sources in the US, which mostly falls on forests and contributes a significant fraction of total nitrogen inputs to rivers (Clair *et al*. 2014). Climate change, in particular changes in precipitation intensity, will alter runoff, thereby influencing the transfer of nitrogen from terrestrial to aquatic ecosystems and groundwater and the water residence times that affect nitrogen removal within aquatic systems (Baron *et al*. 2013).

A US Geological Survey (USGS) decadal assessment of trends in concentrations of nitrogen and phosphorus in freshwater for 1993–2003 showed minimal change in the

Table 2.4.2: Nitrogen loads to North American rivers, US 2005; Canada 2005–2009

Sources of nitrogen inputs to rivers	US*	Canada**
	'ooo tonnes nitrogen per year	
Agriculture	963	274
Sewage/urban runoff	312	137
Atmospheric deposition	375	328
Non-agricultural biological nitrogen fixation	468	212
TOTAL	2 118	951

Note: The atmospheric deposition and non-agricultural biological nitrogen fixation estimates are based on total runoff from forest ecosystems and the relative proportions of inputs to these ecosystems.
Source: *McCrackin et al. 2015; estimates for 2005; **Clair et al. 2015; estimates for 2005–2009 period

Box 2.4.2: Insufficient amounts of water affect ecosystem functions in Canada

Trends over the past 40 years that influence biodiversity in Canadian lakes and rivers include seasonal changes in the magnitude of stream flows, increases in river and lake temperatures, decreases in lake levels, and habitat loss and fragmentation. The retreat of North American glaciers in western Canada and the conterminous US since the end of the Little Ice Age in the 19th century has been linked to declines in late-summer stream flows from glacier-fed catchments (Moore *et al*. 2009).

Annual low flows in natural streams decreased at many sites in southern Canada and increased at several sites in the north, though most sites showed a decreasing trend. Annual peak flows decreased at many sites across Canada, but increased in the Atlantic Maritime region. Other trends, such as changes in seasonal average flows, were also specific to regions and types of streams. Changes in stream flow affect aquatic life, for example, decreased flows can cause problems for late–spawning fish and increase heat stress and predation for all fish. Trends in lakes include decreases in seasonal and year-to-year water-level fluctuations in some of the Great Lakes. In Lake Ontario, since 1960, water-level regulation has reduced plant diversity and altered habitats for animals living along the shoreline.

majority of streams studied across the country, and more upward than downward trends in concentrations at sites with changes (Dubrovsky *et al*. 2010). Upward trends were clear among all land uses, including those far from agricultural or urban development. The median nitrate concentrations in groundwater from 495 wells also increased significantly from 3.2–3.4 milligrams per litre (6 per cent) during about the same period, and the proportion of wells with concentrations of nitrate greater than the maximum concentration limit for drinking water increased from 16 to 21 per cent. In Canada, water quality in agricultural watersheds remained "good" in 2006 based on a composite index of nitrogen, phosphorus, coliforms and pesticides, but had declined from a "desired" status in 1981; largely due to an increased application of nutrients (N and P) as fertilizer and manure (Eilers *et al*. 2010).

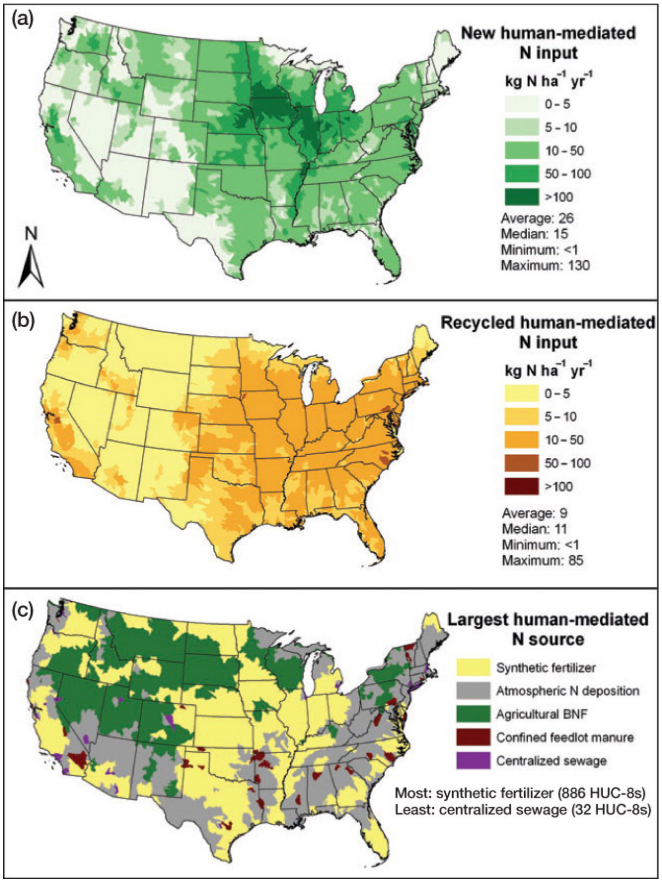
Hypoxia and harmful algal blooms

In freshwater systems, nutrients result in excess algal growth, loss of oxygen at night due to cellular respiration by algae, poor oxygen conditions due to decomposition of algal cells, and, increasingly, the threat of harmful algal blooms. Increased algal growth leads to reduced growth of submerged aquatic vegetation, which is important habitat for reproduction of many species of fish and shell fish (**Figure 2.4.13**).

Algal growth, simulated by nutrients also uses up oxygen as the algae die and decompose. Hypoxia, a deficiency of oxygen, is the greatest concern in eutrophic coastal areas such as the Gulf of Mexico and the Chesapeake Bay. In 350 coastal areas monitored for eutrophication in North America, 267 are hypoxic, though 28 of those show signs of improvement (see Section 2.5.3, Diaz *et al*. 2011).

Although harmful algal blooms have been a concern for many decades, their frequency and magnitude and their impacts on drinking and recreational waters are emerging as a growing threat in North America (US EPA 2015; O'Neil *et al*. 2012; Carrière *et al*. 2010), where, in some lakes, cyanobacteria have increased disproportionately to other

Figure 2.4.12: Sources of human-mediated nitrogen



Source: Sobata *et al*. 2013

plankton (Taranu *et al*. 2015). In 2014, the City of Toledo was forced to abandon its drinking water supply for several days because of a toxic algal bloom in Lake Erie. The US EPA estimates that harmful algal blooms in freshwaters could threaten the drinking water supply for 30– 48 million people in the coming years (US EPA 2015). In addition, recreational exposure to harmful freshwater algal blooms containing microcystins from cyanobacteria can cause rashes, urticarial (hives) and skin blisters. Inhaling algal bloom contaminated water can produce runny eyes and nose, sore throats, asthma-like symptoms and allergic reactions.

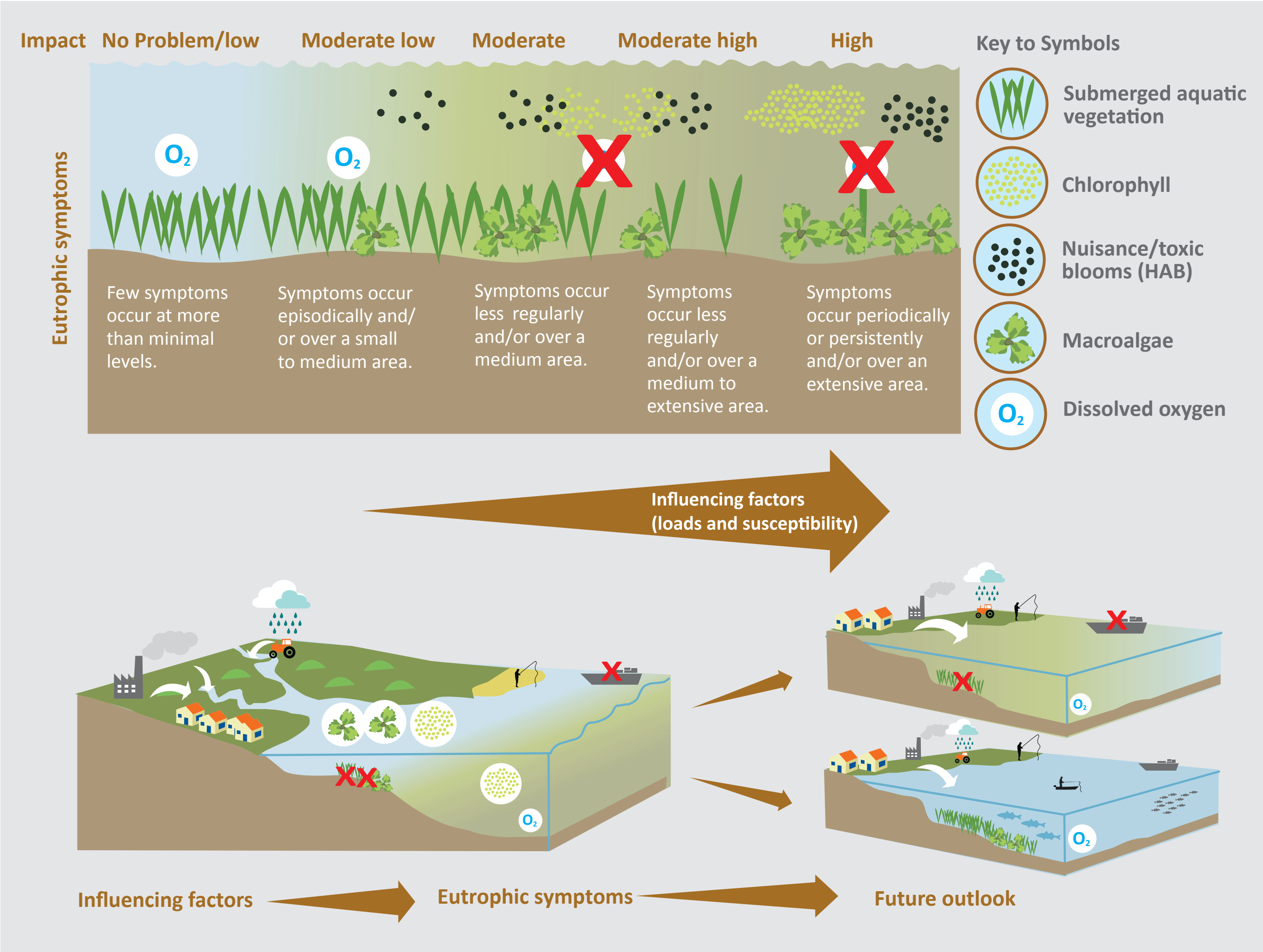
Regulatory mechanisms to address both the public health and the environmental aspects of harmful algal blooms are developing in Canada and the US. In May 2015, the US EPA released the first drinking water health advisory values for the most common algal toxins, microcystin, 0.3 micrograms per litre, and cylindrospermopsin, 0.7 micrograms per litre (US EPA 2015a).

The US is now working towards implementing these standards to ensure safe drinking water supply and plans to release recreational guidelines in 2016. Canada first introduced a Guideline for Canadian Drinking Water Quality of 1.5 milligrams per litre for microcystin-LR in 2002. Health Canada has since worked with the US EPA on the recent development of the risk assessment for Harmful Algal Blooms and will be holding public consultations on the document in early 2016. Whereas the US health advisory is considered guidance only, the Canadian guideline is used by all provinces and territories as a basis to establish drinking water regulatory requirements. Similarly, the Guidelines for Canadian Recreational Water Quality, last updated in 2012, include guidance on both cyanobacterial cells and cyanobacterial toxins.

In addition to an evolving regulatory structure to address this concern, understanding of the underlying drivers (see **Figure 2.4.14**) is also changing. Harmful algal blooms are ultimately driven by eutrophic conditions in lakes and rivers caused by nutrient pollution. However, recent evidence suggests that climate change may increase their frequency and magnitude as they thrive in high nutrient waters that are warm and stagnant (Carey *et al*. 2012; O'Neil *et al*. 2012; and Kosten *et al*. 2011). Other research indicates that cyanobacteria may be driving some aspects of eutrophication (Cottingham *et al*. 2014). In addition, there are new and innovative approaches to monitoring and responding to episodic algal blooms and their impacts, including the use of remote sensing, forecasting (NOAA 2012), and citizen science Harmful Algal Bloom Reporting App, developed by the US Environmental Protection Agency (US EPA 2015h).

The region also continues to develop new responses to the underlying problem of nutrient pollution and eutrophication

Figure 2.4.13: The relationship between overall eutrophic condition, associated eutrophic symptoms and influencing factors

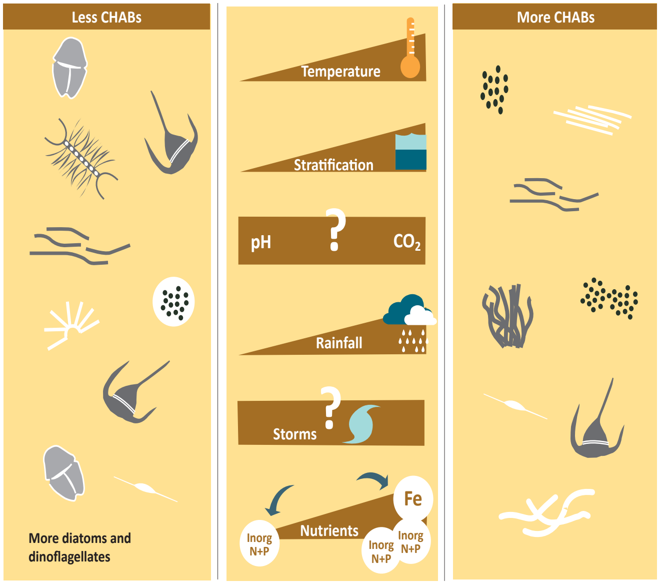


Source: Adapted from Bricker *et al.* 2008

which represent the most common causes of water quality degradation in North American waters. Nutrient-driven water quality problems in the region have generally outgrown the regulatory tools of the past and require new mechanisms for integrated water resource management.

Development of planning documents to control nutrients and restore waters has been increasing in the US since the Clean Water Act was passed in the early 1970s. Since then, individual states and the US EPA have developed more than 6 000 location-specific standards for nutrient total

Figure 2.4.14: Factors affecting increasing prevalence of harmful algal blooms in freshwater



Source: Adapted from O'Neil *et al.* 2012

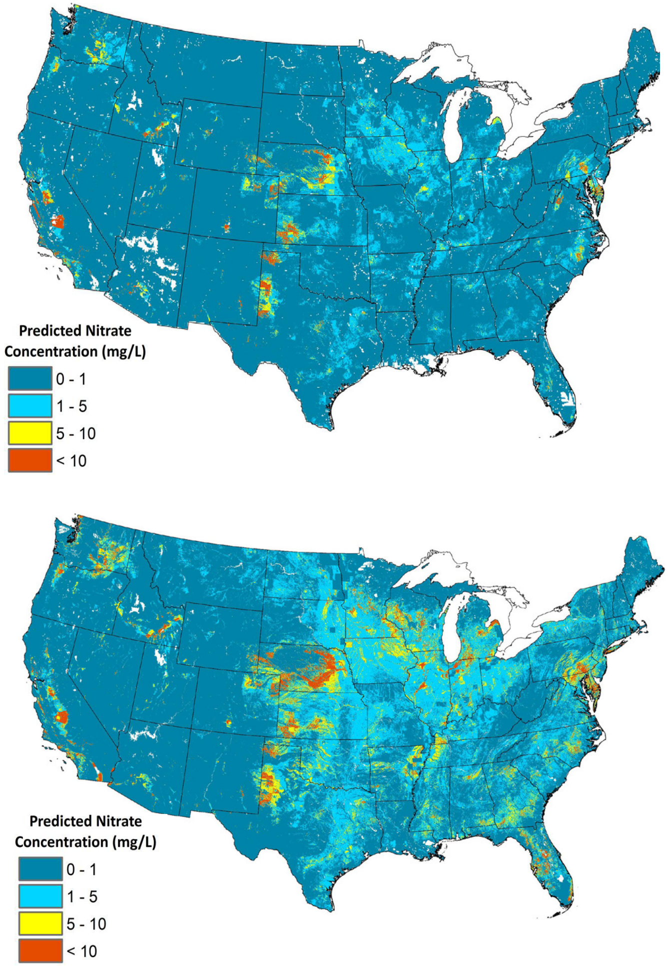
maximum daily loads, with a peak in the 1990s driven by litigation across the country (AskWaters database; US EPA 2015c). Although these standards have driven lower nutrient limits from point-source discharges, it is difficult to evaluate whether their development has resulted in reduced nutrients from non-point sources.

Groundwater quality

Case studies from parts of Canada, for example, southern British Columbia and southern Ontario, show that groundwater contamination from nitrogen fertilizer has been extensive (Canadian Council of Academies, 2013). Similarly, many shallow groundwater aquifers in the US are polluted by nitrates, mainly because of the use of nitrogen fertilizer in the Midwest (DeSimone *et al*. 2014; **Figure 2.4.15**).

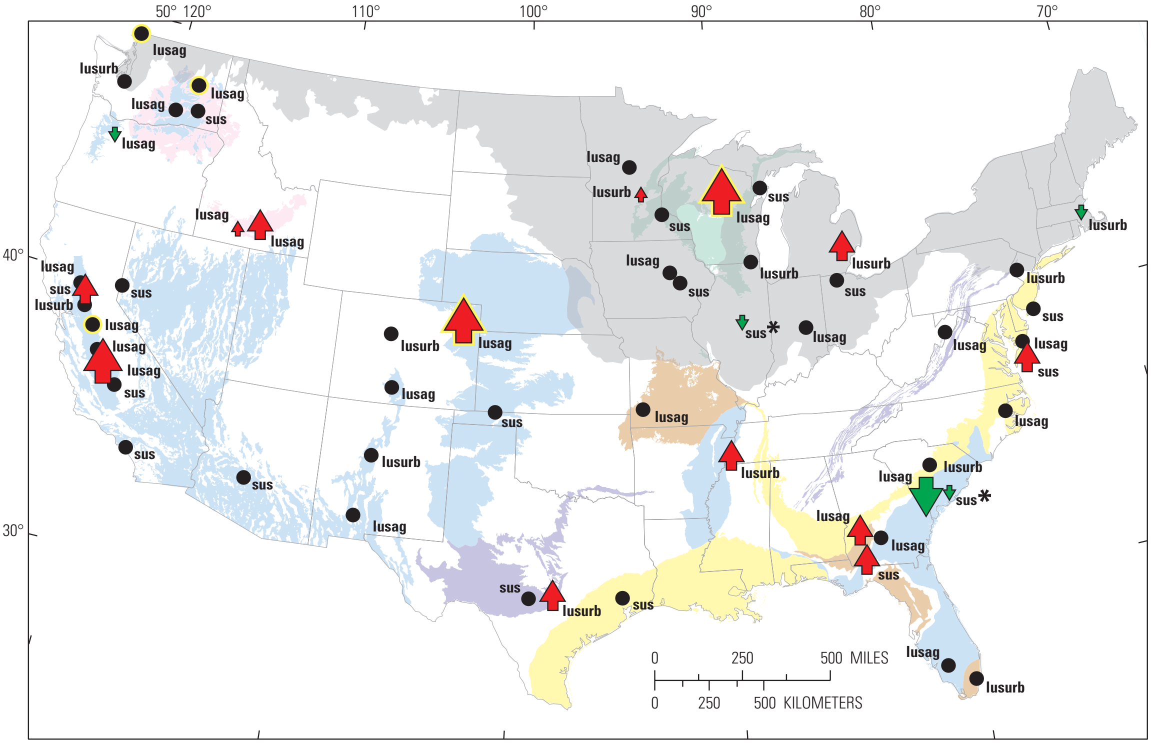
In the US, between 1988 and 2010, more than 66 per cent

Figure 2.4.15a: Predicted nitrates in shallow, recently recharged water; b: Predicted nitrates in deeper groundwater used for drinking water, 2013



Nitrate concentrations greater than MCL of 10 mg/L as N are predicted to occur primarily in the High Plains, northern Midwest, and areas of intense agriculture in the eastern and western US. In shallow, recently recharged groundwater (top), concentrations are predicted to exceed the MCL of 10 mg/L as N beneath nearly 2 per cent of the land area of the conterminous US and to be greater than half the MCL beneath nearly 8 per cent of the land area. Concentrations are predicted to be lower in deeper groundwater from the parts of aquifers used for drinking water (bottom) than in shallow, recently recharged groundwater.
Source: DeSimone *et al.* 2014

Figure 2.4.16: Ground water quality trends in the United States



EXPLANATION

Principal aquifer rock type

- Non-glacial sand and gravel aquifers
- Glacial sand and gravel aquifers—Aquifers are discontinuous within area shown
- Coastal Plain aquifers in semi-consolidated sand
- Sandstone aquifers
- Sandstone and carbonate-rock aquifers
- Carbonate-rock aquifers
- Igneous and metamorphic-rock aquifers

Statistically significant change in nitrate concentrations at the network level shown as arrows, with the size of the arrow representing the median of the difference in concentration for the network in milligrams per liter as N. Yellow highlighting denotes location where median nitrate concentration for the network is greater than 10 milligrams per liter in the second full-network sampling event

Increase	Decrease	
▲	▼	Less than 0.1
▲	▼	0.1–0.5
▲	▼	Greater than 0.5

● No significant change

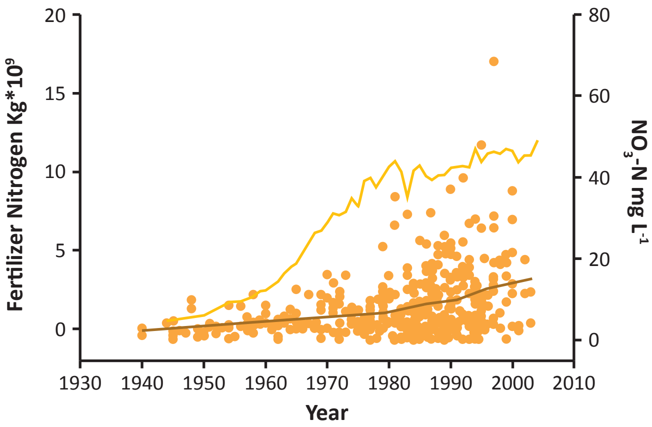
* **Statistically significant change in network where more than half of the data are pairs of nondetects**

Network type

lusag	Agricultural land-use study
lusurb	Urban land-use study
sus	Major aquifer study

Source: Adapted from USGS-NAWQA 2015

Figure 2.4.17: Fertilizer use and nitrate concentration in groundwater at recharge, 1940–2004



Fertilizer use in the US has increased greatly since the 1940s, and nitrate concentrations in groundwater at recharge in agricultural areas have generally followed this trend.
Source: DeSimone *et al.* 2014

of aquifers monitored had significant increases in nitrates, dissolved solids, and/or chloride concentrations. Trends in increased nitrate contamination of the nation's shallow aquifers (**Figure 2.4.16**) reflect a similar increase in the use of nitrogen fertilizer from 1950 to 1980 (Lindsey and Rupert 2012; USGS report 2012-5049; **Figure 2.4.17**). Although nitrogen fertilizer use has levelled off since about 1990 in the US, recent continued increases in groundwater nitrate contamination probably reflect a lag effect between fertilizer use and detection of groundwater contamination.

Microbial pollution

Although not a widespread problem in North America, the main sources of microbial pollution include livestock, contamination from septic systems and combined sewer overflows during storms. Pathogenic organisms are difficult to monitor but are generally correlated with *E. coli*. The most commonly reported illness associated with oral exposure to contaminated water is gastroenteritis, which can cause severe dehydration due to vomiting and/or diarrhoea. Dermal exposure to sewage-contaminated water may result in infection of open cuts or rashes (Haile *et al*. 1999). The quality of waters used for recreation is generally assessed by measuring concentrations of indicator microbes, *E. coli* or faecal coliforms, typically found in high concentrations in human faeces. An elevated concentration of these microbes indicates that the water has been contaminated by human waste and is unsafe for recreational use – this happens most frequently after rain. In both Canada and the US, there are national guidelines for *E. coli* and faecal coliforms to ensure that recreational waters are safe, which health departments test for and close beaches when levels are unsafe. In the US, county and state health departments advise the public never to swim or surf within 72 hours after a rain.

Pathogens in water are not monitored nationally in Canada; however, case studies in various agricultural regions suggest that pathogen contamination may be not uncommon – 80 per cent of surface water samples and 40 per cent of rural wells found evidence of microbial contamination (CCA 2013b).

The number of illness outbreaks associated with recreational waters in the US has been increasing, although the increases may represent an increase in reporting. The number of outbreaks per state is generally less than five per year.

Lake acidification

Although there have been improvements in the prevalence of acid precipitation since the 1980s, it continues to be a serious issue in some areas as a result of local soil and bedrock that are not able to adequately buffer the impacts. of acidic deposition, particularly in eastern North America. Problems in water chemistry remain even after large decreases in sulfate deposition (Clair *et al*. 2011). While studies conducted in eastern North America (and Northern Europe) have demonstrated that once lakes increase in pH >6.0, significant recovery of zooplankton communities can occur (Gray and Arnott 2009). There is also evidence for declining calcium concentrations in temperate lakes that is a legacy of acid deposition (Jeziorski *et al*. 2015). Declining of zooplankton, trending toward less Ca-rich (and less nutritious) species with potential impacts for aquatic food webs (Jeziorski *et al*. 2015).

Metals

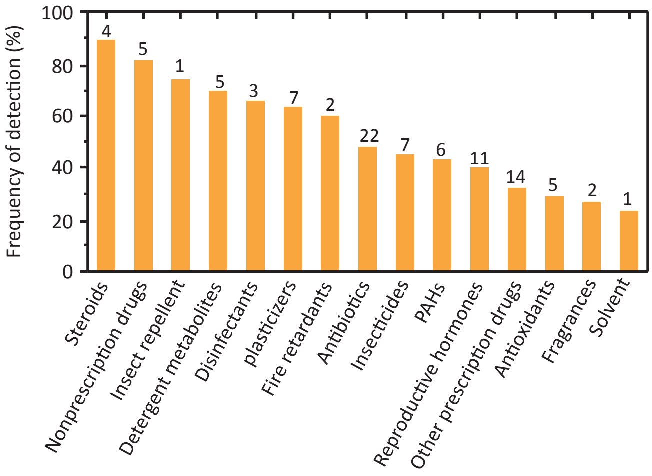
Metal pollution in freshwater lakes has been generally decreasing across the US. In a study of lakes, decreasing trends outnumber increasing ones for the seven metals analysed, cadmium, chromium, copper, lead, mercury, nickel and zinc. The most consistent trends are for lead and chromium: for lead, 83 per cent of the lakes are decreasing and 6 per cent increasing; for chromium, 54 per cent of the lakes are decreasing and none are increasing (Mahler *et al*. 2006).

Contaminants of emerging concern

Municipal and industrial wastewater management in North America has achieved relatively consistent and good treatment of traditional pollutants such as ammonia and biological oxygen-demanding matter. However, wastewater treatment systems were not designed to remove an emerging group of contaminants associated with personal care products, pharmaceuticals, and other compounds common in residential, industrial, and agricultural life.

Contaminants of emerging concern have been documented in waters across North America, including in streams, untreated drinking-water sources in the ground and on the surface, and the Great Lakes Basin (Focazio *et al*. 2008; Blair *et al*. 2013; Hull *et al*. 2015). In 2000, the US Geological Survey (USGS) identified contaminants of emerging concern in 80 per cent of streams sampled. The most frequently detected compounds were coprostanol (faecal steroid indicating sewage contamination), cholesterol (plant and animal steroid), N,N-diethyltoluamide (insect repellent), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri (2-chloroethyl) phosphate (fire retardant), and 4-nonylphenol (non-ionic detergent metabolite) (Kolpin *et al*. 2002; **Figure 2.4.18**). More recently, a US survey of untreated drinking water sources (25 groundwater sites and 49 surface waters)

Figure 2.4.18: Frequency of detection of organic wastewater contaminants by general use in US streams, 2002

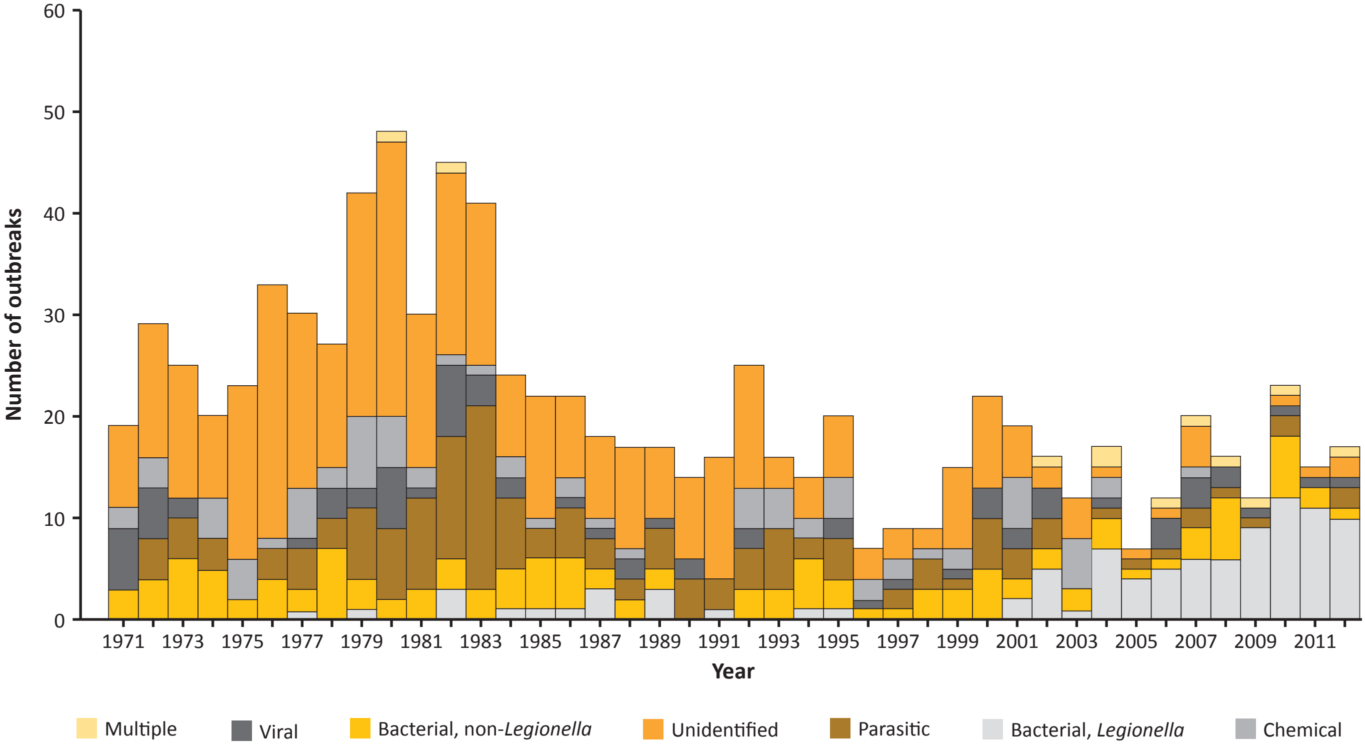


Source: Kolpin *et al*. 2002

showed that 63 of the 100 targeted chemicals were detected in at least one sample but that more than 60 per cent of the 36 pharmaceuticals examined were not detected in any of the waters sampled (Focazio *et al*. 2008). Although the environmental threat they pose in large lake systems has previously been considered minimal due to dilution, Blair *et al*. (2013) indicate that concentrations of 14 of these contaminants pose a significant threat to the health of the Great Lakes, especially to organisms found near shorelines. The persistence of chemicals found in the Great Lakes is demonstrated by measurable concentrations of pesticides that are no longer registered for use in North America, such as azinpho-methyl (Hull *et al*. 2015).

Understanding the effects of CECs on human health and the environment and developing treatment techniques and other technologies to mitigate their impacts is a top priority for North America. Additional information on CECs is available in section 2.6.1 and the North American Outlook (Chapter 4).

Figure 2.4.19: US, etiology of 885 drinking water-associated illness outbreaks, 1971–2012*



*Legionellosis outbreaks were first reported to CDC Waterborne Disease and Outbreak Surveillance System in 2001; Legionellosis outbreaks before 2001 were added retrospectively during the 2007–2008 reporting period.
Source: Adapted from Beer *et al.* 2015

Drinking water

The relatively high quality of drinking water in North America contributes to public health, and North Americans have some of the lowest rates of water-borne disease in the world. The drinking water supply system in North America is fed by surface water from reservoirs and by groundwater aquifers. While some rural residents rely on individual wells, urban residents receive their water from public water systems.

In the US, drinking water is regulated through the federal Safe Drinking Water Act implemented through programmes managed at the state level. Canada has a shared governance model for drinking water. Guidelines for drinking water quality are developed jointly by the Federal-Provincial-Territorial Committee on Drinking Water; these guidelines are used by provinces and territories to set their own regulatory standards. Water treatment and distribution is managed at the municipal level. The variability in approaches to drinking water regulation has resulted in data gaps and disparities between urban and rural populations, especially in some First Nation communities (Dunn *et al*. 2014).

Box 2.4.3: The case of Flint, Michigan

In April 2014, the City of Flint, Michigan changed its water source from Lake Huron to the Flint River that runs through the city. Previously, the city purchased water from Detroit, which pumped it out of Lake Huron. The decision by Flint to make this change in water source occurred because in 2013, Flint had voted to acquire water from a new pipeline being built to Lake Huron rather than Detroit, prompting Detroit to cancel its agreement and raise rates. Rather than agree to higher rates, Flint decided to use the local river as a temporary measure to save money.

By late summer of 2014, customers began complaining of stomach problems, losing hair and developing rashes. In August, *E. coli* was found in the City's water, forcing Flint to issue advisories to boil water before use. Residents were concerned with the odour, colour, and taste of the water. Many alleged that the water appeared to be causing health concerns including rashes, stomach problems, hair loss, respiratory infections, and anaemia. Ultimately, many of the health issues were related to lead contamination in the water system. The water in the Flint River was more corrosive than the previously used water, and caused exposure and corrosion of leaded pipes in the distribution system. Most cities add a chemical to offset corrosion, but Flint River water was not treated with a corrosion-inhibitor, so lead leached out of pipes.

Health records indicate that that the percentage of children with elevated blood lead levels in Flint had gone from 2.4 per cent to 4.9 per cent citywide and that the percentage of children with lead poisoning had doubled since 2013, and tripled in some neighbourhoods. In children, lead poisoning can result in lasting problems with growth and development and can affect behaviour, hearing, and learning. For adults, lead poisoning can damage the brain and nervous system, the stomach, and the kidneys and lead to various other health problems. On October 16, 2015, the City switched back to water from Detroit but it will take some time for the distribution system to become safe again as corrosion exposed leaded pipes that until 2013 had been protected by a layer of calcium carbonate. At the beginning of 2016, Governor Snyder declared a state of emergency, sending state police door-to-door to deliver supplies to residents and opening several sites for water and filter pickup (Barry-Jester 2016). The US federal government has also coordinated a multi-agency response aimed to help state and local leaders to identify the size and scope of the problem and to develop a short-and long-term mitigation plan for the health effects associated with lead exposure (US EPA 2016).

Despite the access to water infrastructure in North America, there are some areas of the region in which safe and reliable sources of drinking water are threatened. These include rural communities dependent on shallow aquifers that are increasingly contaminated by nitrates, water supplies threatened by harmful algal blooms (e.g. Toledo, Ohio), some of US tribal communities and Canadian indigenous communities (Daley *et al*. 2015), and communities dependent on aging infrastructure, including lead-based piping (e.g., Flint, Michigan; see **Box 2.4.3**). According to the US Indian Health Service, less than 1 per cent of the population in the US is without access to safe drinking water, while more than 12 per cent of American Indians and Alaska Native homes are without access to safe water (O'Connor 2015b).

In the US water systems are monitored for a wide variety of contaminants; each regulated contaminant has a calculated maximum contaminant level (MCL). Overall, there are downward trends in the number of water systems with MCL violations (US EPA 2015e). However, water-borne disease outbreaks do occur and are typically the result of plumbing system failures and untreated groundwater. The last surveillance report for waterborne disease outbreaks associated with drinking water in the US assesses data for 2011–2012 (Beer *et al*. 2015). During that year, 32 drinking water-associated outbreaks accounted for 431 cases of illness due to *Legionella* and other pathogens. Nevertheless, the number of outbreaks has declined since the 1970s and efforts continue to improve drinking water infrastructure (**Figure 2.4.19**).

In Canada, 'boil-water' advisories, issued when drinking water quality has been or is suspected to be affected by microorganisms, represent about 98 per cent of all drinking water advisories nationwide (the others being "do not use" and "do not consume" advisories) and about 80 per cent of these advisories occur in small municipalities – those providing water to fewer than 500 residents. Contamination by chemicals is much rarer and typically results in do-not-consume or do-not-use advisories. Most boil water advisories, 74 per cent in 2013, are issued on a precautionary basis when problems with infrastructure or processes used to treat, store or distribute drinking water occur, with only 8 per cent related to *E. coli*, and 18 per cent related to other microbiological concerns, such as total coliform bacteria or unacceptable turbidity levels (EC 2015). The Canadian Network for Public Health Intelligence is developing a process to provide access to real-time notification and information sharing across jurisdictions about drinking water advisories via its Drinking Water Advisories Application

In 2011, public water systems served 90 per cent of the US population, the remainder obtain water from private systems, typically rural wells. There has been a steady increase in the proportion of systems that meet all health-based standards since the early 1990s, and by 2011 93 per cent of systems did (US EPA 2013; Fiscal Year 2011 Drinking Water and Ground Water Statistics). This pattern of continued improvement is also evidenced by a nearly 50 per cent decline in the number of public water systems that have experienced acute health-based violations since 2011.

Private wells that draw water from shallow groundwater aquifers are increasingly threatened by nitrate and other contaminants (**Figure 2.4.20**). In 2004, 23 per cent of sampled wells contained contamination at concentrations that are above standards considered to be protective of human health (DeSimone *et al*. 2009) and one third of wells sampled contained microbial contamination. Most of the contaminants at unhealthy concentrations occur naturally, with the exception of nitrates, which exceeded health-based standards in one per cent of wells sampled.

2.4.4 Water infrastructure

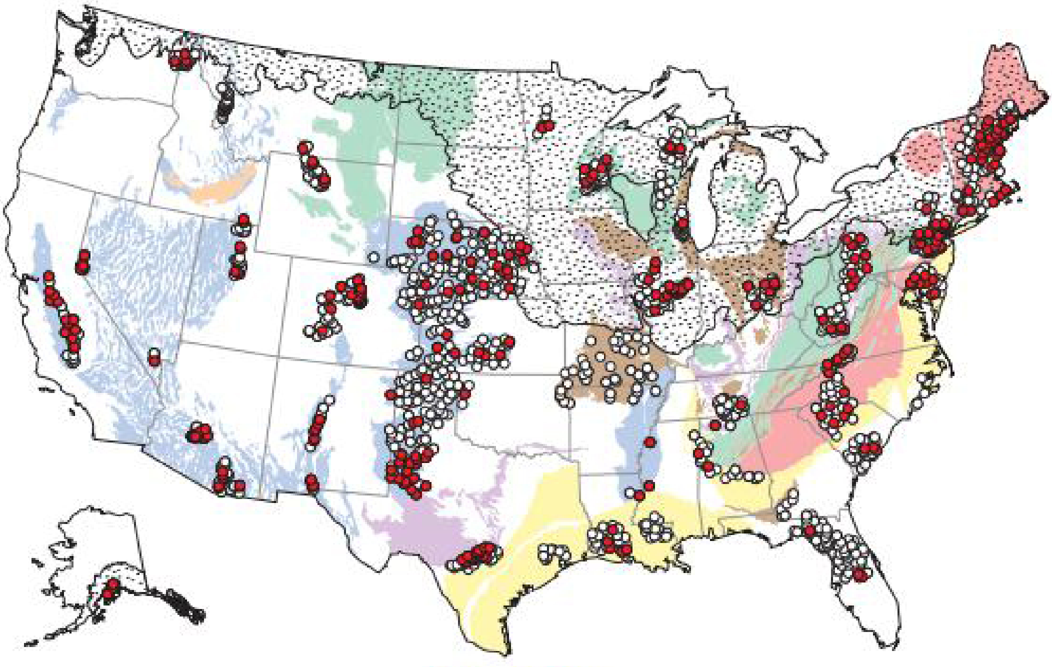
The water quality and drought issues discussed in the previous sections are reflected in a relatively high human water security threat as shown in the right panel of **Figure 2.4.21**. However, North Americans are largely protected from water security threats through investment in infrastructure, as reflected in the left panel of **Figure 2.4.21** showing adjusted human water security threat. Wastewater and drinking water treatment technology largely protect the population from water quality issues that could otherwise affect human health. Water storage in reservoirs and irrigation infrastructure buffer the natural condition of water scarcity during dry summer months and across years especially in arid parts of the region.

The sections that follow describe some of the most critical water infrastructure needs facing the region, in particular for drinking water and water storage and delivery. These needs are in addition to wastewater and stormwater infrastructure needs that are estimated to total USD 298 billion over the next 20 years in the US. These upgrades include addressing sanitary sewer overflows, combined sewer overflows, and upgrading the nation's wastewater treatment infrastructure.

Drinking water infrastructure

Drinking water infrastructure includes the systems of water storage, treatment plants, and piping needed to deliver safe drinking water to public water systems in the region. Much of the service lines and indoor plumbing

Figure 2.4.20: US, extent of private well contamination

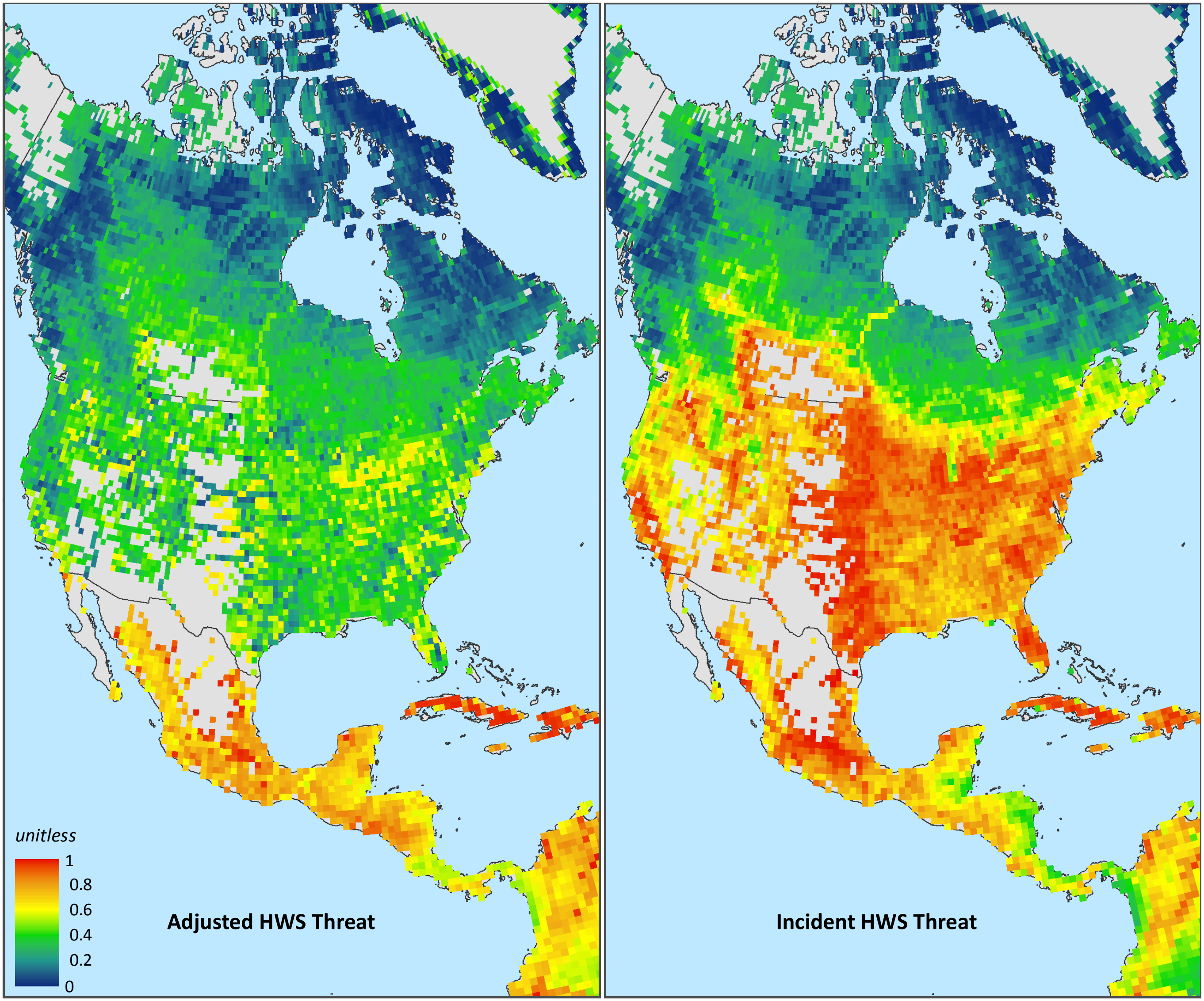


Concentrations of at least one chemical contaminant were greater than a human-health benchmark in 23 per cent of 1 389 domestic wells sampled in 25 principal aquifers. Human-health benchmarks include US EPA Maximum Contaminant Levels (MCLs) and USGS Health-Based Screening Levels. Results are based on the US EPA proposed MCL for radon of 4,000 picocuries per litre. Microbial contaminants are not included.
Source: Adapted from DeSimone *et al.* 2009

used by drinking water utilities was constructed at the time that communities were built and in many cases is quite old. Funding for drinking water infrastructure in the US is largely through a revolving loan fund administered by the US EPA and states under the Safe Drinking Water Act. The lead contamination of drinking water in Flint, Michigan in 2015 (see **Box 2.4.3**) put a spotlight on the state of drinking water infrastructure in the US. A recent USA Today investigative report, triggered by the Flint, Michigan event, identified at least 343 other communities in the US that have experienced repeated exceedances of lead levels at the water tap (Young and Nichols 2016). The risk of lead contamination is greatest in communities and homes that were built before the 1980s and have a higher probability of being served by lead water mains and in-home plumbing. The threat is also higher in communities with more corrosive source water.

It is estimated that more than one million miles of water mains are used to deliver drinking water to residents in the United States. The condition of many of these pipes is unknown, as they are buried underground out of sight, and owned and operated by local entities. Some pipes date back to the Civil War era and often are not examined until there is a leak or a water main break (American Society of Civil Engineers, 2013). Given its age, it is not surprising that

Figure 2.4.21: Water security in North America



Incidence of human water security affected by water scarcity and pollution (right) and adjusted human water security that is mitigated by infrastructure (left)

Source: Adapted from DeSimone *et al.* 2009; Vörösmarty *et al.* 2010 a large proportion of US water infrastructure is approaching, or has already reached, the end of its useful life. There are an estimated 240 000 water main breaks per year in the United States. The need to rebuild pipe networks is in addition to other water investment needs, such as replacement or upgrading of water treatment plants and storage tanks.

The US Environmental Protection Agency (US EPA 2013) estimates that approximately 4 000 to 5 000 miles of drinking water mains are replaced annually. The upgrade and maintenance of drinking water infrastructure in the United States requires investments of USD 384.2 billion over the next 20 years for thousands of miles of pipes, plus thousands of treatment plants, storage tanks, etc. Such investment is necessary to ensure the "public health, security, and economic well-being of our cities, towns, and communities." About two-thirds of the need is for water distribution infrastructure. The rate at which water mains require replacement or rehabilitation depends on pipe material, pipe age, soil characteristics, weather conditions, and construction methods. Some pipe materials tend to degrade prematurely; galvanized pipe is particularly susceptible to corrosion in certain soils, and unlined cast iron pipe is susceptible to internal corrosion.

Assuming every pipe would need to be replaced, the cost over the coming decades could reach more than USD 1 trillion, according to the American Water Works Association (AWWA 2016). Delaying the investment will result in increasing water service disruptions, and increasing expenses for emergency repairs. The needs are greatest in five US regions: Far West, Great Lakes, Mid-Atlantic, Plains, and Southwest where capital spending has not kept pace with needs. Although funds are allocated through the federal Drinking Water State Revolving Fund, there is a trend toward state and local governments' assuming most of the costs, since Congressional appropriations have declined (Copeland 2012).

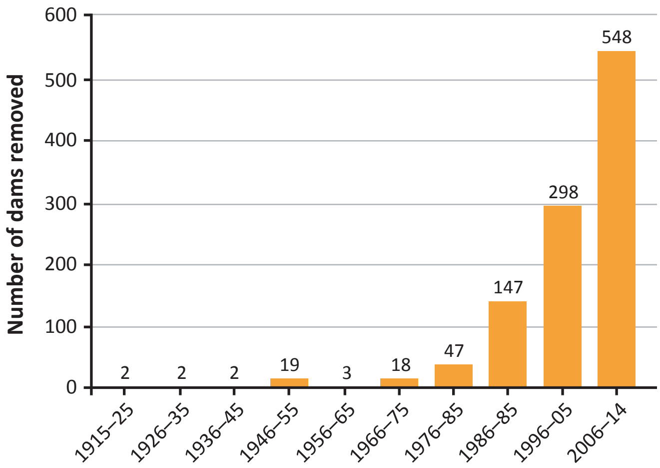
The Canadian drinking water infrastructure was recently rated as over 70 per cent very good or good, with only 17 per cent fair, 9 per cent poor, and 3 per cent very poor (Canadian Infrastructure Report Card 2016). Variations amongst municipal bodies that are often responsible for drinking water treatment also occur, with smaller, rural areas facing challenges with technical and managerial capacity (Hrudey 2008). In addition, rural communities also face challenges related to poorer quality raw water supply (e.g., draining agricultural land) that would pose challenges for even sophisticated treatment facilities (Petersen and Torchia 2008). Recognizing the complexities related to source water, treatment and water supply infrastructure, multi-jurisdictional groups, such as the Federal-Provincial-Territorial Committee on Drinking Water, have developed a series of guidance materials on the multi-barrier approach to safe drinking water for various audiences, including the public, and water industry specialists.

Dams and water storage reservoirs

With some notable exceptions, an era of dam construction in North America, beginning with the New Deal (1933–1938), largely ended in the 1970s. In many parts of the region, especially the interior West, communities depend on the water storage provided by reservoirs. Thousands of dams of varying sizes have been constructed around the region and have substantially altered the flow regimes of rivers and streams. In Canada, one of the world's top dam builders, there are an estimated 933 large dams plus thousands of smaller ones; the bulk of large Canadian dams are used for hydro power (596), with other uses including multi-purpose (86 dams), tailings (82 dams), water supply (57 dams), and irrigation (51 dams) (Environment Canada 2010).

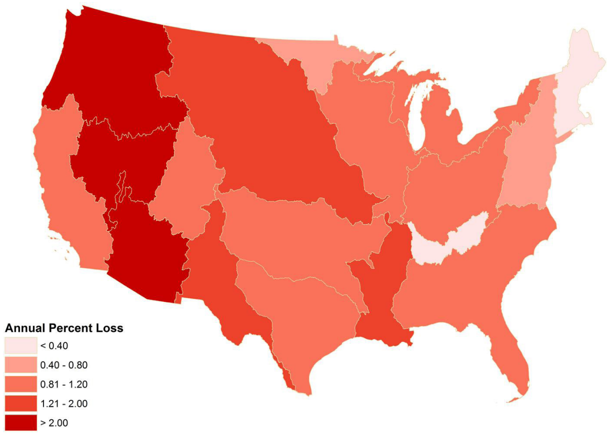
Reservoir storage, created by dams, is critical to the delivery of water resources to western communities in the late summer and early fall. The annual loss of storage capacity in US reservoirs (**Figure 2.4.23**) has been as high as 2 per cent per year in the west where rivers naturally carry large quantities of sediment, predicting a useful life of less than 50 years (Graf *et al*. 2010). Because reservoirs increase the surface area of water in a system, the evaporation from dams represents an important water loss to western areas. In the early 1960s, the USGS estimated that evaporation from reservoirs and

Figure 2.4.22: Rate of dam removal in the US, 1915-2014



Source: O'Connor *et al.* 2015

Figure 2.4.23: Annual storage loss of US reservoir capacity, 2012



Distribution of mean annual loss of reservoir capacity in the continental US. The water resource regions are broadly defined by large river basins.
Source: Graf *et al.* 2010

Glen Canyon Dam on the Colorado River
© Christine Chessia

regulated lakes in 17 western states was 12 229 000 acre-feet and represented more than half of the evaporation of water surfaces (Meyers 1962). More recently, the US Bureau of Reclamation is evaluating evaporation losses in 8 major western river basins, and found that evaporation from Lake Powell and Lake Mead alone represented 10 per cent of the total natural flow in the Colorado River basin (Blanken and Huntington 2015). These findings highlight the need to identify alternative mechanisms for storing water in western states that do not result in high evaporative losses.

Because of the effects of dams on stream and river ecosystems and the high maintenance costs associated with sedimentation and evaporative losses, there has been a recent trend to remove or decommission dams throughout the US (O'Connor *et al*. 2015), where more than 500 dams were removed between 2006 and 2014 (**Figure 2.4.22**). Most river channels stabilized within months, and migratory fish populations have responded quickly to restored river connectivity, indicating a high degree of resilience (O'Connor *et al*. 2015).

An emphasis on better understanding ecological flow requirements has emerged throughout North America in recent years. While many jurisdictions still do not have established processes for considering environmental flows (Linnansaari *et al*. 2013), science-based frameworks have been developed and are being implemented. For example, the Ecological Limits of Hydrological Alteration (ELOHA) was developed to provide a practical framework that could be applied at a regional scale to facilitate the consideration of environmental flows into water decision-making (Poff *et al*. 2010). To date, ELOHA has been applied in at least 10 states in the US as well as in numerous countries worldwide.

2.5 Coastal, marine, oceans

2.5.1 Introduction

Much progress has been made in controlling coastal pollution from point sources. Non-point sources, such as farms, roadways and urban or suburban landscapes remain largely uncontrolled, and are major sources of continuing pollution, especially of nutrients that lead to algal blooms and hypoxia. The historic use of some chemicals no longer manufactured in North America, for example dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs), has left a legacy of contamination, although their levels have been decreasing due to effective policies. These persistent chemicals remain in sediments, and continue to exert toxic effects long after their use has ceased. Continuing and worsening issues include ocean warming and acidification; marine debris, especially plastics; and chemicals of emerging concern such as pharmaceuticals.

2.5.2 Climate-related threats: warming, sea-level rise and ocean acidification

Ocean warming

Ocean warming (see Section 2.3) presents challenges for marine life. One of the major and most conspicuous effects of warmer waters is coral bleaching, the whitening of corals due to stress-induced expulsion of their symbiotic zooxanthellae, single-celled photosynthetic organisms, which are responsible for most of the nutritional needs of the coral animals. If a coral colony survives the stressful period, zooxanthellae may be able to recolonize after weeks or months. Some species of zooxanthellae and corals are more resistant to stress than others (NOAA 2014). If the stress is prolonged and the zooxanthellae cannot recolonize, the coral die. Large coral colonies, such as *Porites*, are able to withstand extreme temperature shocks. Other, more fragile branching corals are more susceptible to stress following temperature change. Coral reefs in North America are found in Hawaii, Florida and Caribbean and Pacific islands.

Coral bleaching

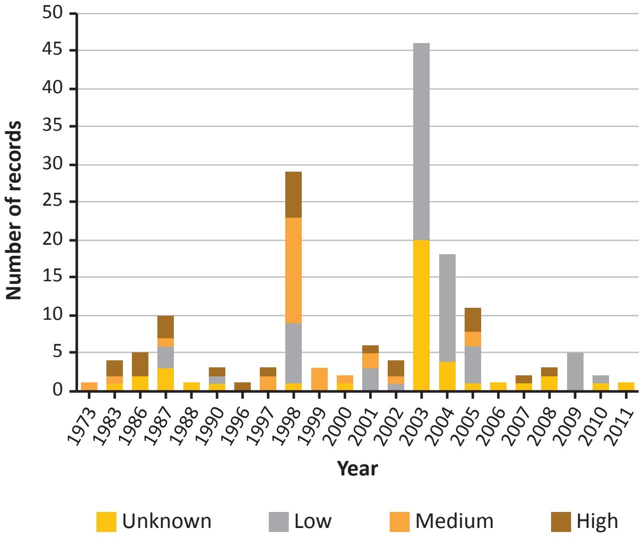
Bleaching occurs when stress causes corals to expel their algal symbionts, and thus turn white. There has been a general upward trend in bleaching since 1980 (**Figure**

Key messages: Coastal, marine, oceans

The coastal and marine environment is under increasing threat in the region, both from harmful trends regarding some traditional environmental pressures such as nutrient loads, as well as new pressures such as ocean acidification, ocean warming, sea-level rise, and novel forms of marine debris.

- Despite the significant progress made in controlling coastal pollution from point sources in North America, non-point sources, such as farms, roadways and urban or suburban landscapes remain largely uncontrolled, and are major sources of continuing pollution, especially nutrients that lead to algal blooms and hypoxia.
- The historic use of some chemicals no longer manufactured in North America, for example dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs), has left a legacy of contamination, although their levels have been decreasing due to effective policies.
- Continuing and worsening issues include ocean warming and acidification; marine debris, especially plastics; and chemicals of emerging concern including pharmaceuticals.

Figure 2.5.1: US Coral bleaching, 1980-2011



Source: Reef Base 2013

Coral bleaching
© NOAA

2.5.1), as ocean temperatures rise, and they are expected to increase in frequency and intensity. Events as severe as that in 1998 are expected to become commonplace, and bleaching events will occur annually in most tropical oceans by the end of the next 30–50 years (Hoegh-Guldberg 1999). In the autumn of 2015, Hawaii suffered the worst bleaching in its history as surrounding water temperatures rose at abnormal rates (Ku'ulei *et al*. 2015).

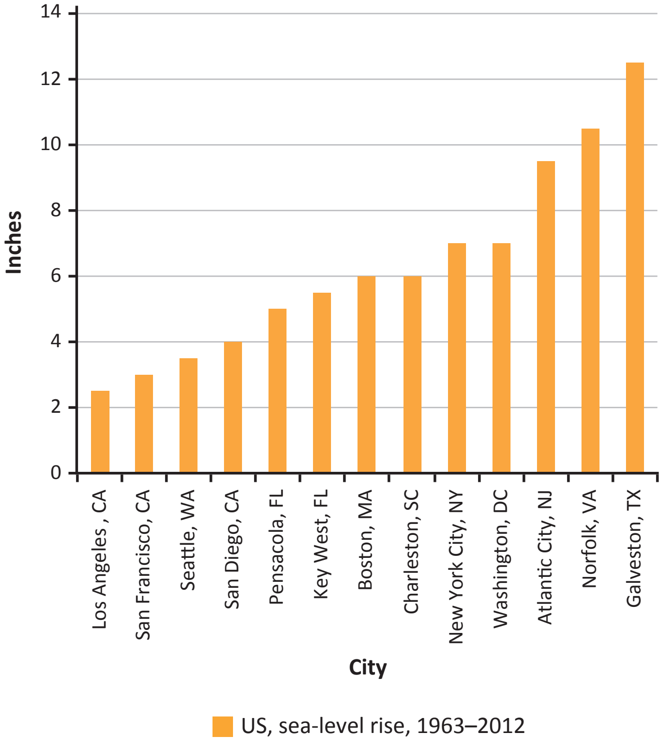
Variation in temperature can also affect the abundance and distribution of plankton. As the ocean surface warms, it becomes more stratified, with larger temperature differences between warm surface water and cooler deeper water. Vertical water movements – upwellings, which bring nutrients up from deeper water to surface waters where most of the phytoplankton live – are reduced. Consequently, phytoplankton receive fewer nutrients and are therefore less productive. Upwellings can be stimulated by mixing due to wind, less wind means less mixing, fewer nutrients for phytoplankton, and fewer phytoplankton to sustain fish populations (Behrenfeld *et al*. 2006).

In response to warming, the geographical ranges of marine species are likely to change, including movements to toward the poles and/or greater depths where temperatures are more suitable. If the oceans continue to warm as projected, there will be a decline in the abundance and diversity of phytoplankton in tropical waters as they shift towards the poles. The poleward movement of many marine animals has already been observed (Poloszanka *et al*. 2013) and many fish species have also been reported to be moving toward the poles (NOAA 2014). Animals that already live in polar regions, however, are finding their habitat shrinking as the ice melts – polar bears, for example, require sea ice, which is disappearing from the Arctic at an alarming rate.

Sea-level rise

Sea-level rise is caused by thermal expansion of the warmer ocean water and by melting glaciers and ice sheets that contribute new water to the ocean. Over the 20th century, global sea level rose at an average rate of about 2

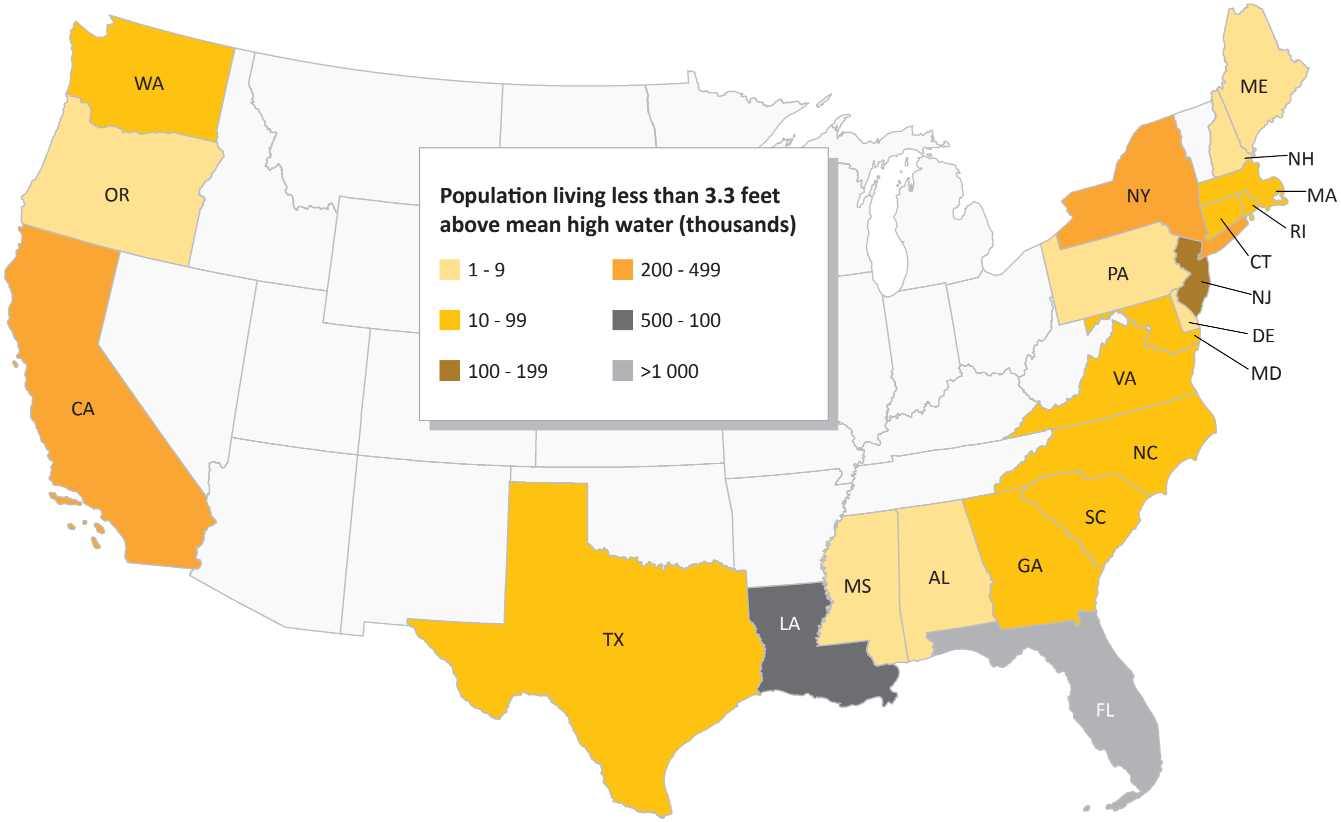
Figure 2.5.2: US, sea-level rise, 1963–2012



Source: Straus *et al.* 2012

millimetres per year, substantially greater than the rate of the previous three millennia. Recent measurements and re-analysis indicate that sea level is already rising twice as fast as in previous decades and is exceeding the rise predicted by climate models (Hay *et al*. 2015). About 25–50 per cent of sea-level rise since 1960 has been attributed to thermal expansion. Small glaciers and ice caps shrank considerably during the 20th century and freshwater run-off from melting land-based ice is projected to increase. Over the past 20 years melting glaciers have become a major contributor to sea -level rise (Larsen *et al*. 2015), and will remain the dominant contributor in the 21st century if current trends continue.

Figure 2.5.3: US coastal states at risk of sea-level rise



People in states with low-lying coastlines have been subject to severe flooding and damage from coastal storms in recent years. Although all coastal states are vulnerable, Florida, Louisiana, New York, and California have the most residents living on land less than 3.3 feet above high tide.
Source: Adapted from NOAA 2012a; Strauss *et al.* 2012

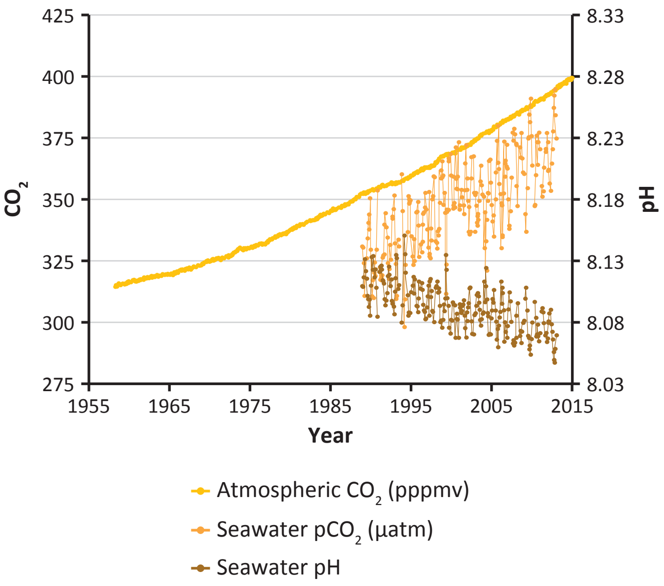
Rising sea-levels could make entire areas and island nations uninhabitable or extremely vulnerable to flooding and storms. Because of dense concentrations of people and development in coastal zones, many countries are vulnerable to sea level rise and coastal flooding. Tens of millions of people around the world are already exposed to coastal flooding from tropical cyclones and climate change has the potential to increase flooding from more severe hurricanes and sea level rise. Developing countries, particularly small islands and low-lying areas, are especially vulnerable and have limited capacity to adapt to rising sea levels (UNEP 2014). Low-lying areas in developed countries, such as Long Island, New York, and South Florida are also at great risk (**Figures 2.5.2** and **2.5.3**). Coastal populations are particularly vulnerable to natural disasters including tsunamis, floods, and hurricanes. Since over a third of the world's population lives in coastal zones within 100 kilometres of the shore, effects could be disastrous.

Sea-level rise also affects natural communities such as salt marshes and mangroves at the edge of the water. These communities will have to migrate inland or increase their elevation in order to avoid being submerged by rising seas. As these are important habitats for birds and marine animals that use them as nursery habitats, many species are at risk if these wetlands cannot migrate. Coastal salt marshes and mangroves also serve as buffers, protecting human communities from storm surges and flooding. These wetlands provide many other benefits to humans, including habitat for commercially important fisheries and wildlife; improved water quality through sediment, nutrient, and pollution removal; recreation; and aesthetic values. These valuable ecosystems are highly vulnerable to the sea-level rise projected to occur during the next century as a result of global warming. In many areas, marshes are not expected to be able to increase their elevation fast enough to keep up with sea-level rise, but if storms transport new sediments into the marshes, they may be able to increase their elevation and persist for a longer time. In developed areas, there are roads, houses, etc. just landward of the marshes, which prevent them from migrating inland.

Ocean acidification

When carbon dioxide from fossil-fuel burning enters the atmosphere (see Energy in Section 2.9), about one-third of it dissolves in the ocean where it combines with water to form carbonic acid, which becomes bicarbonate ions and hydrogen ions, making the water more acidic (**Figure 2.5.4**). Since the industrial age began in the 19th century, the acidity of the oceans has increased by 0.1 pH unit, which represents a 30 per cent increase in acidity. The extent of ocean acidification varies naturally between seasons, from one year to the next, and among regions and locations. Winds and currents that carry water around the ocean create localized pathways and acidic patches. In addition, direct observations only go back 30 years. Nevertheless, if carbon dioxide emissions continue at the present rate, models project an average worldwide increase of 0.2-0.3 pH units by 2100, in addition to what has already happened, doubling the current ocean acidity. The current change is extremely fast, more than one pH unit to 200 years. While some marine organisms will be able to tolerate these conditions or evolve to tolerate them, changes may be too fast for many to adapt (Kroeker *et al.* 2010).

Figure 2.5.4: Rising CO_2 in atmosphere, CO_2 in oceans, and pH of seawater



The graph shows the correlation between rising levels of carbon dioxide (CO^2) in the atmosphere at Mauna Loa with rising CO2 levels in the nearby ocean at Station Aloha. As more CO2 accumulates in the ocean, the pH of the ocean decreases.
Source: Adapted from Feely *et al.* 2009

Ocean acidification threatens the ecological health of the oceans and the economic wellbeing of the people who depend on a healthy marine environment. It is expected to harm a wide range of ocean life, particularly those that use calcium and carbonate ions from seawater to produce calcium carbonate for their shells. Larval molluscs and some other calcifying organisms are already showing impaired shell formation at some locations, and calcareous plankton, including some phytoplankton at the base of oceanic food webs, corals and shellfish are threatened.

Water off the North American Pacific coast already has a low carbonate saturation state. When surface winds blow the top layer of water out from coastal regions, deeper water with higher acidity can well up, and harm shellfish. Periodic upwelling of carbon-dioxide-rich water has already happened on the US west coast, where larval oyster survival has been very low. There has been a reduced natural set of juvenile oysters in some Pacific coast estuaries where the commercial shellfish industry relies on natural reproduction of oysters. Researchers showed that impaired shell production by larval oysters was due to the increased acidity of the water (Barton *et al*. 2012). Hatchery staff now monitor ocean pH levels and time water intakes to ensure that oysters are exposed to less acidic water.

Ocean acidification effects are not restricted to shell production. Effects have been seen on behaviour and development of a number of marine animals. Exposure of eggs and larvae of a common estuarine fish to elevated carbon dioxide severely reduces survival and growth (Baumman *et al*. 2012). Behaviour is also altered in many animals, especially that related to the olfactory system. Fish in acidic water in the lab or living next to natural seeps, where carbon dioxide is released by volcanic activity, lose their natural fear of the odour of predators and become attracted to them. But predatory behaviour can also be impaired. Munday *et al*. (2014) found that shark attraction prey odour decreases in seawater with elevated carbon dioxide levels.

Eutrophication is an additional source of carbon dioxide in coastal waters (Sunda and Cai 2012). As organic matter decays and uses up oxygen, it also releases carbon dioxide, which speeds up acidification of coastal waters and estuaries in particular. Combined effects of hypoxia and acidification intensify the negative effects (Gobler *et al*. 2014). While the long-term solution to ocean acidification is reducing emissions of carbon dioxide through international agreements, other short-term approaches are feasible locally. Since excess nitrogen (eutrophication) contributes to elevated carbon dioxide levels in coastal waters as well as reduced oxygen, it is possible to mitigate acidification by reducing effluents and runoff of nutrients.

2.5.3 Water quality: key threats and their implications

Contaminants

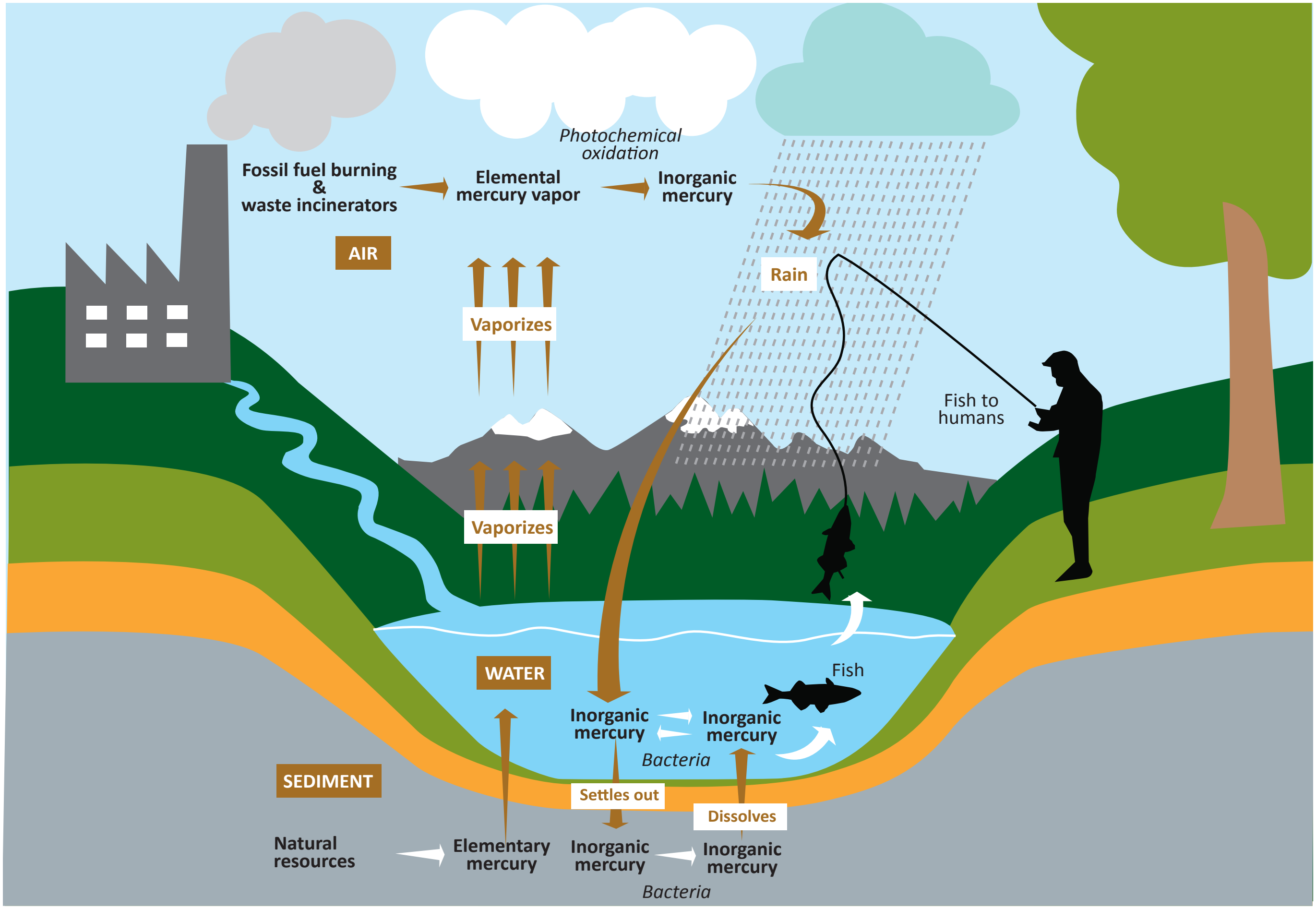
Toxic chemicals that were recognized decades ago as threats are generally declining slowly. Toxicants can disrupt metabolic, regulatory or disease defence systems, and compromise reproduction and even survival. Early life stages, gametes, fertilization, embryonic and larval development, are most sensitive. The hormonal control of reproduction can be affected by many contaminants, now called endocrine disruptors (Colborn *et al*. 1993). Exposures during early life stages may cause effects that appear later, sometimes many years later. Thus, long-term delayed effects and indirect effects are important.

Metals

The US National Oceanic and Atmospheric Administration (NOAA) survey of metals in coastal bivalve molluscs, the mussel watch programme, found no overall national trends (Kimbrough *et al*. 2008). There were 27 sites that had significant decreases, many in southern California, while nine showed significant increases. Levels were highest in urban and industrialized areas. Copper and mercury are among the most toxic metals to aquatic life. The fish olfactory system is especially sensitive to copper (Hansen *et al*. 1999; Hansen *et al*. 2004) and it is also especially toxic to algae and molluscs; it is used as an algicide and molluscicide. Mercury is a highly toxic metal that is found both naturally and as a contaminant. Its risk is determined by the form of mercury present in the environment. Methylmercury is the most toxic form (AMAP 2016; Legrand 2010), and inorganic mercury can be converted to methylmercury by bacteria in marine sediments. In addition to being far more toxic than inorganic forms of the metal, methylmercury is also biomagnified up the food chain.

Certain types of chemical contaminants, including methylmercury and chlorinated hydrocarbons tend to biomagnify through food webs, so the top carnivores have

Figure 2.5.5: Pathways of mercury into fish and humans



Source: Adapted from Driscoll *et al.* 2013

the highest body burdens of these harmful chemicals. Top carnivores include large, long-lived fish such as tuna, sharks and swordfish that are eaten by humans, who can be affected by eating them. The development of the human nervous system is especially sensitive to methylmercury (Boucher *et al*. 2012).

Effects of build-up of toxic chemicals are slow and chronic, rather than showing acute illness as caused by pathogens or algal toxins. The consumption of fish is by far the most significant source of ingestion-related mercury exposure in humans (**Figure 2.5.5**). Young children and pregnant women are the most vulnerable. Since mercury is a neurotoxin, symptoms typically include sensory impairment (vision, hearing, and speech), disturbed sensation and poor coordination (Counter and Buchanan 2004).

Sediment cores indicate reductions in mercury in water bodies over time (Wentz *et al*. 2014), suggesting that levels in fish will decrease. Monitoring and posting of no-fishing signs and fish advisories where levels are high can reduce human consumption of fish contaminated with mercury or other toxicants such as PCBs. However, individuals in lower income groups may be more likely to ignore the warnings in favour of a "free meal" and limited other food options available to them, an issue related to environmental justice.

Petroleum hydrocarbons

Petroleum hydrocarbons have been a long-standing problem, despite the number of spills from tanker ships decreasing over the past three decades, both large spills and small ones (Musk 2015). The NOAA mussel watch programme found decreases in polyaromatic hydrocarbons (PAH) over two decades (Kimbrough *et al*. 2008).

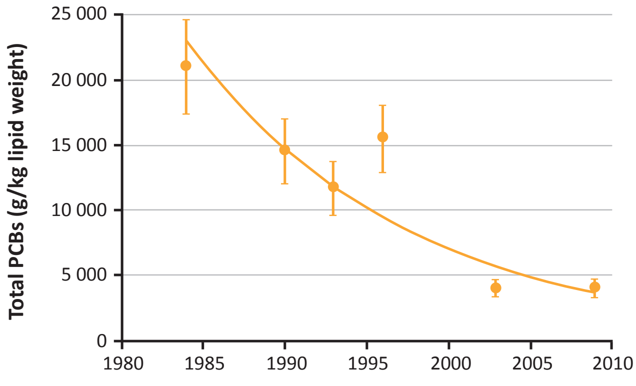
Nonetheless there is great public concern about oil spills and the resultant shoreline fouling and mortality of marine birds and mammals. Major oil disasters in recent years include the Exxon Valdez in Alaska in 1989 and the 2010 blow-out of the BP Deepwater Horizon well in the Gulf of Mexico. Many of the major spills have had long-term consequences, associated mainly with estuaries and marshes, due to the persistence of petroleum fractions in these low-energy environments (Peterson *et al*. 2003; Sanders *et al*. 1980). The bio-availability of residual oil to animals that live beneath the surface of the sea or lake floor is influenced by water solubility, weathering rate and sediment grain size. Effects on behaviour, development, genetics, growth, feeding and reproduction may last for decades (Macdonald *et al*. 2008). After a spill, most of the oil undergoes a weathering process, but in marshes or sandy beaches it can sink to depths where it persists for decades in the absence of oxygen. After the Exxon Valdez spill it became clear that long-term impacts at the population level, as well as interactions among species and abiotic variables, need to be considered (Peterson *et al*. 2003). The application of dispersants may increase toxicity by increasing hydrocarbon exposure to water-column species. Many scientists are concerned about severe impacts on Gulf species exposed to Corexit, a dispersant, and oil in the water column. For vulnerable species such as seagrasses, corals, plankton, shrimp, crabs and small fish, the toxicity of dispersants plus oil is greater than that of oil alone (Anderson *et al*. 2009, Couillard *et al*. 2005, Ramachandran *et al*. 2004).

Persistent organic pollutants

Persistent organic pollutants (POPs) that have been of greatest concern are chlorinated pesticides and polychlorinated biphenyls (PCBs), both of which were banned in the 1970s in both Canada and the US. Only recently have people become concerned about persistent brominated and fluorinated chemicals; these are discussed below in the section on Contaminants of Emerging Concern.

NOAA's mussel watch programme found significant decreases in chlorinated pesticides (chlordanes, DDTs, dieldrins) over two decades, as well as in PCBs (Kimbrough *et al*. 2008). Monitoring of fish in North America indicates a sharp decline in levels following the bans of organochlorines, demonstrating the success of these policies. Surveys have shown a consistent decline in DDT in the early 1980s.

Figure 2.5.6: Canada, PCB reductions in harbour seals, 1980–2010



Source: Ross *et al.* 2013

PCBs, which are also chlorinated hydrocarbons, were banned in the US in 1979. Canada prohibited the import and sale of PCBs, and restricted their use in 1977. PCBs include more than 200 congeners with differing numbers of chlorines on different locations on the biphenyl structure, and have a range of toxicity. Polychlorinated biphenyls were used in industrial and commercial applications including electrical equipment; as plasticizers; in pigments and copy paper; and other applications. The entered the environment during their manufacture as well as use. They can still be released into the environment from poorly-maintained hazardous waste sites, leaks from electrical transformers and disposal of PCB-containing products into landfills.

Chlorinated hydrocarbons are highly persistent and remain in the environment, especially in sediments, so they continue to be found long after being banned (King *et al*. 2004). Resistant to microbial degradation, they remain for long periods, cycling between air, water and soil. PCBs are carried long distances and have been found far away from where they were released. Like chlorinated pesticides and methylmercury, PCBs biomagnify. Animals higher on the food chain have higher concentrations than smaller ones. Levels are decreasing following the ban on use. **Figure 2.5.6** shows reductions in PCBs in harbour seals in Canada (Ross *et al*. 2013).

Noise pollution

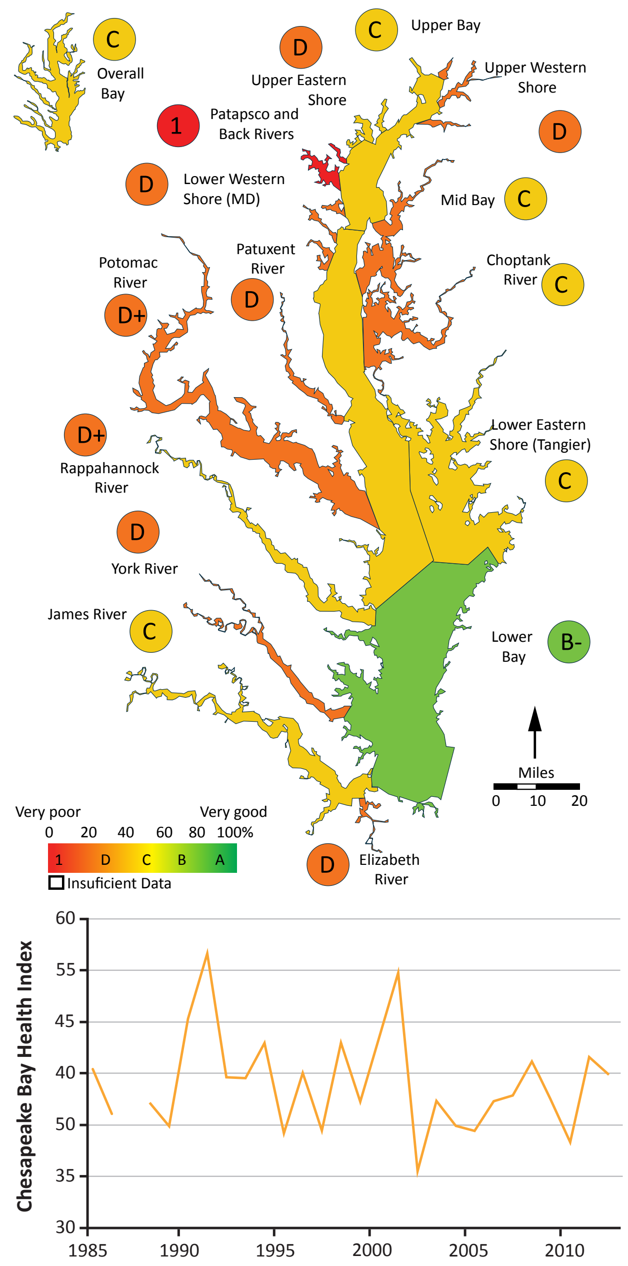
Noise pollution in the ocean is another emerging concern. Many marine species have specialized hearing, communication skills and echo-location abilities. Human activities such as commercial shipping, exploration and extraction of oil and minerals, air guns used for seismic exploration, sonar and even jet skis contribute to the increased level of underwater noise. Sound travels four times faster in water than in air, 1 230 metres per second as opposed to 340 metres per second, so it travels further under water and as water is denser than air, sound waves travel though water at higher energy levels and are hence louder. As a result, high-intensity sound in the oceans can travel for thousands of kilometres and have lethal and sub-lethal effects (André *et al*. 2011). Animals are alarmed by the sounds, which may damage internal organs, especially ears, and cause a panic response. Normal communication between marine animals can be disrupted by noise. The death of animals, especially cetaceans, often occurs hours after exposure to extreme underwater noise (Peng *et al*. 2015) – for example, whales die after beaching themselves shortly after a tactical sonar exercise; this is a rather common occurrence and has been reported in the coastal US areas where sonar exercises are common. Since ships are getting larger, it is likely that noise pollution is increasing but data on this trend could not be identified.

Nutrients and eutrophication

Nutrient enrichment due to excessive amounts of nitrogen is the main cause of impaired coastal waters worldwide, including North America. Sewage, even after treatment, contains high levels of nutrients, while excess nitrogen flows from agricultural fields, suburban lawns and stockyards, entering freshwater and going down to estuaries along streams and rivers. It is also released from septic tanks and reaches water bodies through groundwater, and comes from the atmosphere in precipitation. These nutrients cause algal blooms and when the algae die and sink to the bottom, bacterial decay uses up oxygen, resulting in hypoxia (low oxygen) in deeper waters. Seasonal occurrences of dead zones with no oxygen have expanded in many areas, and are abundant and increasing along the coasts of North America, the largest being in the Gulf of Mexico.

Studies by the US EPA in the 1980s established that excess nitrogen and phosphorus were the main source of pollution in the Chesapeake Bay. This finding led to the formation of the Chesapeake Bay Programme (CBP), which is a regional partnership made up of federal and state agencies, local governments, non-governmental organizations and academic institutions, with the mission of directing Chesapeake Bay restoration and protection. The CBP Executive Council includes the governors of Maryland, Pennsylvania and Virginia, the Administrator of the US Environmental Protection Agency, and the Mayor of the

Figure 2.5.7: Chesapeake Bay health report card, 1996–2013



Source: The University of Maryland Center for Environmental Science

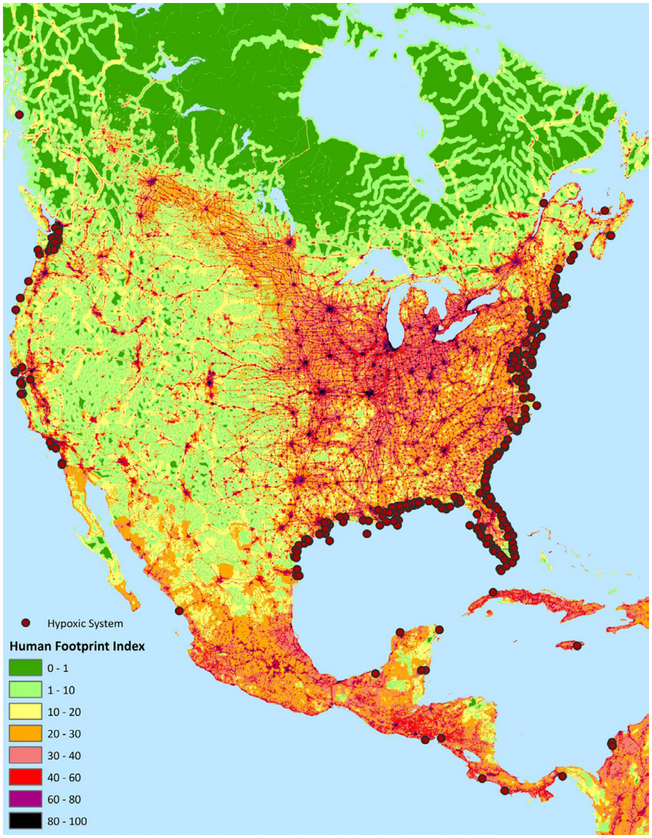
District of Columbia. They are supported by an appointed Management Board, staff assigned from the partner institutions, advisory bodies of citizens, local governments, and scientific institutions, and an independent evaluator action team.

After more than 25 years of restoration efforts, data generally show decreasing long-term pollution trends from the Bay's major rivers. Although some signs in some regions are positive, other key indicators are lagging, including little progress in reducing overall total nitrogen and phosphorous concentrations. Overall, the Bay remains degraded and was recently given an overall score of C in the Bay Health Index for the Chesapeake Bay Report Card by the University of Maryland Center for Environmental Science **(Figure 2.5.7)**. The report card includes 15 reporting regions corresponding to the major tributaries, for which ten indicators (dissolved oxygen, total nitrogen, total phosphorus, chlorophyll a, water clarity, aquatic grasses, benthic community, blue crab, Bay anchovy, and striped bass) are determined annually. Each indicator is compared to scientifically derived thresholds or goals and scored to determine the overall grade. The objectives are not only to track progress on reaching restoration goals for the Chesapeake Bay, but also to galvanize efforts by communities and states to improve their grades.

Algal blooms that produce toxins may result in fish kills, human illness through shellfish poisoning, and death of marine mammals and shore birds. Not only has the frequency of harmful algal blooms been increasing, new toxin-producing species have been found to cause serious problems. **Figure 2.5.8** shows sites where harmful algal blooms have occurred along almost the entire North America Atlantic coast.

Toxins produced by these species of plankton can be accumulated by filter-feeding shellfish. When people consume these shellfish, they can be subjected to a variety of diseases that can be serious, and sometimes deadly. Dinoflagellates are the major causative agents, producing toxins that can be effective at very low dosages. Consumption

Figure 2.5.8: North America, harmful algal blooms on the Atlantic and Pacific Coast, 2011



Source: Adapted from Diaz *et al.* 2011; WCS/ CIESIN 2005

of seafood contaminated by algal toxins results in various poisoning syndromes, including paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, diarrheic shellfish poisoning and ciguatera fish poisoning. Most of these are caused by neurotoxins that have specific effects on the nervous system by interfering with nerve impulse transmission (Wang 2008). The consumption of shellfish, for example mussels and clams, is one of the most common ways for algal toxins to impact human health as cooking does not destroy the toxins. The near-shore marine waters of the US have experienced increases in the number, frequency, and type of harmful algal blooms in recent years.

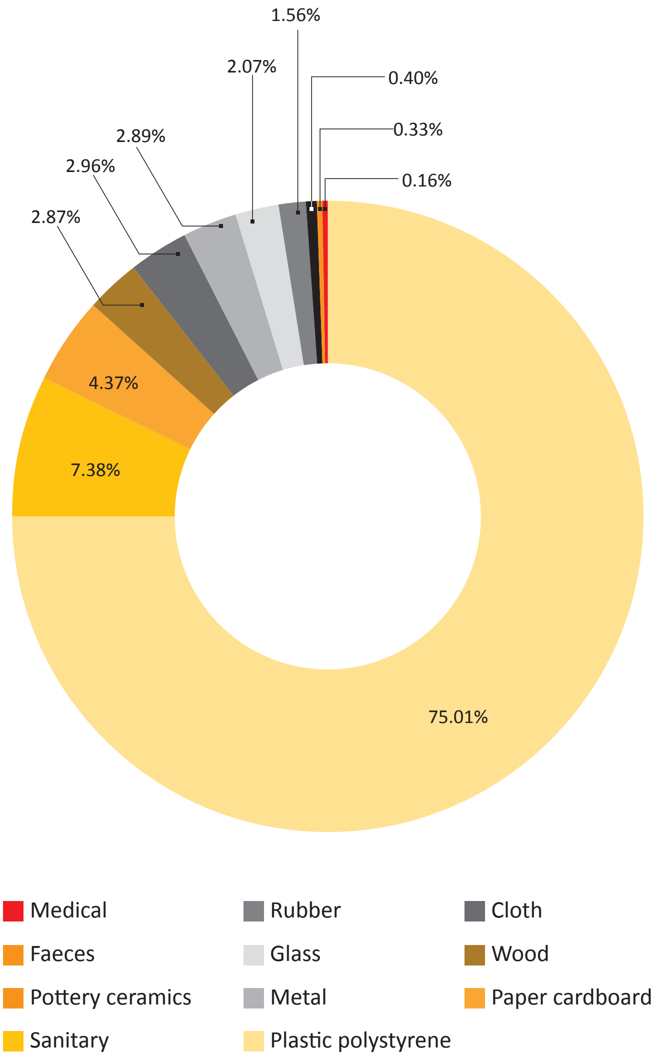
Marine debris: plastics

Some sources of marine debris are littering, dumping in rivers and streams, lost fishing gear, poorly managed landfills in coastal areas, and industrial losses, for example spillage of materials during production, transport and processing (Browne *et al.* 2011). It is estimated that about 4.8-12.8 million tonnes of plastic alone end up in the oceans every year from land-based sources (Jambeck *et al*. 2015). This estimate does not include sea-based sources, or other types of marine litter. Plastics comprise a large proportion of the total debris (**Figure 2.5.9**), and the variety and quantity of plastic items has increased dramatically, including domestic material, shopping bags, cups, bottles, bottle caps, food wrappers, balloons, etc.; industrial products, plastic sheeting, resin pellets, etc.; and lost or discarded fishing gear, including nets, buoys, traps, lines, etc.

In addition to the visible litter that washes up on beaches, entangles marine animals and is ingested by marine animals, microplastics (less than 5 mm diameter) can be generated from breakdown of larger pieces, from washing synthetic clothes, or from microbeads contained in personal care products. Plastic pieces smaller than 1 millimetre are accumulating in the marine environment and eaten by filter feeding animals and entering the food chain (Law *et al.* 2010). Ingestion of microplastics has been demonstrated in a range of marine organisms, a process that can cause deleterious physiological effects and may also facilitate the transfer of chemical pollutants to biota, since many chemicals concentrate on the surface of microplastics (Wright *et al*. 2013a, b) (see also discussion in Sections 2.3.6 and 2.6.1).

A new report (Rochman *et al*. 2015) suggests that an outright ban on the use of microplastics in products that enter wastewater is the best way to protect water quality, wildlife, and resources used by people. Non-toxic and biodegradable alternatives exist and some companies have committed to stop using microplastics in their products (Rochman *et al.* 2015). However, "biodegradable" plastics generally don't degrade at the temperatures of the marine environment, and such plastics may fragment more readily.

Figure 2.5.9: Marine litter, proportion of categories on reference beaches



Source: Ocean Health Index 2015

The Government of Canada is working towards adding microbeads to the List of Toxic Substances under the Canadian Environmental Protection Act, 1999 and developing regulations that would phase out the use of microbeads in personal care products (see Proposed Regulation, February 2016). In the US, after various states passed bans, Federal legislation was passed banning microbeads in personal care products, which was signed into law in December 2015.

2.6 Chemicals and wastes

2.6.1 Introduction

Chemicals are an integral part of everyday human life in the 21st century with over 100 000 different substances in use. Industries producing and using these substances have an enormous impact on employment, trade, and economic growth worldwide. There is hardly any industry where chemical substances are not implicated, and there is no single economic sector where chemicals do not play an important role.

Often the benefits from chemicals come at a higher than expected price. It is increasingly recognized that, if not managed properly, many chemicals can threaten human and environmental health. Health-related consequences range from acute poisoning to slow-onset conditions, and to long-term outcomes such as birth defects, neurological disorders, hormone disruption, and cancers. Chemicals and wastes continue to pollute North American water, air, and soils, despite concentrations of tracked pollutants decreasing by 70 per cent or more since the 1980s. This decrease resulted from public demand, legislative action, and technological innovation. However, non-traditional pollution sources present new threats to human and ecosystem health. They include novel materials such as microbeads used in cosmetics; new combinations of toxic materials such as ash residue from coal scrubbers; and hazardous compounds resulting from hydraulic fracturing and tar sands exploitation (UNEP 2012).

Key messages: Chemicals and wastes

Concentrations of tracked pollutants have decreased by 70 per cent or more since the 1980s, however, chemicals and wastes continue to pollute North American water, air, and soils.

- Legislative action, technological innovation, and public demand have contributed to important progress in reducing chemical pollution and improving waste management in North America.
- However, progress in chemical and waste management has been uneven across different sectors and is not increasing at a rate that would yield timely solutions to current problems.
- Non-traditional pollution sources, including novel materials and new combinations of toxic materials, such as ash residue from coal scrubbers and hazardous compounds resulting from hydraulic fracturing and tar sands exploitation, present new threats to human and ecosystem health.
- Pharmaceuticals, personal care products, estrogens, and other contaminants not previously recognized as pollutants, have been found at low concentrations in water, sediments and organisms as they are not removed from wastewater by sewage treatment plants.
- Additional resources, human and financial, are required, for improved chemicals and wastes management together with a more robust legislative structure and capacity to better report and monitor data across sectors and jurisdictions.

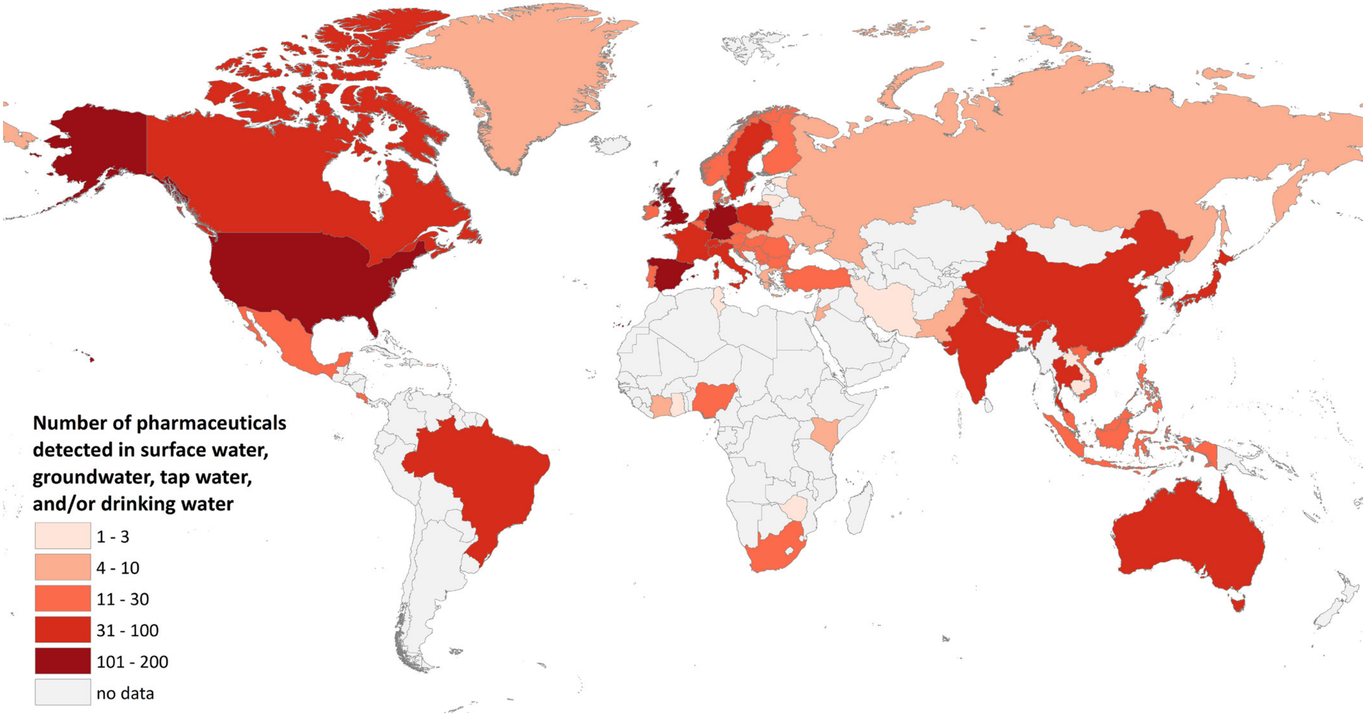
2.6.2 Contaminants of emerging concern

Wastewater contaminants

Pharmaceuticals, personal care products, estrogens, and other contaminants not previously recognized as pollutants, have been found at low concentrations in water, sediments and organisms as they are not removed from wastewater by sewage treatment plants (Daughton and Ternes 1999). Despite their disparate properties and sources, the common threads of these contaminants include their frequent detection in aquatic systems once they are sought (Cizmas *et al.* 2015) and the fact that their effect on water quality, aquatic food webs, and human health is not well understood, either as single compounds or as mixtures (Schaumann *et al.* 2015; Bellenger and Cabana 2014; Rosi-Marshall and Royer 2012). These threads also apply to some of the best-studied products such as pesticides: while there may be large quantities of toxicity data for the active ingredients, there is little understanding of effects from degradation products or novel mixtures that challenge attempts at risk assessment (Canadian Council of Academies 2012).

Pharmaceuticals and personal care products are contaminants with various potential environmental and human health implications (Arnold *et al*. 2014). More pharmaceuticals have been detected in North America than most other regions of the world (**Figure 2.6.1** and **2.6.2**). Recently, North American water bodies have been shown to contain antidepressants (Metcalfe *et al*. 2010), hormones (Conley *et al*. 2016), and antibacterial personal care products such as triclosan (Drury *et al*. 2013). In an aquatic environment, triclosan generates dioxins and other hazardous substances and is bioaccumulative (Halden 2015).

Figure 2.6.1: Pharmaceuticals in surface water, tap water and/or drinking water, 2013

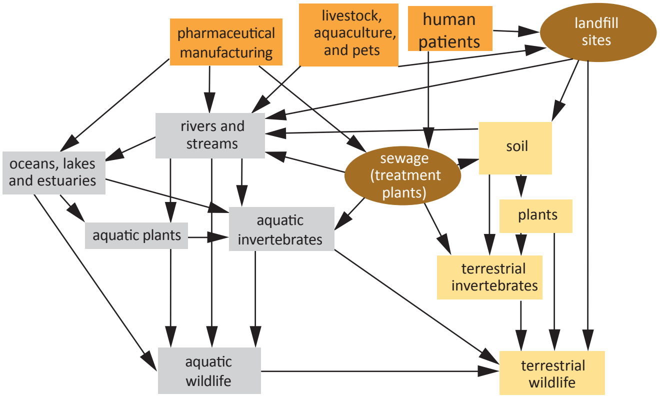


Source: Adapted from Weber *et al.* 2016

Harmful effects of pharmaceuticals and endocrine disrupting compounds released from wastewater systems extend to natural ecosystems far from urban waste cycles. While the health benefits of medication are important for humans and livestock, the potential environmental risks of these substances to wildlife are just beginning to be clarified. A controlled experiment studying the effects of endocrine disruptors on fish found that exposure to synthetic oestrogen at concentrations similar to those found in wastewater resulted in near-extinction of the population (Kidd *et al.* 2014). There are a number of uncertainties associated with the environmental risk assessment of pharmaceuticals in the wild due to lack of knowledge concerning their fate in wastes and the environment, their uptake, metabolism and excretion in wildlife, and their target affinity and functional effects in non-target species (Arnold *et al*. 2014).

There are serious environmental hazards posed by two chemicals commonly used as antibacterial agents in a broad range of consumer products such as liquid soaps, toothpaste and deodorant (Aiello *et al*. 2007; Larson *et al*. 2004; USFDA 2013). A range of studies has produced no evidence suggesting that antibacterial soap and products provide any greater health benefits compared with old-fashioned soap and water. Furthermore, studies verified by GreenScreen assessment found that Triclosan and Triclocarban, both

Figure 2.6.2: Pathways of pharmaceuticals in the environment



Pharmaceuticals can disperse through the environment through multiple and potentially complex pathways. Sources of pharmaceuticals in the environment (orange boxes) include pharmaceutical manufacturing, livestock, aquaculture and pets, and human patients. Pharmaceuticals can then disperse directly into the environment or via sewage treatment facilities and landfill (ovals). The fate of pharmaceuticals in aquatic (grey boxes) and terrestrial environments (light brown boxes) can result in uptake of pharmaceuticals in wildlife. Simple food webs are shown to illustrate the potential for pharmaceuticals to bioaccumulate.
Source: Adapted from Arnold *et al.* 2014

found in antibacterial products, have a broad range of negative effects ranging from significant damage to aquatic ecosystems to potentially interfering with the human endocrine system. A remarkable 95 per cent of Triclosan and most of Triclocarban goes into the sewage system and subsequently into lakes and rivers.

Plastics, microbeads, and nanoparticles

Plastic debris represents an additional group of emerging contaminants, and includes macroplastics (>5mm) and microplastics. Microplastics are generally defined as small pieces of plastic <5 mm in diameter that may come from personal care products, synthetic clothing fibres, or breakdown of macroplastics (see also discussions in Section 2.5, 2.3.6 and chapter 4).

As with other emerging contaminants, challenges remain with data availability and comparability to understand the extent of plastic contamination in North American freshwater systems. In the Great Lakes, surface water densities of plastics are as high as those reported for some ocean gyres (Driedger *et al.* 2015). Because plastics degrade slowly in the environment, the effects on open-water, shoreline, and benthic environments are worrisome for lake managers. Efforts to resolve the problem of plastics in the Great Lakes through reduction of plastic debris entering the system as well as clean-up are estimated to cost more than USD 400 million per year (Driediger *et al.* 2015).

Plastic debris remains a concern and has garnered international recognition as a problem, particularly in marine systems and for wildlife (Provencher *et al.* 2015; UNEP Yearbook 2014). Despite the general attention it has received, the presence of plastic debris making its way back to humans through the food web has only recently been documented: of the fish recently sold for human consumption in a Californian market, 25 per cent were found to contain microplastic debris (Rochman *et al.* 2015b). Indeed, compared to other contaminants of emerging concern, microplastics have received the least research attention to date, though they are now becoming a major interest (Halden 2015).

One of the greatest threats to marine biodiversity is the accumulation of plastics in the oceans, lakes, and rivers. While this problem has been acknowledged for many years in the context of the oceans, recent findings indicate disturbing levels of micro-bead plastic in the Great Lakes and St. Lawrence basin (Provencher 2014; Johnston 2013). Remote Arctic sea ice has already been found to contain high concentrations of microplastics, and the extent to which melting ice will release anthropogenic particulates back into the ocean is not yet fully known (Obbard 2014). Microplastics have already entered the food chain and are regularly ingested by fish, birds, and marine mammals; toxic bioaccumulation, and in some cases asphyxiation and starvation, often result.

Microbeads in personal care products are designed to be flushed down drains, ultimately ending up in both freshwater and marine environments and in biota. Much of the focus has been on their presence and effects in marine systems, while information about the fate of both macro- and microplastics in freshwater is still scarce (Eerkes-Medrano *et al*. 2015). While the specific effects on water quality, biota, and human health remain unclear, the presence of microplastics has been documented in a variety of North American lakes and rivers and they may have the potential to affect invertebrates and fish (Eerkes-Medrano *et al*. 2015; Eriksen *et al*. 2013).

Nanomaterials or nanoparticles (<100nm) are another group of emerging contaminants, covering a variety of substances including organic carbon nanotubes and inorganic nanosilver materials, as well as nanoplastics (Bernhardt *et al*. 2010). These materials are used in cosmetics, electronics, drug delivery, manufacturing, paints and other products. They are released into the environment through runoff and sewage effluent and accumulate in depositional environments, including freshwater and coastal areas. The vast number of these products and their extremely small size gives them distinctive properties but also makes understanding their impacts on the environment and human health a major challenge (Schaumann *et al*. 2015; Canadian Council of Academies 2008).

Although the subject of an increasing body of scientific and popular literature, contaminants of emerging concern remain a challenge to regulate due in part to their diversity and quantity, the complexity in monitoring them, the lack of standard products against which to compare them, and uncertainty regarding their impacts on ecosystems and human health. Some monitoring issues might be addressed through the identification of indicator contaminants (Metcalfe 2013).

2.6.3 Risks from extraction and transport of coal, oil, and gas

Every year, the US's coal power plants produce 140 million tonnes of coal ash pollution, the toxic by-product that is left over after coal is burned and results from scrubbing the emissions before they are released into the atmosphere. The ash is typically placed near power plants across the nation—into open-air pits and surface-waste ponds. According to experts, many of these sites lack adequate safeguards, leaving nearby communities at risk from potentially large-

Box 2.6.1: Experimental Lakes Area

Comprised of 58 small lakes and their watersheds, in a sparsely populated region of northwestern Ontario, Canada, the Experimental Lakes Area (ELA) is an exceptional natural laboratory for the study of whole freshwater ecosystems. By introducing and monitoring specific chemicals or physical changes, scientists are able to examine how all aspects of the ecosystem, from the atmosphere to fish populations, respond. This provides real-world, science-based evidence to guide science policy decisions (Norman *et al*. 2015, Kidd *et al*. 2014; Cheng *et al*. 2012; Schindler 2012).

© Canadian Boreal Forest Agreement (CBFA) scale disasters, like the massive coal ash spill in Tennessee in 2008, and from gradual yet equally dangerous contamination when coal ash toxins seep into drinking water sources or are blown into nearby communities (Ruhl *et al*. 2010; Aboulhosn 2011; **Figure 2.6.3**).

Coal ash pollution contains high levels of toxic heavy metals such as arsenic, lead, selenium, and other cancer-causing agents. The public health hazards and environmental threats to nearby communities from coal ash dumping have been known for many years, including increased risk of cancer, learning disabilities, neurological disorders, birth defects, reproductive failure, asthma, and other illnesses.

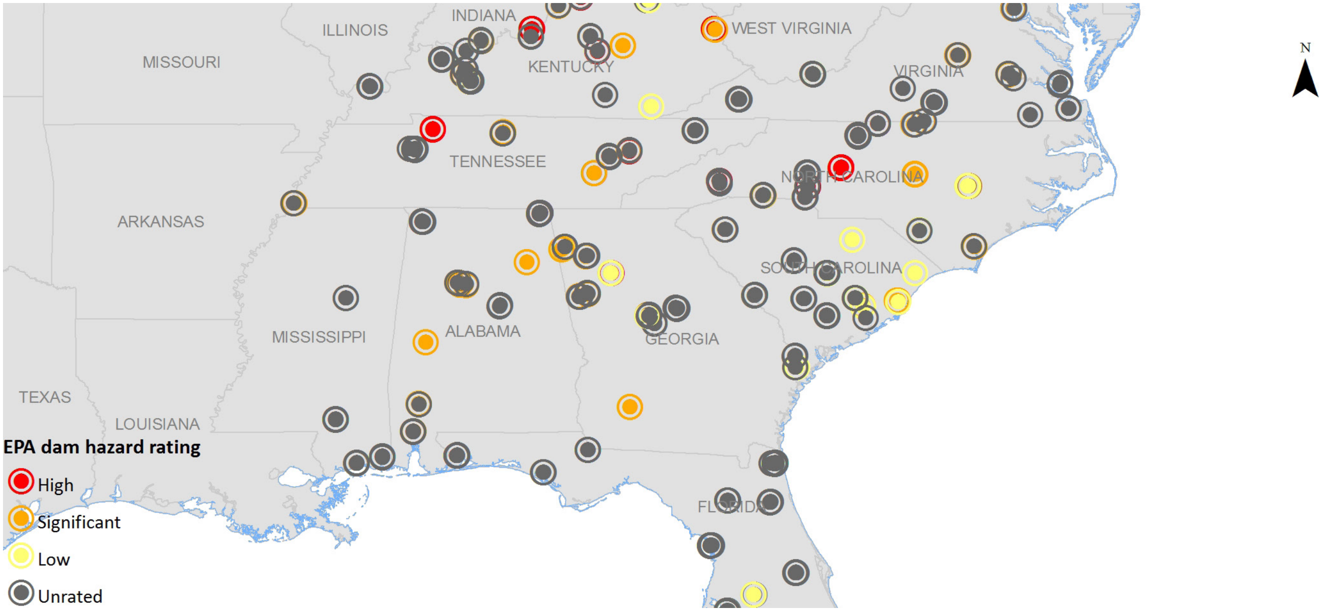
After the Tennessee ash pond wall collapsed, the storage of toxic coal ash in these holding ponds has come under public scrutiny (Goodell 2010).

2.6.4 Air-borne critical loads

Many everyday activities cause air pollution: fossil fuel burning emits sulphur dioxide and nitrogen oxides, while agricultural activities are the primary source of ammonia released to the atmosphere. These emissions lead to the atmospheric deposition of sulphuric acids, nitric acids, and ammonium on ecosystems. In sensitive ecosystems, especially those perched on granite bedrock common in the eastern part of North America, these acid compounds can acidify soil and surface waters, affecting nutrient cycling and impeding ecosystem services.

Even if ecosystems are not vulnerable to the effects of acidification, nitrogen deposition can lead to chemical and biological changes through nitrogen saturation. The effects of nitrogen enrichment, or eutrophication, are generally

Figure 2.6.3: Coal ash dam hazard rating map



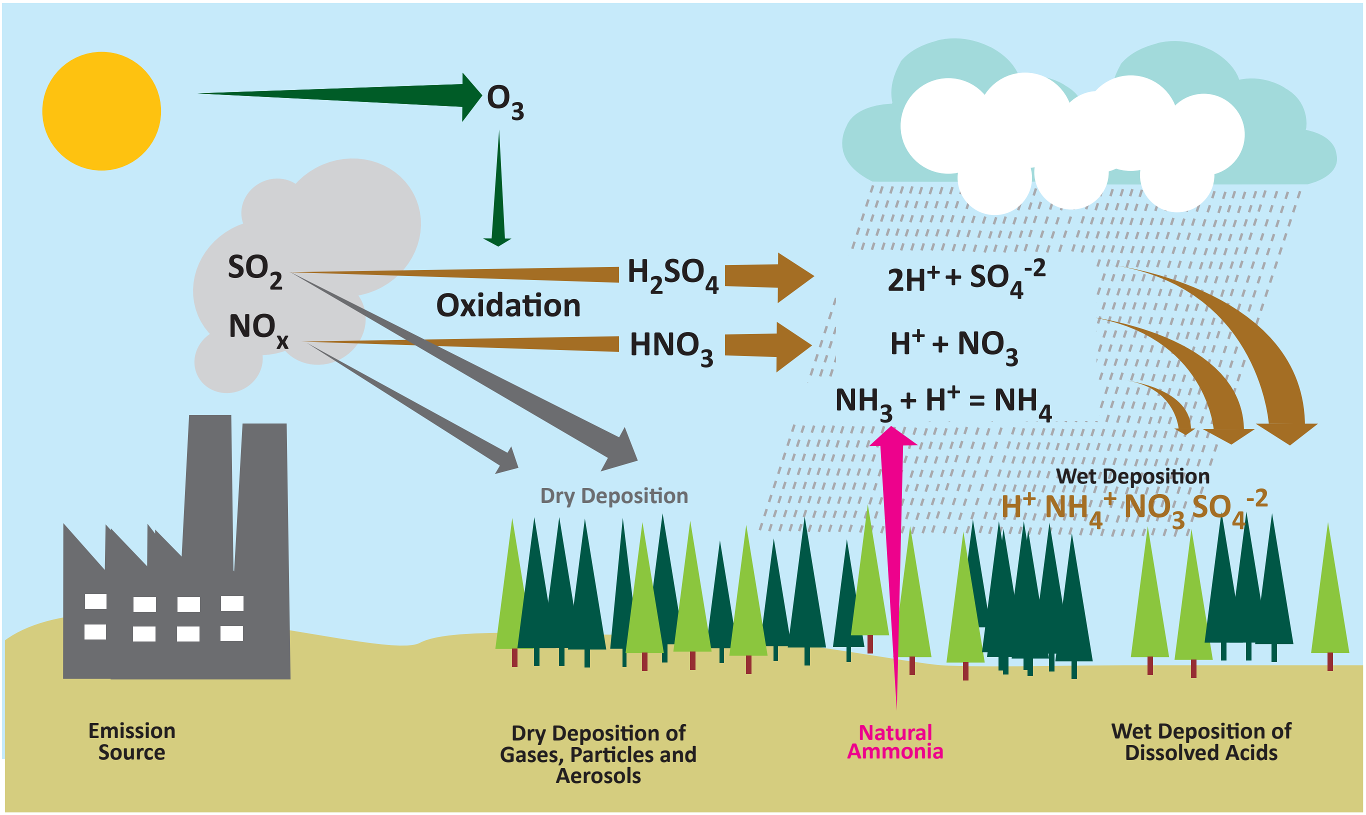
Source: Southeast Coal Ash Waste 2012

more important than soil acidification in many western areas of the region because of the higher amount of nitrogen deposition than sulphur deposition.

Toxic air contaminants like mercury are emitted mainly by coal-fired utilities and may be carried thousands of miles before entering lakes and streams as mercury deposition. Sulphate affects conversion of mercury into biologically available methylmercury, a neurotoxin that accumulates up the food chain. The US Forest Service's Air Quality Portal and National Atmospheric Deposition Programme looks at both wet deposition (national trends network, atmospheric integrated research and monitoring network, mercury deposition network) and dry deposition (partnership with clean air status and trends network, ammonia monitoring network, atmospheric mercury network) of pollutants (NADP 2014).

The National Atmospheric Deposition Programme looks at the different means of atmospheric deposition: wet, dry, cloud, and fog. Dry deposition involves gases and particles

Figure 2.6.4: Nitrogen oxides and sulphur dioxide released into the atmosphere from a variety of sources fall to the ground as wet or dry acid deposition



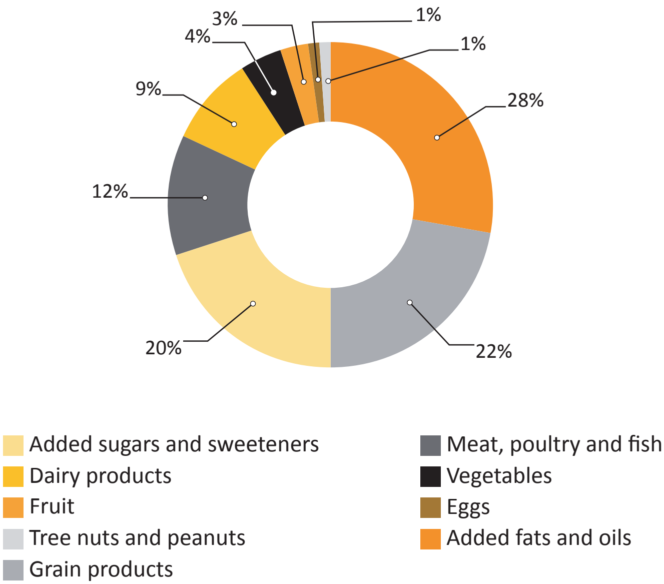
and occurs when deposited chemicals meet water and are converted into acids, while wet deposition involves rain and snow and occurs when nitrogen oxides and sulphur dioxide are converted to nitric acid and sulphuric acid, or when ammonia is converted into ammonium. The actual amount of atmospheric deposition an area receives is affected by both the deposition loading pathway and the concentration of pollution in the atmosphere. Factors including climate, meteorology, and topography can influence how much pollution reaches an area from its source and how much of that pollution actually impacts the earth's surface through its deposition form (**Figure 2.6.4**).

2.6.5 Agricultural/ food wastes and urban systems

In the US, an estimated 31 per cent (or 60 million tonnes of the 195 million tonnes) of the available food supply at the retail and consumer levels in 2010 went uneaten (Buzby *et al.* 2014). This amount of loss totalled an estimated USD 161.6 billion if purchased at retail prices. The US Department of Agriculture's Economic Research Service estimated the calories associated with food loss (**Figure 2.6.5**). An estimated 141 trillion calories per year, or 1 249 calories per person per day, in the food supply in 2010, went uneaten. The top three food groups in terms of share of total value of food loss are meat, poultry, and fish (12 per cent); vegetables (4 per cent); and dairy products (9 per cent). The report also provides a brief discussion of the economic issues behind post-harvest food loss (Buzby *et al.* 2014).

Considered as a cross-cutting issue, the problem of food waste illustrates the need for a systems approach to the environmental dimensions of the Sustainable Development Goals. While North America is, on the whole, a food secure region, North America is not immune to hunger (Buzby *et al.* 2014). There are also potential local and regional problems relating to industrial activity, water management, large-scale industrial agriculture, urbanization and climate change in general. A system-wide strategy could enhance local and regional food security, improve water management, reduce greenhouse gas emissions, reduce the use of chemical fertilizers with their resulting effects on watersheds, and

Figure 2.6.5: Food loss in the US at consumer and retail levels by food group, 2010



Source: Adapted from Buzby *et al.* 2014

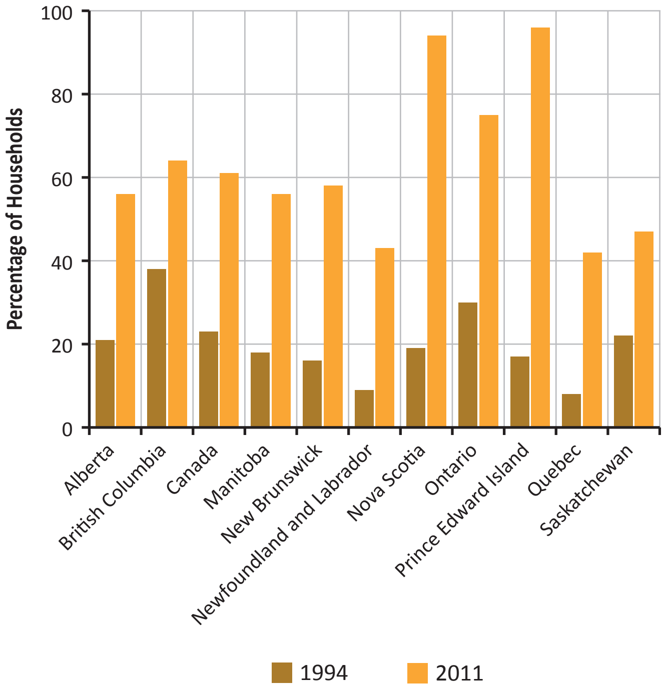
reduce the stress on arable land. Without food waste, the same scale of production can feed many more people. Where food waste still occurs, improving the diversion rates for organic materials through composting will reduce landfill volumes, as well as greenhouse gas emissions, and provide non-industrial fertilizer. Landfills emit large amounts of methane, a potent greenhouse gas, as a result of decomposing food waste (Cheng and Hu 2010).

The rate of composting in Canadian households has more than doubled from 1994 to 2011, with 61 per cent participating in some form of composting activity. Only 45 per cent of all households, however, were composting kitchen waste (**Figure 2.6.6**). Of the households that composted in 2011, 63 per cent of yard waste and 60 per cent of kitchen waste were directed to curbside collection, implying that initiatives by municipal government significantly contributed to this increase. Much more, however, needs to be done. There is potential and urgent need in cities of significant sizes that have no curbside composting collection, whereas in places like Prince Edward Island, the 96 per cent participation rate relates to the municipal requirement for curbside composting collection in major centres. The type of dwelling also was a factor, as more than 50 per cent of those in single family or detached housing participate in composting, compared with 22 per cent of those living in apartments (Mustapha 2013).

In the US, national data for composting is gathered under the umbrella of Municipal Solid Waste (MSW) through the EPA. Per capita rates of waste generation have dropped steadily over the past 15 years since it peaked in 2000, to a low of about 2 kilograms per day in 2012. Recycling rates have increased from less than 10 per cent of MSW in 1980 to more than 34 per cent in 2012. Diversion rates have increased from 11 per cent to 46 per cent in the same period. This translates into 251 million tonnes of trash in 2012, with 87 million tonnes diverted from landfill through composting or recycling (USDA 2014).

Industrial biogas production offers another solution for urban organic waste. As concerns about climate change and energy independence grow, biogas production industries have developed a promising technology that captures energy from the breakdown of organic wastes and diverts methane from the atmosphere. When agricultural residue, livestock manure, and food processing waste are disposed of in landfills and holding ponds, large volumes of methane are released into the atmosphere. However, when processed and captured, these wastes can all serve as fuel for biogas production. This biogas can then be burned to generate electricity and heat, or processed into natural gas. Biogas generation projects can be profitable by offsetting on-farm energy costs, selling electricity, renewable energy subsidies, and selling solid by-products as fertilizer. Biogas production has become a staple of European renewable energy technology, but is still fairly new in North America. Small-scale systems have begun to proliferate in the US over the past decade, particularly on dairy farms (Lazarus and Rudstrom 2007; El-Mashad and Zhang 2010). Hog and poultry wastes serve as promising biogas feedstocks. In its

Figure 2.6.6: Composting, Canada and provinces, 1994 and 2011



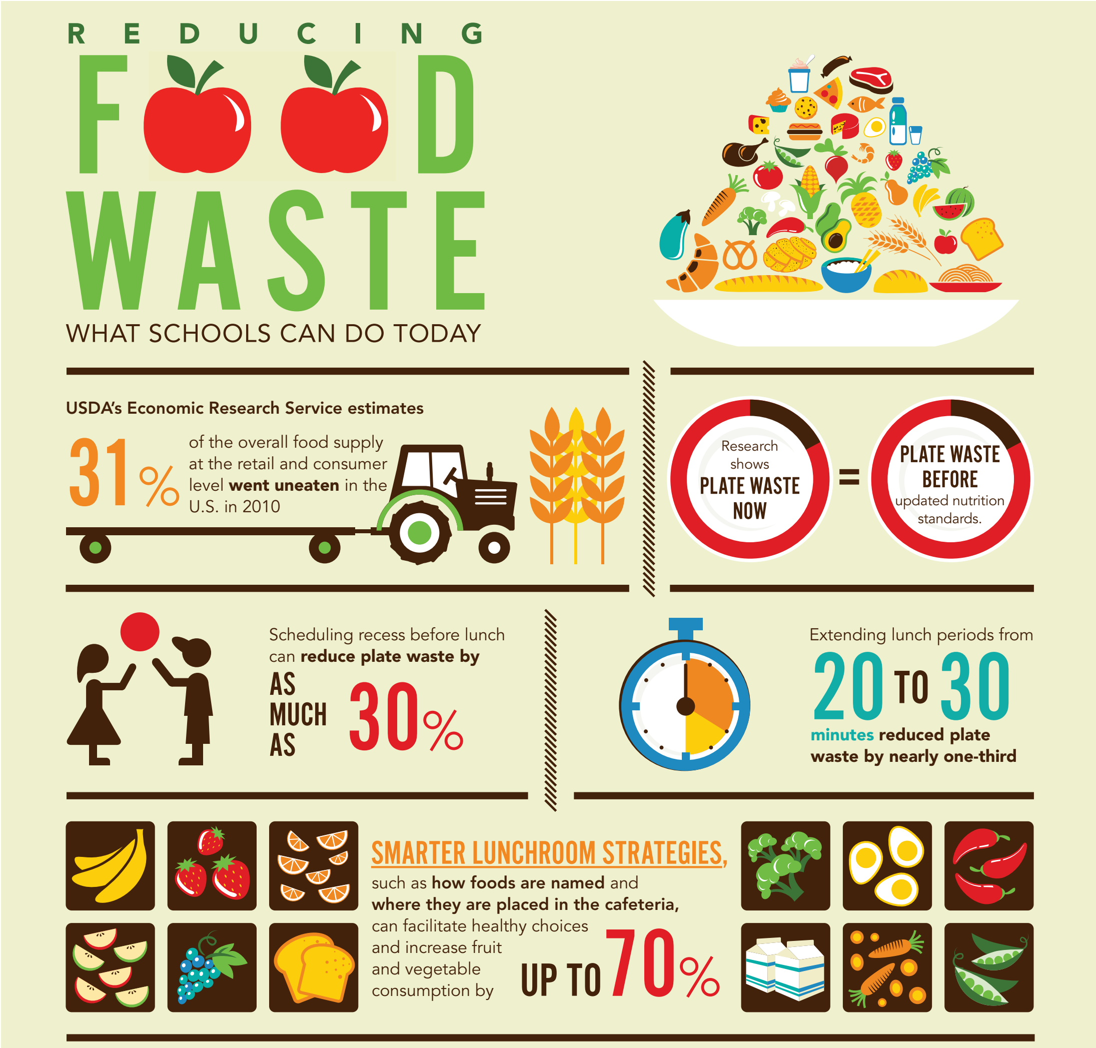
Source: Statistics Canada 2013

renewable energy portfolio standard, North Carolina has mandated minimums of energy production from both hog and poultry waste (Fryberger 2014).

2.6.6 Chemicals and waste problems persist

While there has been progress in chemical and waste management in North America, it has been uneven across different sectors and is not increasing at a rate that would yield timely solutions to current problems. More resources, human and financial, are required, together with a more robust legislative structure and capacity to better report and monitor data across sectors and jurisdictions. Currently, different reporting strategies and categories make national or regional comparisons between Canada and the US difficult.

Figure 2.6.7: Reducing food waste



The US Department of Agriculture sponsors efforts to cut food waste in schools. This infographic, which targets school administrators, emphasizes behavioural and non-invasive ways to reduce plate waste, a term for all the food that students leave uneaten. Simple adjustments, such as scheduling recess for before lunch or providing a table where students can leave unopened packaged goods or uneaten produce, can reduce plate waste and eventual landfill demand while saving on haulage fees.
Source: USDA 2014

In Canada, from 2002 to 2008, municipal solid waste disposal per person increased slightly from 769 kilograms to 777 kilograms per person diversion also increased from 212 kilograms to 254 kilograms (25 per cent in 2008). In 2012 in the US, per person waste generation was lower, at 727 kilograms, with a diversion rate of 34.5 per cent. Yet of the 58 per cent of Canadian households that had batteries to dispose of in 2009, 42 per cent discarded them in the garbage. In the US, however, the highest rate of recovery (96 per cent) was lead-acid batteries (Statistics Canada 2012; US EPA 2013).

In 2009, 82 per cent of Canadian households were connected to municipal sewer systems, while 13 per cent used private septic systems and one per cent used communal septic systems. In terms of industrial wastewater generation, discharge for manufacturing, mineral extraction (excluding oil and gas extraction) and thermal-electric power generation was 29.9 billion cubic metres in 2009. Industrial wastewater treatment and discharge costs were CAD 532.2 million, approximately 37 per cent of total industrial water costs in 2009 (Statistics Canada 2012).

Some pollution reduction initiatives were clearly successful in some sectors, while in other sectors, levels increased. In Canada from 1985 to 2009, emissions of sulphur oxides decreased by 60 per cent, emissions of carbon monoxide by 43 per cent and emissions of nitrogen oxides by 18 per cent. On the other hand, Canada's total greenhouse gas emissions reached 690 million tonnes in 2009, a 17 per cent increase since 1990. Meanwhile, from 2001 to 2008, solid waste generation from mining activities in Canada increased by 55 per cent (Statistics Canada 2013).

2.7 A rapidly changing Arctic

2.7.1 Introduction

Changes in the Arctic, especially losses of summer sea ice cover, are driving weather systems and climate extremes that reach far south of the Arctic Circle on to the continents of Europe and Asia, as well as North America (Francis and Skific 2015). In this GEO-6 assessment, North America includes coverage of the worldwide atmospheric teleconnection patterns originating in the Arctic that affect other regions and countries around the globe. Scientists around the world and in North America now recognize these processes and trends as well as the growing use of new data and communication tools. Certain processes–including glacier ice loss, sea level rise, ocean acidification, and changes in ocean salinity and circulation–are accelerating in the Arctic due to warming of average global temperatures. Manifestations and consequences experienced at lower latitudes are addressed in the following section on climate change.

Rising temperatures have triggered an amplification of natural response processes in the Arctic. Thawing of permafrost is progressing at an accelerated rate, releasing carbon dioxide and methane that leads to further warming while polar sea ice shrinks to smaller areas in seasonal pulses. The effect on human settlements in the Arctic can be devastating: the land surface becomes unstable and sporadically collapses under pressure as permafrost thaws; food sources are disappearing as biotic ranges shift; and rising sea levels and increased storms are consuming the shorelines and piers of villages and towns along the coast.

Several climate impact assessments on Arctic regions have been undertaken in the last decade, including the synthesis report Snow, Water, Ice and Permafrost in the Arctic, the State of the Arctic Coast reports, Arctic Resilience Interim Report, and the findings of the International Polar Year (AMAP 2011; Krupnick *et al*. 2011; Carlson 2011; Romanovsky *et al*. 2010; Allison *et al*. 2007). These, and the recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, reveal a consistent pattern of climate-driven environmental, societal and economic change in the Arctic since the late 20th century (Stocker *et al.* 2013).

2.7.2 Sea ice loss

Over the past twenty years, a progressive and dramatic decrease in summer sea ice extent has led to an increased surface area of blue water during the summer months.

Key messages: A rapidly changing Arctic

The Arctic is experiencing a profound transformation that is having important impacts on North America and the world as a whole. These rapid changes in the Arctic are driven largely by interacting forces of climate change and increased human activities.

- As one of the first areas of the world to experience the impacts of climate change, the Arctic region serves as a barometer for change in the rest of the world.
- The Arctic's unique underlying social, institutional, and ecological patterns make this area highly vulnerable to continued climate change, especially in light of the difficulties for the region to adapt, which may trigger cascading risks.
- Warming in the Arctic has increased at twice the global average since 1980. Other prominent processes that signal greater climate change impacts include glacier and ice sheet melt, altered salinity concentrations and ocean circulation patterns, sea level rise, and ocean acidification.
- While the strong adaptive capabilities of Arctic peoples have served them well over the centuries, there is growing concern that their distinct and traditional ways of life will be irrevocably affected by the profound transformation taking place so rapidly across the region.

This results from a general warming trend on land, as well as permafrost thaws, which together with increased greenhouse gas emissions into the atmosphere, reinforce a biophysical feedback loop. The warmer the temperature, the more melting; the more melting, the greater greenhouse gas emissions that then lead to higher temperatures. The change in albedo from the loss of snow and ice in the north–absorbing the sun's heat rather than reflecting it–further escalates climate change (NSIDC 2015).

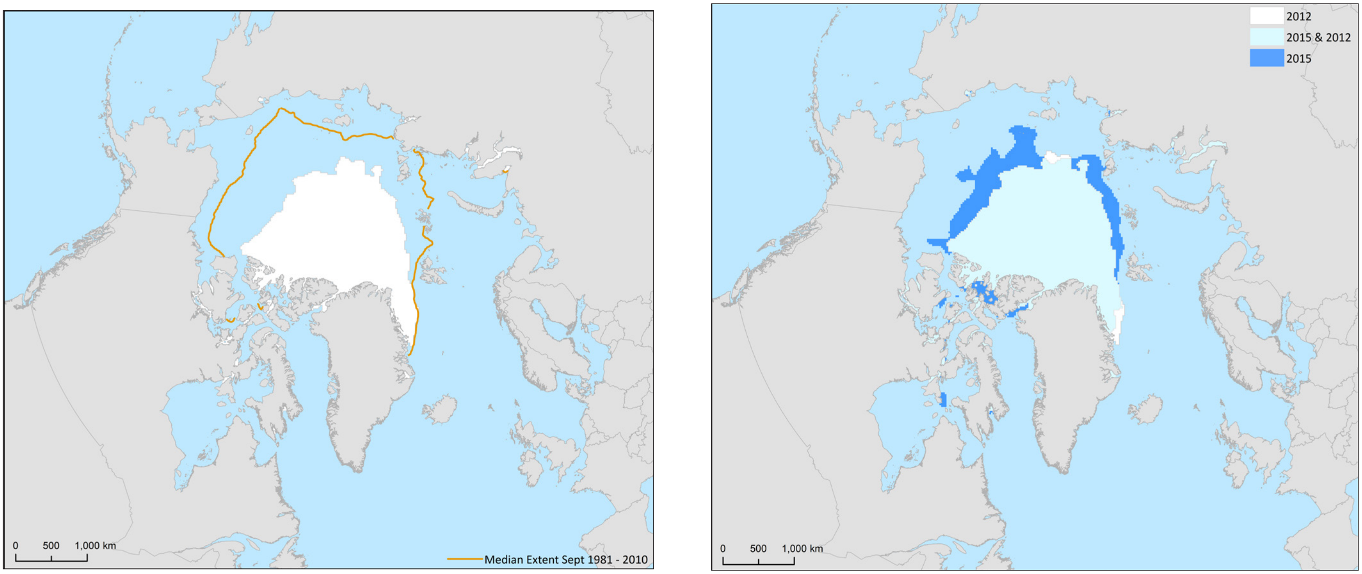
2.7.3 Amplification explained

At near ground level, the northern hemisphere high latitudes are warming at double the rate of lower latitudes: this is Arctic amplification. It occurs all year round, but is strongest in autumn and winter. Several processes contribute to it, including local radiative effects from increased greenhouse gas forcing, changes in the surface albedo feedback induced by a diminishing snow and ice cover, changes in aerosol concentrations and deposits of black carbon on snow and ice surfaces, changes in Arctic cloud cover and water vapour content, and the slowing rate of release to space of long-wave radiation in the Arctic (**Figure 2.7.2**). In addition to these local drivers, Arctic conditions vary in response to changes in heat and moisture transported into the Arctic from lower latitudes (Cohen 2014; Stocker *et al*. 2013).

2.7.4 Thawing permafrost and its consequences

The frozen ground of the Arctic is an important but poorly understood element of the entire Arctic and its connections to the global climate. There are trillions of tonnes of carbon frozen in the permafrost of Arctic soils. For millions of years, these carbon stores have not interacted with the atmosphere or hydrosphere. Now they are, or soon will be, affecting the rates and magnitude of global warming (NAS 2015). Although the Polar Research Board of the US National Academy of Science concludes that the near term

Figure 2.7.1: Sea ice extent



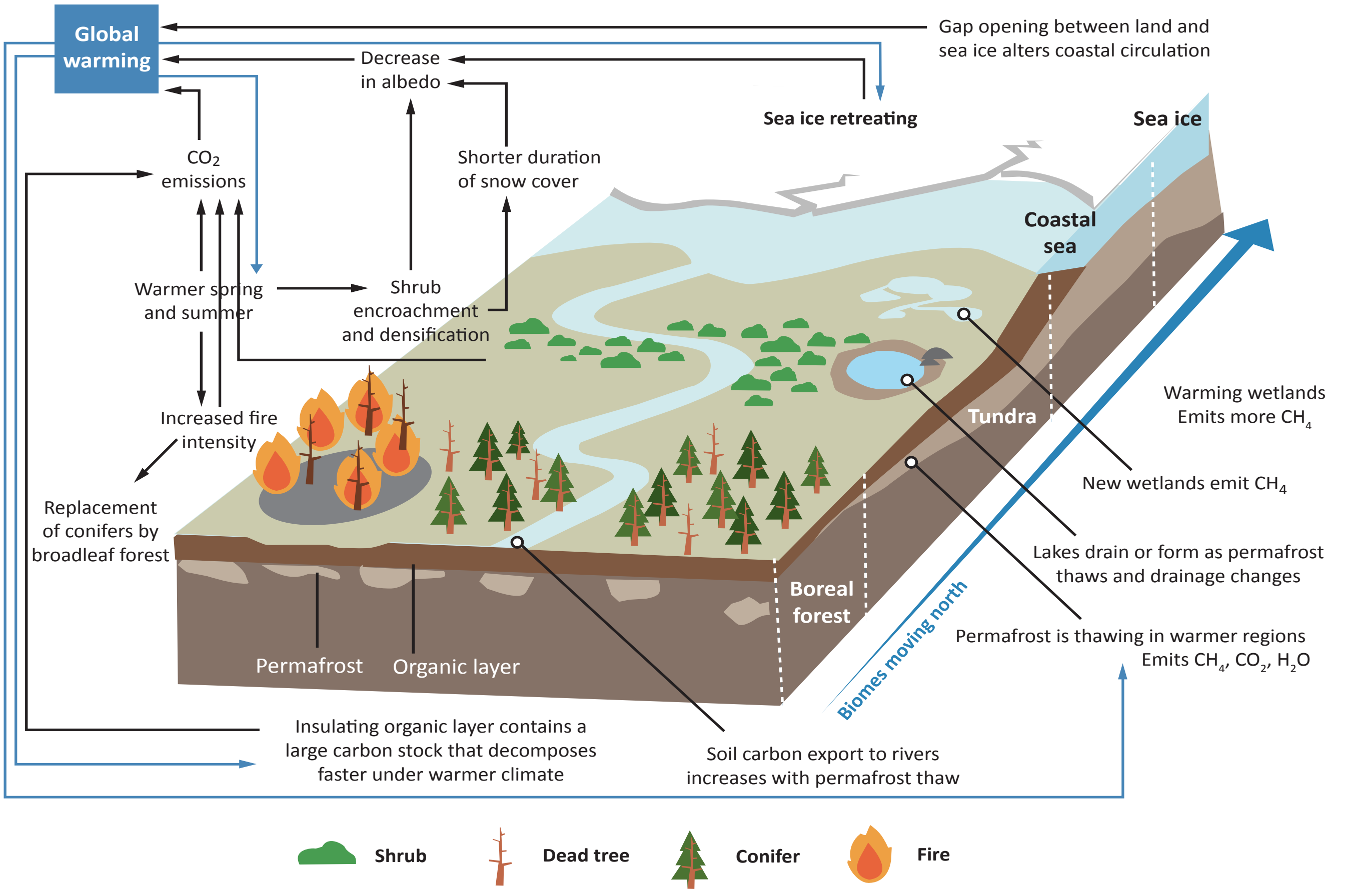
Source: Adapted from NSIDC 2015

potential for methane release at a catastrophic scale is small (Huntington and Pfirman 2014), the potential for slow onset and gradually increasing carbon dioxide and methane release from thawing permafrost is a real threat, and will accelerate and add substantially to the greenhouse gases in the atmosphere over many decades to centuries. There have been many reports, field studies and assessments of the potential of release of methane from these Arctic soils, most of which suggest that the rate of growth of methane in the Arctic is comparable to that already in the global atmosphere. There are other consequences of the thawing of the permafrost, including the impacts on built infrastructure such as roads, utility supply line corridors and the foundations of buildings (NAS 2015).

There is high confidence that permafrost temperatures have increased in most regions since the early 1980s, with strong warming of permafrost recorded with averages at 3°C in parts of Northern Alaska and 2°C in parts of European Russia, and a general reduction in permafrost thickness and surface extent (Stocker *et al*. 2013). The southern boundary of permafrost is retreating: the continuous permafrost has migrated 50 kilometres north since the 1980s and the discontinuous permafrost 80 kilometres north, with the thickness of the overlying active layer generally increasing (Stocker *et al*. 2013; **Figure 2.7.3**).

The carbon stores in Arctic soil are there due to the plants that grow in the thin layer of unfrozen soil on top of permafrost. When a plant dies in a temperate area, it decomposes, releasing some of its carbon into the air and some into the soil. But when a plant dies in the Arctic, it simply stays put, locking its carbon in place, and after many seasons, over many centuries, that carbon accumulates. If large areas of permafrost were to thaw, all of that previously frozen plant matter would decompose, releasing huge quantities of carbon into the atmosphere in the form of carbon dioxide or

Figure 2.7.2: Arctic amplifying feedbacks



Source: Adapted from Stocker *et al.* 2013

methane. Much of the carbon stored in the Arctic is frozen within icy crystals called methane clathrates (Schuur *et al.* 2015). As ice and permafrost continue to degrade and collapse, the clathrates can release more methane into the atmosphere (NAS 2015).

Although both carbon dioxide and methane are greenhouse gases, they behave differently in the atmosphere. Carbon dioxide persists for many decades or centuries in the atmosphere and is the major driver of long-term climate change. Over short time frames, such as a decade, methane is many times more potent as a greenhouse gas. Thus an abrupt release of a large quantity of methane could cause larger, more rapid climate changes, but the magnitude of the effect would taper gradually as the methane breaks down and recombines with oxygen in the atmosphere to form carbon dioxide (NAS 2015). Whether the warming occurs over years or centuries, once it has happened it is essentially irreversible.

2.7.5 Processes monitored in the Arctic, experienced worldwide

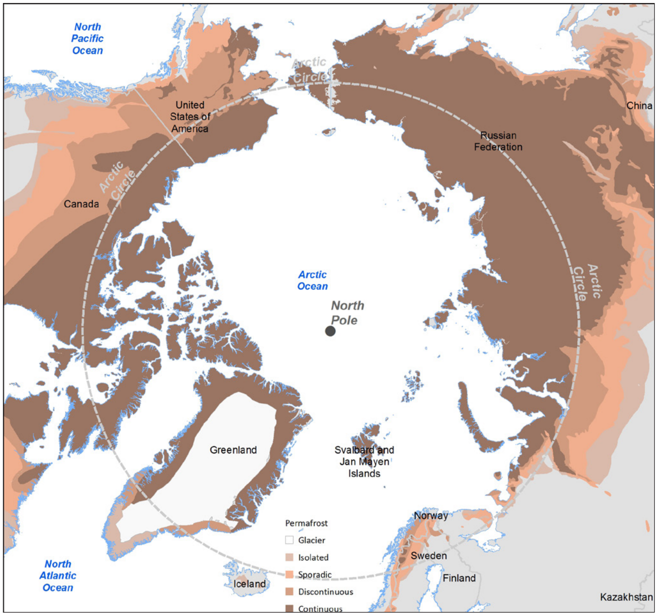
Certain processes–including glacier ice loss, sea level rise, ocean acidification, and changes in ocean salinity and circulation–have been accelerating in the Arctic due to warming of the average global temperature. While these climate change impacts have become very obvious in the Arctic, they are also observed worldwide.

Glacier ice loss

The Fifth IPCC Assessment found very high confidence that the largest contributions to global glacier ice loss during the early 21st century were from glaciers in Alaska, the Canadian Arctic, and the periphery of the Greenland ice sheet, as well as in the Southern Andes and Asian mountains. Together these areas account for more than 80 per cent of the total ice loss (Stocker *et al*. 2013; Field *et al*. 2014). Total mass loss from all glaciers in the world, excluding those on the periphery of the ice sheets, was around 225 gigatonnes per year in the period 1971–2009, 275 gigatonnes per year in the period 1993–2009, and 301 gigatonnes per year between 2005 and 2011 (Stocker *et al*. 2013). This strong melt indicates significant and global disruption in glacier mass-balances, which in turn implies that glaciers in many regions will suffer further ice loss, even if the climate were to remain stable (Zemp *et al*. 2015).

Long-term observations show that glaciers around the world are in retreat and losing mass. The World Glacier Monitoring Service, which has a series of datasets collected since the 17th century, coordinates world-wide glacier-monitoring activities that provide an unprecedented dataset of glacier observations from ground, air, and space (Zemp *et al*. 2009). Glacier studies generally select specific parts of these datasets to obtain optimal assessments of mass-balance data relating to the impact that glaciers have on global sea-level fluctuations or on regional runoff. The data tracking glacier front variations have delivered clear evidence that centennial glacier retreat is a global phenomenon (Zemp *et al*. 2015). Intermittent re-advance periods, at regional and

Figure 2.7.3: The distribution of permafrost in the Arctic



Source: Adapted from NSIDC 2015

decadal scales, are normally restricted to a subsample of glaciers and have not come close to achieving the maximum positions of the Little Ice Age that unfolded from the 16th to 19th centuries. Glaciological and geodetic observations show that since 2000 the rates of glacier-mass loss are unprecedented on a global scale, at least compared to the centuries of observation and probably also for recorded history, as indicated in reconstructions from written and illustrated documents (Roer 2008; Zemp *et al.* 2015).

Sea-level rise

The global average rate of sea-level rise is accelerating, with about 40 per cent of the global mean sea-level rise coming from the melting of the Greenland Ice Sheet and other high latitude land-based glaciers (NSIDC 2015). The increasing loss of land-based glacial ice is having a profound effect on global sea-level. Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75 per cent of the observed global mean sea-level rise. Over the period 1993–2010, global mean sea-level rise is, with high confidence, consistent with the sum of these observed contributions: from ocean thermal expansion due to warming, ~1.1 millimetres a year; from Arctic glaciers, ~0.76 millimetres a year; from the Greenland ice sheet, ~0.33 millimetres a year; from the Antarctic ice sheet, ~0.27 millimetres a year; and from land water storage discharge, ~0.38 millimetres a year. The sum of these contributions is ~2.84 millimetres a year (Stocker *et al*. 2013).

Ocean acidification

Ocean acidification is intensifying more rapidly in the Arctic Ocean than in other locations. This will produce consequences for marine ecosystems, Arctic fisheries, the value of Arctic ecosystem services, and marine management (AMAP 2013). The levels of acidification in the Arctic seas are generally higher than the global mean, with the level in the Norwegian Sea about 200 per cent higher that the global mean (AMAP 2013), which itself is about 30 per cent higher than in pre-industrial times. Expected levels of ocean acidification, driven by the continued absorption of carbon dioxide into the water, are higher than levels for millions of years, as estimated from ocean floor sediments and ice cores (AMAP 2013; Ridgwell and Schmidt 2010; Caldiera and Wickett 2003).

Ocean circulation and changes in salinity

As Arctic ice melts, freshwater is discharged into the Arctic Ocean and the North. Scientists predict this freshwater influx will have significant impacts on the circulation of ocean water worldwide, because the vertical circulation of ocean currents is driven by water temperature and salinity (**Figure 2.7.4**). In turn, ocean circulation–both vertical and horizontal–is a major driver of weather patterns in the Arctic and around the world (Collins *et al.* 2010).

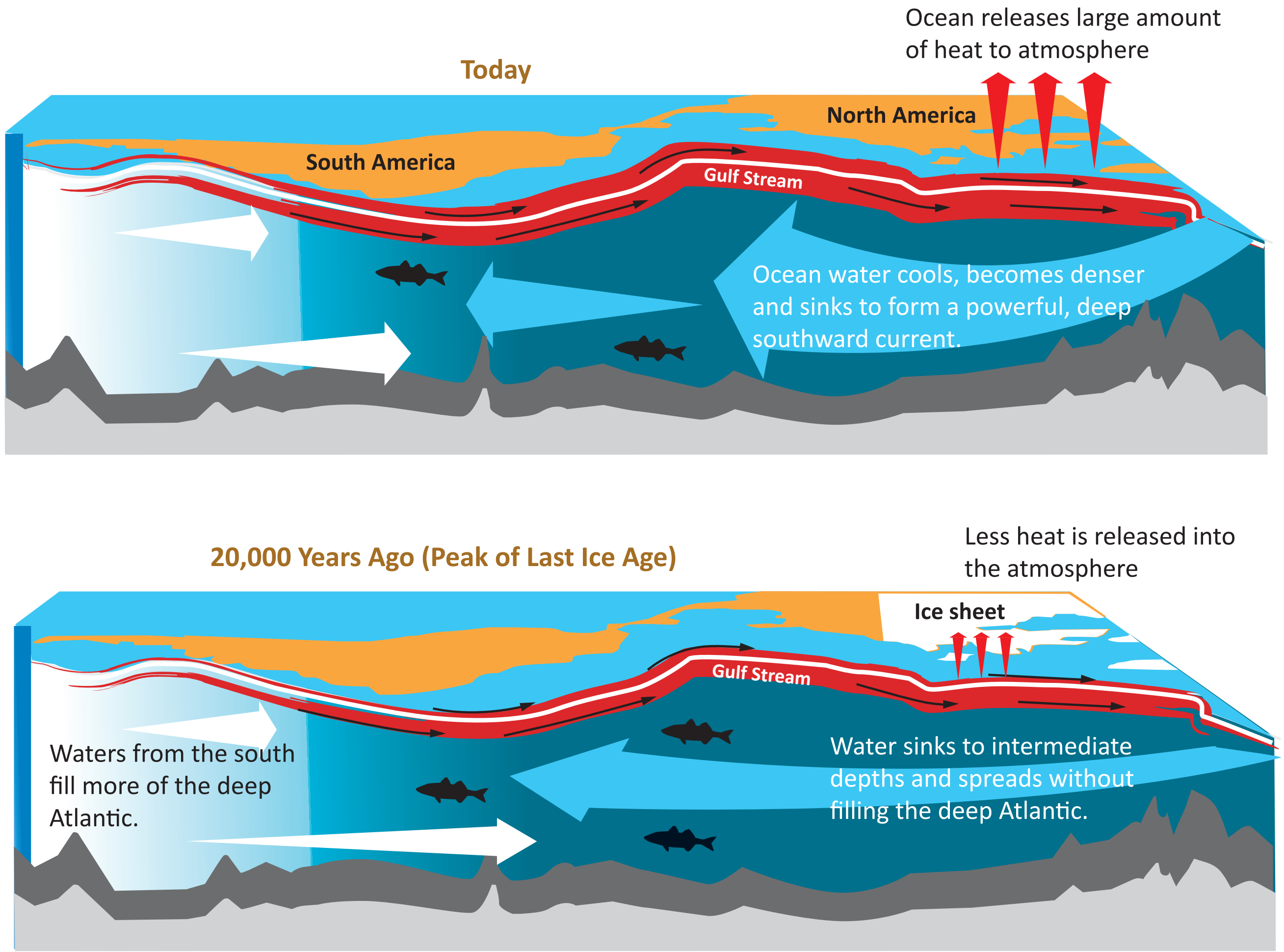
Recent studies suggest that the Atlantic meridional overturning circulation, which includes the Gulf Stream, is already slowing and may be the cause of a persistent cold-water anomaly in the North Atlantic between Greenland and Ireland. Further research suggests that a slowing Gulf Stream–resulting from colder freshwater discharged into the North Atlantic from Greenland ice melt–contributes to the higher rates of sea level rise measured along the North American Atlantic coast (NAS 2015; Ezer 2015; Rahmstorf *et al*. 2015).

2.7.6 Physical and ecological effects

The speed of the changes taking place as a consequence of warming in the Arctic are putting pressure on local ecological systems to adapt to such a rapidly changing environment (Maranger *et al*. 2015). This may have implications for the future survival of species unique to the Arctic, ranging from large animals at the top of the food chain, such as caribou and polar bears, to micro-biota sensitive to even minor changes in temperature (Sistla and Schimel 2013; Johnsen 2010).

As a result of these changes, some habitats and their associated ecosystems are expanding, while others are undergoing rapid contraction. The warming of the Arctic's frozen environment is limiting the range for cold-adapted biota as less specialized species, including invasive alien species from the south, become increasingly common.

Figure 2.7.4: North Atlantic Ocean Circulation



The Atlantic meridional overturning circulation (AMOC) carries a tremendous amount of heat from the tropics northward, warming the North Atlantic region. When the surface water cools at high latitudes, this large volume of cold salty water sinks and flows southward, filling up the deep Atlantic Ocean basin and eventually spreading into the deep Indian and Pacific Oceans. Changes within the Arctic could influence ocean circulation—and in turn, affect global climate.
Source: Adapted from NAS 2015; Oberlander 2014

Extreme climate events, such as winter thaws, happen more frequently and may accelerate shifts in ecological community structure and processes. As Arctic ecosystems are interdependent, changes in the frozen environment are altering physical, biophysical, and biological links. All of these climate-related effects are compounded by rapid socio-economic development in the North, creating additional challenges for northern communities and indigenous lifestyles that depend on Arctic ecosystem services (Vincent *et al*. 2011).

Regional consequences of Arctic warming include the alteration of watersheds by glacial melt and the loss of large ice sheets. This melting leads to the exposure of coastlines not previously subject to coastal erosion, which is compounded by a rise in sea levels and increased vulnerability to extreme weather conditions (NRC 2008). Combined with thawing permafrost, this affects the migration patterns of larger animals, changing or denying access to seasonal habitat and altering the local balance between predator and prey (NRC 2008).

2.7.7 Marine ecosystems

The melting of sea ice has created new expanses of open ocean, allowing large populations of phytoplankton to bloom and alter the marine food chain. On land, shrublands are expanding into the tundra and invasive insects are spreading across the forests. As Arctic summers warm and the ice-free season lengthens, more species from the south migrate northward. Competition from these species for food and other resources could potentially lead to major ecosystem reorganization and species extinction. Arctic ecologists are particularly concerned about tipping points: thresholds at which a small change in climate could precipitate abrupt, major, and irreversible ecological consequences (Schuur *et al*. 2015; Everett *et al*. 2014).

Vegetation in the high Arctic is affected by continuing summer land-temperature increases resulting from sea ice loss. Areas marginal to perennial sea ice and the margins of the large glaciers will see the most rapid changes as ice vanishes (Bhatt *et al*. 2010). The decline of sea ice affects marine mammals throughout their key life history stages. Ice-obligate species–polar bears, walruses, and some seals–need sea ice as a platform for hunting, birthing, and rearing young. And, while some seal species are fully adapted to sea ice habitats, they sometimes reproduce and feed from shore, so are considered ice-associated species. The three endemic Arctic cetacean species are also ice associated, and at least five cetacean species migrate to and occupy Arctic habitats, primarily during the productive summer–autumn season (Bhatt *et al.* 2014; **Figure 2.7.5**).

2.7.8 Terrestrial ecosystems

The expected and partially observed increased primary productivity of Arctic tundra may increase the supply of food for Arctic ungulates. However, the overall quality of forage may decline during warming, for example, if the nitrogen content of key fodder species for ungulates dropped. At the same time, lichen biomass, an important winter fodder for reindeer, is decreasing over parts of the Arctic region (Joly *et al*. 2009; Turunen *et al*. 2009).

More frequent rain-on-snow icing events and thicker snow packs, caused by warmer winters and increased precipitation, may restrict access to vegetation and have profound negative influences on the population dynamics of Arctic ungulates (Hansen *et al*. 2011). Heavy mortality due to such conditions has been documented in some semi-domestic reindeer herds and musk oxen in recent years (Bartsch *et al*. 2010; Forbes *et al*. 2009; Grenfell and Putkonen 2008). Studies also document that these icing events affect the dynamics of a resident vertebrate community–including small mammals, reindeer, and Arctic fox–in Svalbard (Hansen *et al*. 2013). In contrast, Tyler *et al*. (2008) and Tyler (2010) suggested that generally warmer winters enhance reindeer populations.

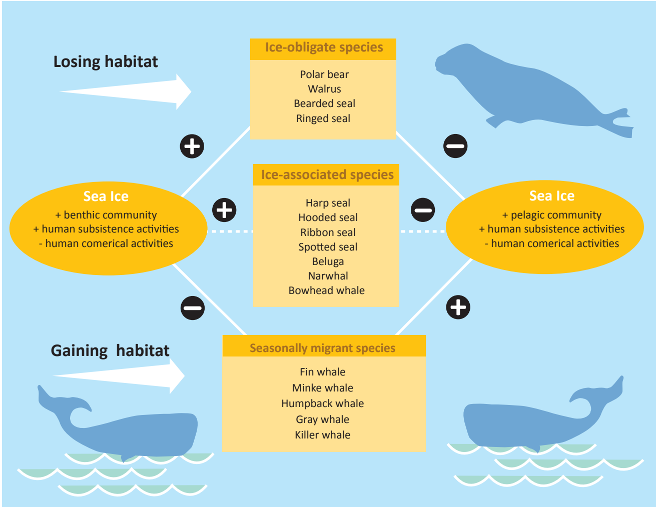
Warming-induced mismatches between forage availability and quality, and timing of calving may have a role in the decline of circumpolar reindeer and caribou populations (Post *et al*. 2009a; b; Post and Forchhammer 2008), although these conclusions have been disputed (Post *et al*. 2009a; Post *et al*. 2008). Adjustment via phenotypic plasticity–the ability to manifest inherited ability to physically adjust to environmental variations, such as growing thinner or thicker coats–will likely dominate vertebrate responses to rapid Arctic climate change, and many such adjustments have already been documented (Gilg *et al*. 2012).

2.7.9 The human experience

Approximately 4 million people live in the Arctic, similar to the population of New Zealand or the Republic of Ireland. About 3.6 million live in larger towns or cities, and work in businesses or industries such as mining and oil and gas extraction. At least 400 000 people, the population of Malta or the Maldives, are indigenous people from different ethnic groups whose ancestors have lived in the Arctic for millennia. Many of these indigenous groups are associated with specific regions or lands and live mostly in small, remote settlements (Galloway-McLean 2010; Nakashima *et al*. 2012; Bogoyavlenskiy and Siggner 2004). The Arctic environment is the center of their identity, well-being, and culture with livelihoods dependent on reindeer herding, hunting, sealing, whaling, and fishing (Galloway-McLean 2010). These unique and diverse Arctic communities face an uncertain future. Many indigenous peoples are considered particularly vulnerable to climate change and development (Larsen *et al*. 2014). Thawing permafrost poses particularly significant and severe challenges, erosion-induced damage to buildings, roads pipes and key infrastructure. Low-lying communities and those situated along coasts have become increasingly vulnerable in the Arctic.

Most Arctic human communities, especially indigenous peoples, are already affected by interconnected climate-related factors that include reductions in sea ice thickness and extent, changes in seasonal ice and melt/freeze of lakes and rivers, increased permafrost thaw, more extreme and unpredictable weather and severe storms, changing water temperatures, sea level rise, flooding, increased coastal erosion, and changes in precipitation timing and type (Bennett *et al.* 2014; Larsen *et al.* 2014). These stresses

Figure 2.7.5: Response of marine mammal species to sea ice loss mediated by their reliance on it for key aspects of their survival



The dramatic loss of sea ice area and thickness over the past decade has stressed some populations of ice-obligate species but has been advantageous for seasonally migrant species.
Source: Adapted from Bhatt *et al.* 2014

create challenges for communities to maintain their social, cultural, economic, and physical health and well-being due to food insecurity, damage to critical infrastructure, lack of access to clean water, injury and risk from extreme weather, more difficult access to subsistence species, forced relocation of communities, and loss of culture (Bennett *et al.* 2014; Larsen *et al.* 2014; Maynard 2013; Parkinson 2009).

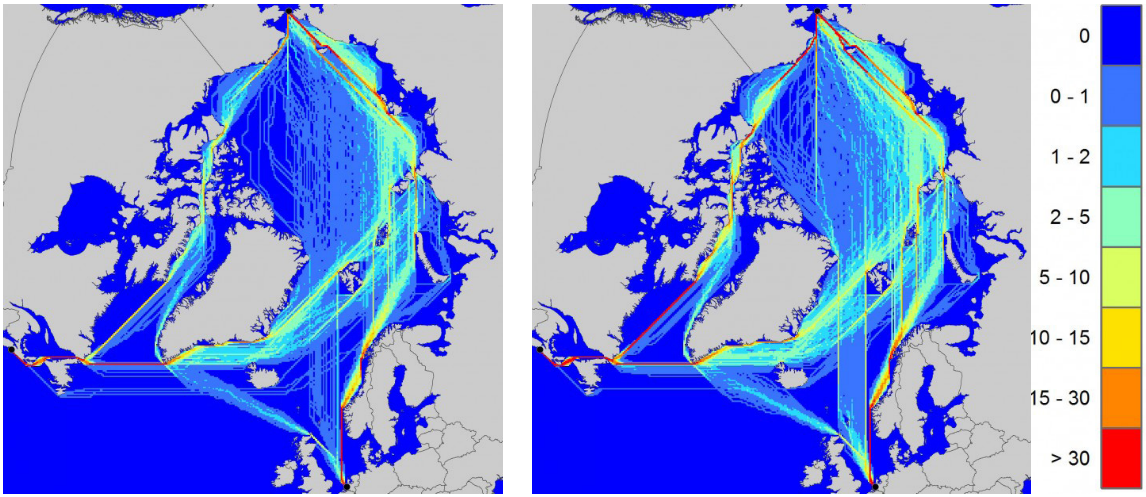
When considering these various climate related consequences for the people of the Arctic, it is important to keep in mind that there are multiple additional environmental stressors increasingly affecting them. These include local and long-range contaminants like persistent organic pollutants, heavy metals, and radionuclides.

Box 2.7.1: Opening of a seaway

The thinning of the Arctic sea ice, and dramatic reductions in its seasonal extent, is opening opportunities and creating new challenges related to new shipping and trade routes; the exploitation of natural resources including fisheries, oil, gas, and minerals; tourism; and changes to the lifestyles of coastal communities, particularly indigenous peoples (2011 to 2014 NPAC). Satellite observations document that Arctic sea ice extent in mid-September, when it is at its minimum, has declined at a rate of about 10 per cent per decade since the late 1970s, and the rate of decline has accelerated recently. The accelerated warming of the Arctic has not only dramatically reduced the volume and extent of sea ice: the age of 85 per cent of the sea ice is now between one or two years old. The age of sea ice is an important indicator of Arctic conditions. A loss of older ice suggests that the Arctic is losing ice faster than it is accumulating it. Evidence also suggests that the melt season has become longer; the ice is starting to melt earlier in the year and freeze later. (Kattsov *et al*. 2010; Stocker *et al.* 2013).

This reality reduces the need for high-powered icebreakers substantially, as the ice is thinner and patchy. The opening of Arctic seaways has several major socio-economic implications. Interest continues in the exploitation of oil and gas deposits in the Arctic. Opening of Arctic seaways has increased interest in transportation within and through the Arctic, particularly potential for trans-Arctic shipping (Young *et al*. 2014; Andrew 2014).

Figure 2.7.6: Potential shipping routes in the Arctic, (2011-2035) and 2036-2060



The opening of the Arctic seaways has several major socio-economic implications. Interest is growing in the exploitation of oil and gas deposits in the Arctic, which gives the projections indicated in this graphic.
Source: CIESIN 2015

State and trends

Box 2.7.2: Issues affecting the health and well-being of peoples of the Arctic, especially indigenous and isolated communities

- Food insecurity due to changes in climate and development: decreased opportunities for safe or successful hunting, fishing, and herding as some subsistence species are displaced, as well as loss of traditional food preservation opportunities and forced reliance on less healthy processed store-bought foods (Bennett *et al*. 2014; Larsen *et al*. 2014; Virginia and Yalowitz, 2011; Ford and Berring-Ford, 2009; Parkinson and Evengard, 2009).
- Infrastructure and water security: damage to the built environment affecting already limited housing; breakage of sanitation infrastructure; water supply systems for clean water; sickness from sewage and other pollutants; background levels of contaminants and their bio-magnification; infectious diseases; sea level rise and salt water intrusion (Larsen *et al*. 2014; AMAP 2011; 2009; Brubaker *et al* 2011; Parkinson and Evengard, 2009; Parkinson *et al*. 2008; Revich, 2008; Berner *et al*. 2005).
- Extreme weather: injuries, accidents, and risks from extreme weather events and temperatures; rapid onset of storms; inundation by large storm surges; unsafe conditions for hunting, fishing, herding, travel, and subsistence gathering; in isolated villages loss of services and supplies, for example food, fuel, and telecommunications (Larsen *et al*, 2014; Brubaker *et al*, 2011; Ford and Pearce 2010; Ford and Furgal 2009; Revich 2008).
- Changes in snow and ice and ecosystems: changes in the state of snow and ice, with resulting shifts in animal and plant ranges and populations; new species; infectious diseases; zoonotic diseases; changes in exposure to background contaminants; loss of forage and food; fewer habitats of subsistence species; changes in migration routes and grazing lands (Larsen *et al*. 2014; Brubaker *et al*. 2011; AMAP 2011; Ford and Fugal, 2009; Revich, 2008; Huntington *et al*. 2007).
- Community well-being and cultural integrity: threats to cultures, families and communities due to relocation from villages damaged by permafrost thaw and erosion; forced relocation and other changes causing mental health issues among indigenous and isolated communities, including increased numbers of suicides especially among youth (Brubaker *et al*. 2011; Coyle and Susteren 2012; Portier *et al.* 2010; Abryutina 2009)

Sun in Cambridge Bay (Iqaluktuuttiaq), Nunavut, Canada

Box 2.7.3: Engaging tribal governments and indigenous peoples in Canada and the US

Consultation and Coordination with Tribal Governments in the US

The US Government's policy is to consult on a government-to-government basis with federally recognized Tribal governments when the actions and decisions of a federal agency, such as the US EPA, may affect tribal interests. Consultation is a process of meaningful communication and coordination between the federal agency and tribal officials prior to taking actions or implementing decisions that may affect tribes. As a process, consultation includes several methods of interaction that may occur at different levels.

The US Government Policy establishes national guidelines and institutional controls for consultation across the government. In the case of the US EPA, programme and regional offices have the primary responsibility for consulting with tribes. The US EPA has engaged with Tribal governments through innovative information solutions such as the Circumpolar Local Environmental Observer (CLEO) Network. Under the US Chairmanship of the Arctic Council (AC), partners in the Council's Arctic Contaminants Action Programme (ACAP) workgroup and its subsidiary Indigenous Peoples Contaminants Action Programme (IPCAP) are building on the success of the LEO network in Alaska and developing the foundation for a CLEO network. Using funding from the US Environmental Protection Agency and the North American Commission for Environmental Cooperation, ACAP IPCAP members are working with communities in western Canada to establish new LEO observer communities and regional hubs that would lead to a North American regional CLEO network.

Consultation and engagement with Indigenous peoples in Canada

Environment and Climate Change Canada (ECCC) aims to foster meaningful engagement and constructive dialogue with all Canadians, civil society, and Indigenous peoples. Consulting Indigenous peoples is one of the key steps to making good, sound and sustainable environmental decisions. ECCC consults with Indigenous groups for legal reasons, including the government's duty to consult and, where appropriate, accommodate when contemplating actions that could adversely impact Aboriginal or Treaty rights.

ECCC has statutory and contractual obligations to consult with Indigenous groups—for example, to meet the requirements of agreements such as modern treaties. The department also engages with Indigenous peoples for good governance reasons—for example, to make informed and appropriate decisions, create and improve working relationships, and address new developments. ECCC engages with Indigenous peoples on a wide range of issues—from specific conservation decisions, to compliance and enforcement issues, to international policy issues such as climate change and biodiversity. For example:

- National Indigenous Organizations were part of Canada's delegation in Paris for the 21st Conference of the Parties and are participating in the development of a pan-Canadian framework on climate change and clean growth.
- The Species at Risk Act sets out specific requirements for consulting with wildlife management boards when proposing to list species under the Act, incorporating Aboriginal Traditional Knowledge into species assessments, and cooperating with Aboriginal organizations and wildlife management boards when developing recovery strategies.
- ECCC has been engaging with Indigenous communities on the further development of domestic access and benefit sharing policy for genetic resources and traditional knowledge associated with genetic resources.

Development in the Arctic: Challenges and opportunities

The race to develop the extraction of energy and mineral resources, efforts to exploit territories on land and sea, tourism, fisheries, and shipping, and the opening of the seaways poses yet another set of pressures and cascading impacts for Arctic communities (Corell 2013). These development activities are accompanied by a major influx of people, competing national claims, new infrastructure, and companies into the Arctic–all bringing change to the physical environment, as well as to the social order (Larsen *et al*. 2014; Maynard 2013).

Oil and gas development in particular is accelerating other development in the Arctic through the creation of roads, economic activity and new settlements. Various corridors of intensive development, including the Beaufort-Mackenzie-North and Barents Sea-Pechora basin, will have major implications for the future of many Arctic indigenous communities. These developments bring new economic activity and development into vulnerable regions and communities – many of which are characterized by traditional hunting or reindeer herding; and many sensitive coastal and marine habitats (Grid-Arendal 2015). Balancing the inherent challenges and opportunities that accompany economic development, new infrastructure and investments will require a concerted effort by all parties.

Although the strong adaptive capabilities of Arctic peoples has served them well over the centuries, there is concern that they and their traditional ways of life will be irrevocably affected by the profound transformation taking place so rapidly across the region from climate change, globalization, economic development, and the opening of seaways (Larsen *et al*. 2014; Corell 2013; Maynard 2013). Thus, it is increasingly important to ensure that the peoples of the Arctic have a strong voice and an essential role in the future of the Arctic.

Traditional indigenous knowledge

Despite these many changes, Arctic indigenous peoples have historically adapted to climatic and environmental variability, as well as to more recent social and technological changes. Their adaptability can, in part, be attributed to their rich storehouse of traditional knowledge and flexible social networks (Larsen *et al*. 2014; Williams and Hardison 2013; West and Hovelsrud 2010). While indigenous peoples are now facing unprecedented pressures on their ways of life from climate change and the development of oil and mineral resources, they have already been developing some creative ways to cope, including both short-term and more formal long-term planning efforts (Nakashima *et al*. 2012; Brubaker *et al*. 2011).

Traditional ecological knowledge is the understanding indigenous peoples have accumulated over many generations about the systems at work in their surrounding environment (see **Box 2.7.4**). It has emerged as an important

Box 2.7.4: Embracing traditional ecological knowledge into science

Alaska Natives of northwest Alaska are highly dependent on barren-ground caribou (*Rangifer tarandus)* for meeting their nutritional and cultural needs. The Alaska Native village of Noatak borders the Noatak National Preserve, an area historically and presently used by Iñupiaq for subsistence caribou hunting and other traditional activities. A collaborative research project was undertaken between the National Park Service, the Native Village of Noatak, and the University of Alaska-Fairbanks to document traditional ecological knowledge (TEK) of the Western Arctic caribou herd. This study specifically looked at changes to caribou migration and behavior, potential impacts to caribou, and how those changes may, in turn, impact subsistence hunters. In addition, the study area of northwestern Alaska is used by non-local (resident and non-resident) Alaskans for big game hunting. Commercial operators in the region, and activity associated with small aircraft use, is a major concern for Indigenous hunters, who claim human disturbance impacts caribou. Main findings of this research showed that Noatak hunters perceive that changes to caribou and caribou hunting are primarily a result of aircraft activity and non-local hunters in the region. Climate change, changes to habitat, and predation, were also identified as main causes of change to caribou migration. Noatak hunters also reported that caribou hunting has changed substantially in the last five years, with less caribou harvested and hunters having to adapt to accommodate caribou migration shifts.

Noatak resident helps to map caribou hunting grounds and river crossing locations
© NPS/ Gabriela Halas

A variety of tools were used to gather and document TEK, including quantitative survey data, qualitative interview narratives, and GIS information. A filming project was also undertaken with elders of the village, which was used to produce educational films on the importance of caribou to Indigenous hunters. The study was completed from 2012 to 2015 and documented Noatak residents' traditional knowledge of caribou ecology and caribou hunting as a way of informing caribou science and wildlife management in northwestern Alaska.

knowledge base for addressing the effects of climate and other changes, as well as for the development of formal adaptation strategies (Larsen *et al*. 2014; Nakashima *et al*. 2012). In recent years, there have been a growing number of collaborations between scientists and indigenous experts in which traditional knowledge complements formal scientific knowledge to create more robust adaptation strategies. In Canada, collaboration between Inuit experts and meteorologists has explained significant recent changes in wind direction and speed (Overland *et al*. 2012; Gearheard *et al*. 2011).

2.7.10 Conclusion

It is very likely that globally anthropogenic warming of surface air temperatures over the next few decades will proceed more rapidly over land than over oceans, and it is very likely that the anthropogenic warming over the Arctic in winter will be greater than global mean warming (Stocker *et al*. 2013). The Arctic region is changing, and the changes are accelerating at rates and levels unprecedented for at least 800 000 years–and quite possibly for millions of years.

The Arctic and its peoples are witnessing tangible realities that arise from climate change: melting ice, increased industrial activities, and the development of the region's rich natural resources. As with so many climate change impacts, the profound challenges faced by the peoples of the Arctic are a likely harbinger of implications for North America, the northern hemisphere, and for the entire planet (Young *et al*. 2014).

Key messages: Climate change

While scientists continue to refine projections, and strengthen the evidence of human-induced climate change, observations in North America, and beyond, unequivocally demonstrate that the climate is indeed changing and that the warming of the past 50 years is largely due to human-induced greenhouse gas emissions.

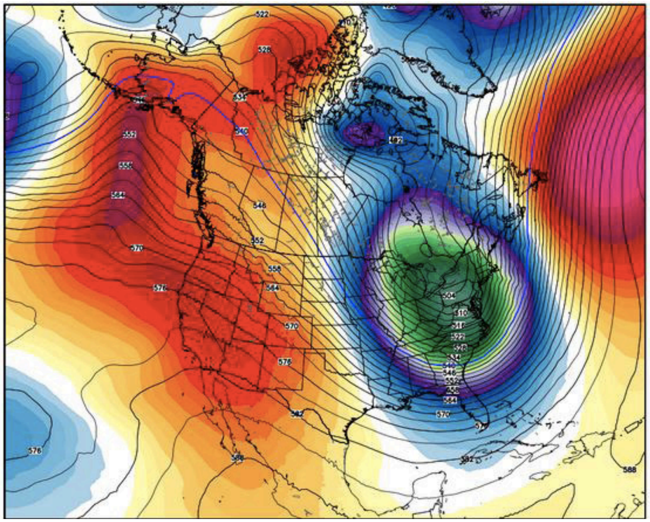
- The impacts of climate change are increasingly being felt across the entire region, affecting human health, well-being, and in some cases human security.
- The prospect for these impacts to worsen in both the near and long term constitutes a priority issue for North America.
- Canada and the US are taking steps both to mitigate the unmanageable and adapt to the unavoidable impacts of climate change across the region and beyond.
- Efforts to mitigate climate change through reductions in greenhouse gas emissions and enhanced carbon sequestration are beginning to show tangible results and to create a foundation for potentially major advances.
- Mitigation successes derive from a wide range of measures, across the federal, regional and local levels and across the public and private sectors, including: energy efficiency product standards, low-carbon electricity generation, transportation plans, building codes and standards, and other efforts.
- Efforts to adapt to climate change are also underway at many levels among governments, businesses, and communities in North America.

2.8 Climate change

2.8.1 Introduction

In North America, climate change traditionally occupied a theoretical dimension; something that will happen in the future. Evidence to the contrary was relegated to the Arctic where extreme transformations due to high temperatures have been underway for at least two decades. In the past decade, however, the effects of climate change are manifesting at lower latitudes: in hurricanes that generate human and infrastructural disasters in important cities, intense and enduring regional droughts, ecosystem and species migration that can disrupt livelihoods and lifestyles, and even in the temperature and precipitation extremes associated with shifting weather patterns experienced across the continent during all seasons. These extremes damage the built environment, challenge regional and global food security, and threaten the livelihoods and opportunities of citizens throughout both countries (Horton *et al*. 2015; Williams 2014; Scott *et al*. 2015; IPCC 2014a; AAFC 2015).

Figure 2.8.1: An analysis of pressure over North America



Shown above is an analysis of pressure over North America for February 20th, 2015 illustrating a strong ridge of high pressure over the western USA and Alaska and a deep trough in the east, which is allowing polar air to drive south.
Source: Adapted from Weather Bell 2015

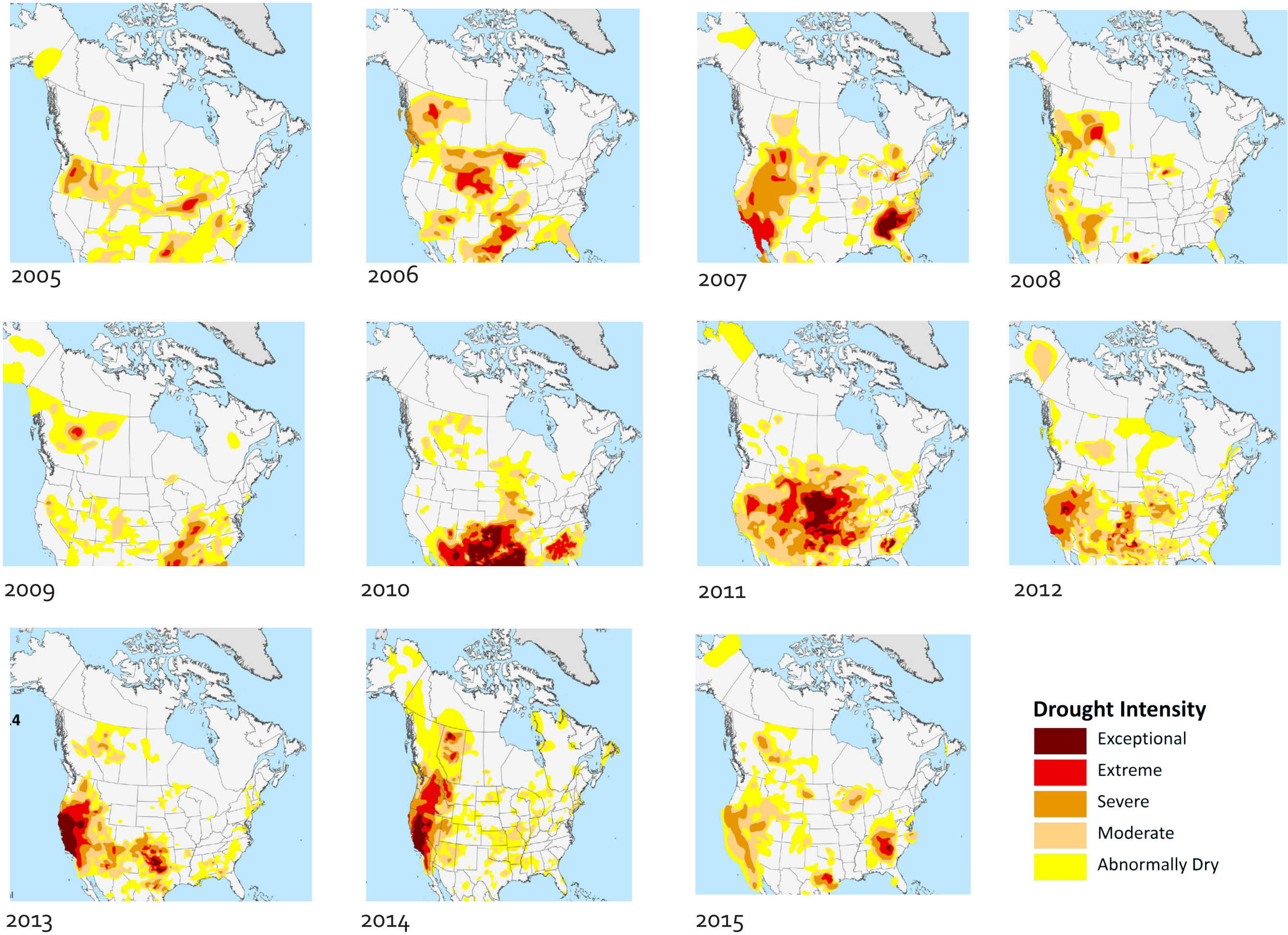
2.8.2 Newly erratic atmospheric systems

The West and South of North America have been experiencing drought and all parts of the continent have suffered from extreme summer heat waves since at least 2000. However, unexpected impacts are dominating the continent's Atlantic coastal region. Patterns such as the North Atlantic oscillation and the Atlantic multi-decadal oscillation affect weather and climate from Hudson Bay to the Arabian Peninsula. Temperature trends over the past few decades show a conspicuous region of cooling in the northern Atlantic. This cooling trend tracks a slowing in the south to north Atlantic current, the Atlantic meridional overturning circulation (AMOC) that includes the Gulf Stream, over the 20th century and particularly since 1970. Some of this slowing is likely due to contributions of cold fresh water from the melting of the Greenland ice sheet. Close inspection of data suggests that the AMOC's weakness after 1975 is unprecedented in the past millennium. Further melting of the Greenland ice sheet in the coming decades could contribute to further weakening of this south to north circulation in the North Atlantic. An accelerated rate of sea level rise along the continent's east coast is already apparent and attributed to this slowing of the Gulf Stream (Rahmstorf *et al*. 2015).

These circulation changes may bring anomalously persistent and cold oceanic and atmospheric temperatures to the North Atlantic that also enhance sea-level rise along the coastline of North America. At the same time, the ice-free status of the Arctic coast in summer may be another complex factor contributing to the very apparent changing climate on the North American continent (Francis and Skific 2015; Rahmstorf *et al*. 2015).

New research suggests that disproportionate Arctic warming and the consequent weakening of expected equator-to-pole temperature gradients cause the northern hemisphere

Figure 2.8.2: North American Drought Monitor, October 2005–2015



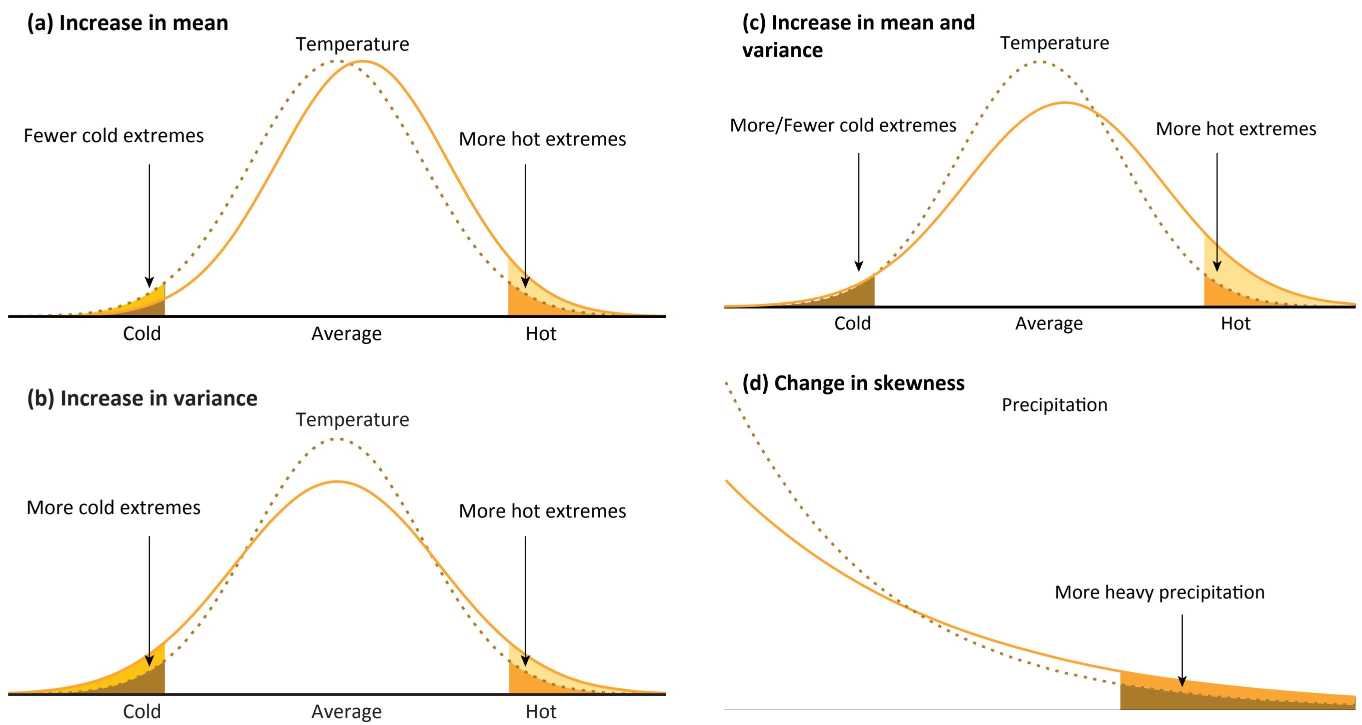
Source: NOAA 2015

circulation to adopt a more exaggerated but non-uniform north-south amplitude. As well, the evidence indicates these highly amplified jet-stream patterns are occurring more frequently. Further, such patterns will likely result in extreme weather events (Francis and Skific 2015; NOAA 2015a).

2.8.3 Persistent droughts, disrupted ecosystems

In North America, a dominant climate change threat is recurring drought, particularly in the south and west of the region. A 2000 to 2004 drought in western North America was described as *"the most severe drought over the past 800 years, significantly reducing the modest carbon sink normally present in this region"* (Schwalm *et al*. 2012).

Figure 2.8.3: Effect of changes in temperature distribution on extremes



Different changes in temperature distributions between present and future climate and their effects on extreme values of the distributions: (a) effects of a simple shift of the entire distribution toward a warmer climate; (b) effects of an increased temperature variability with no shift of the mean; (c) effects of an altered shape of the distribution, in this example an increased asymmetry toward the hotter part of the distribution and (d) change in skewness.
Source: Adapted from Stocker *et al.* 2013

Projections indicate that, at least through the end of the 21st century, drought events of that length and severity will be commonplace. More disturbing, projections also suggest that by 2099, the 2000–2004 drought will be considered the wet end of a drying period. Apart from sporadic and short-lived episodes of abundant precipitation, drought conditions are expected for the whole 21st century. Decreases in crop productivity, net primary production, large-basin runoff, and carbon dioxide uptake by the land surface–as documented in the 2000–2004 drought–could become the new norm, realized as 21st century mega-drought conditions (Schwalm *et al.* 2012; Williams *et al.* 2014; Scott *et al*. 2015).

A prominent five-year drought around the state of Texas ended in the spring of 2015 with devastating floods. The persistent drought conditions migrated north and westwards to California, the source of a significant proportion of US food production. Since January 2014, California's Governor has released a series of declarations concerning emergencies, drought, and wildfire; restrictions of water use; and water transfers (CDWR 2015).

After decades of research, the complexity of influences dominating the dimensions between weather and climate continue to challenge scientists. While key features of

Box 2.8.1: Urban complex in the eye of a storm

Examples of policy solutions to climate change problems too often originate in serendipity rather than deliberate choices: a case in point is the persistently low carbon/climate footprint of New York City citizens, relative to other US citizens. In addition to gaining this status through responsible planning, it also is the product of persistently high property values and the constraints imposed by the boundaries of the island of Manhattan. High-density housing, default dependence on public transport, and relatively low automobile ownership result in efficiencies in transportation and in heating and cooling systems, cutting average consumption of fossil fuels (Kelly *et al*. 2015). While these efficiencies were not purposely chosen, since the late 1990s they have been deliberately built upon and reinforced by municipal and community-level campaigns. These circumstances serve as good-practice models for other cities and communities looking for adaptation responses and smart solutions in the face of changing climate.

New York City's low-lying areas are home to a large population; critical infrastructure; and iconic natural, economic, and cultural resources. These areas are currently exposed to coastal flooding by warm-season tropical storms such as Hurricane Sandy and cold-season storms from the northeast. Sea-level rise is increasing the frequency and intensity of coastal flooding: for example, the 30 centimetres of sea level rise off New York City since 1900 likely expanded Hurricane Sandy's flood area by approximately 65 square kilometres, flooding the homes of more than 80 000 additional people in New York and New Jersey alone (Patrick *et al*. 2015).

Figure 2.8.4: Vulnerable New York City

Sources: Adapted from FEMA Data 2015; TerraMetric 2015

Hurricane Sandy was directly responsible for approximately 150 deaths and USD 70 billion in losses (Buss 2013; Horton *et al*. 2015). About half of the deaths occurred in the Caribbean and half in the US, including 44 in New York City. Sandy's 39-centimetre surge above mean low water set the record at official tide gauges. Several factors contributed to the extreme surge. Sandy's minimum pressure was the lowest ever recorded at landfall north of Cape Hatteras, North Carolina. With a tropical storm-force wind field of close to 1 600 kilometres in diameter, Sandy was also among the largest storms recorded in the region. Its unusual westward-turning track also concentrated surge, wind, and waves in the New York metropolitan region. Another contributing factor to the extensive coastal flooding was the peak surge coincided with high tide (Horton *et al*. 2015; Sweet *et al*. 2013) the major 1998-1999 El Niño Southern Oscillation (ENSO) event—which brought several weather extremes and unusual weather patterns worldwide—were known to scientists, its full extent was not predicted until six months prior to the event (Trenberth 2013). Major improvements in observing systems, together with advancements in science and experiential learning have improved our understanding of the connections between the tropical Pacific and the rest of the world, as ENSO patterns become increasingly recognizable. This learning is being repeated as the repercussions of the 2015-16 El Niño phase are studied.

2.8.4 Food security and North American climate change: increased variance

A convergence of factors has made food security an important issue globally, as well as in North America. An increasing population wants a more varied diet, but is trying to grow more food on less land with limited access to water, while facing increased fertilizer, fuel, storage, and transport costs (UNEP 2012). The added effects of climate change exacerbate the uncertainties. More frequent occurrences of droughts, floods, unseasonal temperatures, and erratic seasonality are affecting food supplies and security. As droughts continue and millions of hectares in less arid regions are left unsown due to excess moisture or flooding, misgivings develop about climate change-induced agricultural and food-system fragility in North America (AAFC 2015).

Recent studies show that one-half to two-thirds of the temperature influence on drought conditions in California during 2012–2014 can be attributed to the warming trend, depending on the climate datasets considered (Williams *et al*. 2015). While the drought is primarily a consequence of natural climate variability, however, the findings suggest that climate change exacerbated it by approximately 15-20 per cent. The probability of California suffering future dry spells, such as the one that began in 2012, have roughly doubled over the past century (Gillis 2015).

Projected declines in global agricultural productivity, particularly in North America, have implications for food security (IPCC 2014a; Ray *et al*. 2015). North America is a major exporter, so shifts in agricultural productivity regionally are likely to have implications for global food security including food costs, nutrition and potentially human health (FAO 2009; Schlenker and Roberts 2009). Canada and the US are relatively food-secure, although households living in or close to poverty are vulnerable (IPCC 2014a).

Increasingly frequent and intense weather events, exacerbated by climatic variability within and between seasons, create stresses on agriculture and food systems (Thornton *et al*. 2014). These complex and dynamic systems, which have developed to survive and thrive within a coping range, are now facing climate variability beyond that. In North America, recent variability includes early heat waves and late cold spells in spring, possibly matched by the inverse in autumn. The winters of 2013/2014 and 2014/2015 were cold and snow-laden throughout the east of the region, while summers were extremely hot. Mean temperatures may not have changed but the extremes have intensified.

The types of extreme events that are likely to increase include the frequency and intensity of heat waves, frequency of heavy precipitation events and associated floods, intensity of tropical cyclone events, and incidence of extremely high sea levels compounded by storm surges. Longer dry spells in some areas are likely to increase as will the area affected. In the short term, therefore, increasing climate variability has a more significant effect than longer-term change in mean values, and the appropriate focus of adaptation is management of climate risk. The need to focus on managing climate risk will continue even though the need to address changes in mean values over the longer term will increase (SREX 2012).

Given the distribution of heat waves and cold spells occurring in and out of season throughout the region while the temperature mean may only be rising slightly, the variance of temperatures seems to be increasing. Since 1999, a marked increase in crop losses attributed to climate-related events such as drought, extreme heat, and storms has been observed across North America, resulting in significant

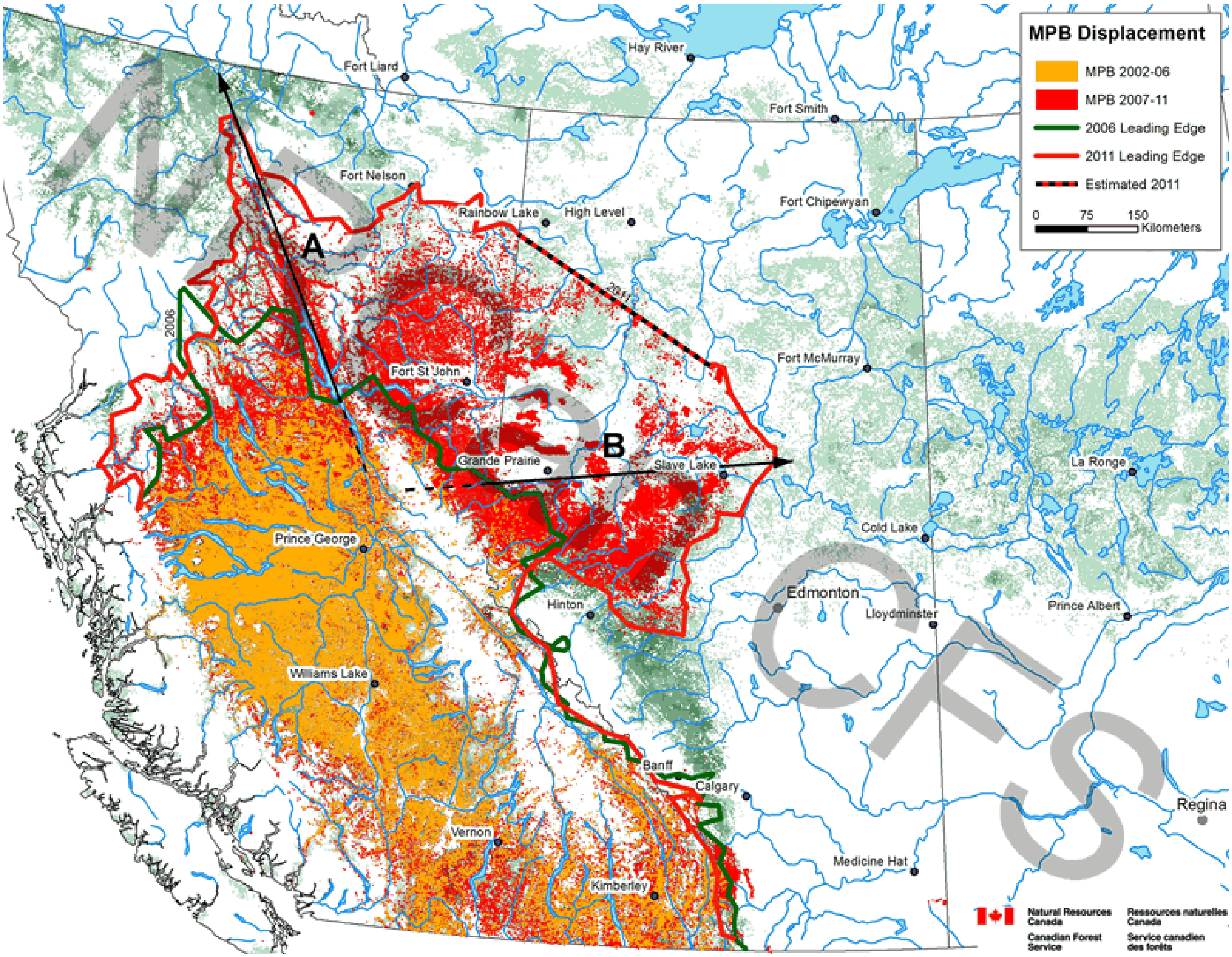
Box 2.8.2: Mountain pine beetle outbreaks: natural selection for climate change adaptation?

Insect outbreaks are increasing in size and severity on a global scale, attributable to climate change (Allen *et al* 2010; Bentz *et al*. 2010). In North America, the current mountain pine beetle (*Dendroctonus ponderosae*) outbreak is an order of magnitude larger than any bark beetle outbreak previously recorded (Mitton and Ferrenberg, 2012; Raffa *et al*. 2008). Outbreaks have played a major role in the evolution of coniferous forest ecosystems, as bark beetles are largely dependent on availability of stressed, dying, or recently-dead host trees. As well, insect populations typically decline as the supply of such trees is exhausted (Schowalter 2014). Historically, bark beetle outbreaks end with cold weather at crucial points in a population's potential eruptive dynamic (Six *et al*. 2014). Outbreaks erupt only when multiple thresholds–involving temperatures, tree defences, and brood productivity–are all surpassed, allowing positive feedbacks to amplify across several scales (Raffa *et al*. 2008). While outbreak development is complex, the primary elements that must exist are an abundance of suitable hosts and a trigger (Bentz *et al*. 2010).

The warming North American climate and the severe drought conditions in the West and Northwest have supported, and triggered, the mountain bark beetle outbreak in two ways (Allen *et al*. 2015). First, the hot and dry conditions stress trees, leaving them vulnerable to infestation; and second, the year-round warming conditions encourage an extension of the breeding season and the breeding territory (Showalter 2015; Mitton and Ferrenberg 2012). By 2010, researchers verified an extent eastward into Alberta, with an unprecedented species jump to infest jack pine (*Pinus banksiana*), the dominant boreal forest species in North America (Cullingham *et al*. 2011). This eastward progress suggests the pest may reach across the continent's northern boreal forest and prey on eastern forests (Natural Resources Canada 2015; Cullingham *et al*. 2011; Carroll *et al*. 2004; see **Figure 2.8.5**).

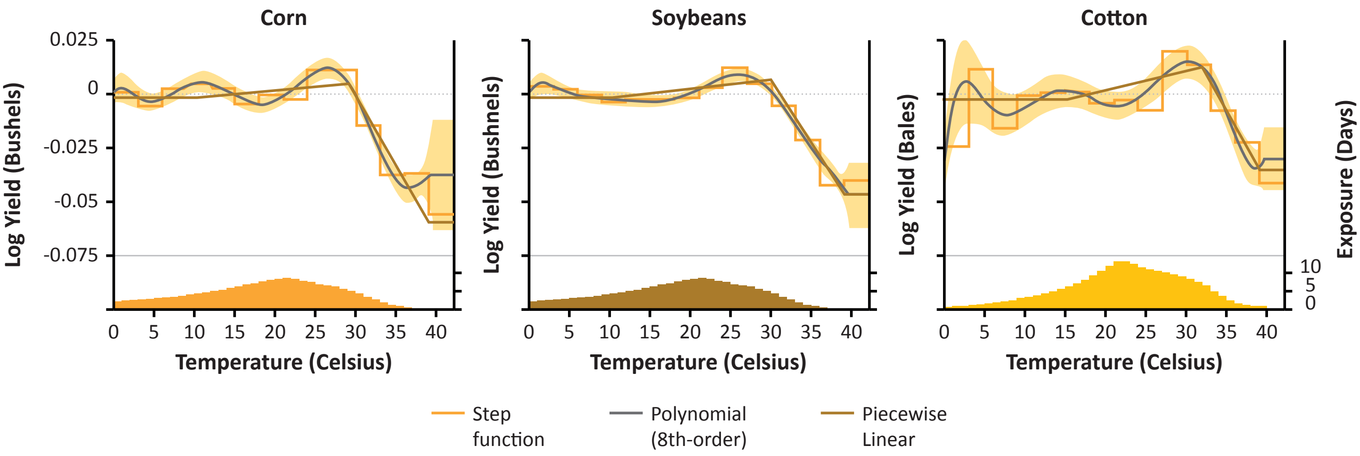
Since the outbreak began in the 1990s, standard management practices have involved various methods of removing trees, either to isolate infested stands or to thin them. A number of recent studies looking at the trees remaining after a beetle infestation asked whether the forest is better off with management or without (Kayes and Tinker 2012; Diskin *et al*. 2011). These studies highlight an elusive, but intriguing, outcome after a beetle outbreak: that an outbreak seldom removes all mature trees and can act as a natural agent to thin a stand of trees. These outcomes could be an important part of the ecological role that the beetle plays in western pine forests (Hansen 2014). The trees that survive the infestation in unmanaged areas remain because of inherent resilience, usually the result of genetic variation. In contrast, the trees that survive in managed areas remain because foresters selected which trees to remove. The possibility presents itself: stands that survive beetle outbreaks may be a variety with resistance to beetle outbreaks and to hotter climate (Six *et al*. 2014; Millar *et al*. 2012).

Figure 2.8.5: Mountain Pine Beetle, annual displacement



Source: Natural Resources Canada 2015

Figure 2.8.6: Nonlinear relation between temperature and yields



Graphs at the top of each frame display changes in log yield if the crop is exposed for one day to a particular 1° C temperature interval where we sum the fraction of a day during which temperatures fall within each interval. The 95 per cent confidence band, after adjusting for spatial correlation, is added as light yellow area for the polynomial regression. Curves are centered so that the exposure-weighted impact is zero. Histograms at the bottom of each frame display the average temperature exposure among all counties in the data.
Source: Schenkler and Roberts 2009

economic loss (Hatfield *et al*. 2013). Thus, over time, regional yield fluctuations have been attributed to climate variability (Cabas *et al*. 2010; Ray *et al*. 2015).

Historic yield increases are attributed in part to warmer temperatures in Canada and higher precipitation in the US, although multiple non-climatic factors affect historic production rates (McKenney *et al*. 2014; Nadler and Bullock 2011). In many North American regions, optimum temperatures have been reached for dominant crops, thus continued regional warming will diminish rather than enhance yields (Schenkler and Roberts 2009; see **Figure 2.8.6**).

The scientific literature evaluating effects on agriculture from climate change focuses mainly on assessments of changing temperatures, precipitation patterns, and increased carbon dioxide levels that affect crop yields. Less attention has been paid to the consequences of extreme weather events or to the adaptive responses by producers; and even less consideration of consequences throughout the larger food system (Miller *et al*. 2013; Rupp *et al*. 2012).

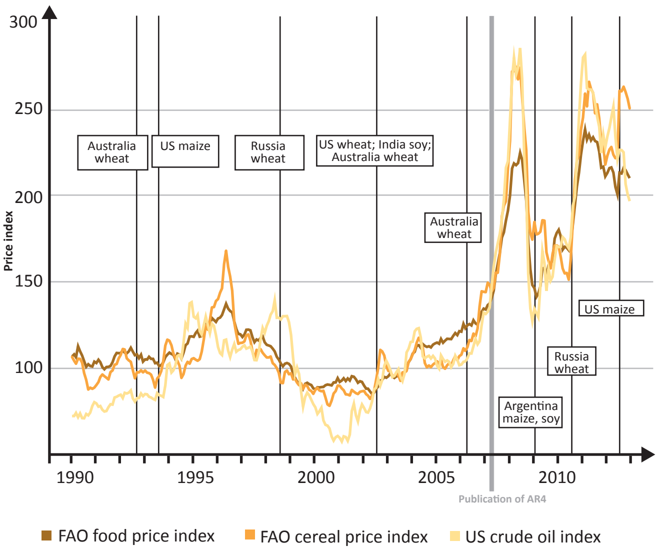
Strategies for increasing farming system resilience in the face of expected climate fluctuations depend in part on greater spatial and temporal diversity in planting patterns. Most notably, a number of choices exist in adaptation strategies for agricultural production (Miller *et al.* 2013). A case in point is small farms, which are more economically vulnerable to climate change due to tight profit margins that hinder their ability to respond to risk. On the other hand, small farm decisions tend to be short-term so there is a high level of farmer/crop adaptive capacity (DEFRA 2013).

2.8.5 Current understanding of impacts on regional agricultural production

Many international organizations are working on the emerging relationship between climate change and agricultural systems (Porter *et al*. 2014). In North America, Natural Resources Canada examined food production as part of its 2014 assessment, while the US Global Change Research Programme produced its National Climate Assessment in 2014 with agriculture as one of the key themes (NRCan 2014; Melillo *et al*. 2014).

Despite a wide range of regional and sub-regional climate change and agricultural system research efforts currently underway in North America, there is still limited regional research on the intersection of agriculture and food production that incorporates potential impacts of climate-induced biotic stressors and extreme events within the context of bioregions. There is also a need to improve the scientific understanding of climate impact on the vulnerability and adaptive capacity of bio-regional food production and food supply chains (Miller *et al*. 2013). For instance, the 2012 drought in the US Midwest resulted in low water levels in the Mississippi River, the region's main agricultural shipping artery. Barge traffic slowed, and lighter loads were required, resulting in decreased trade within the US and globally.

Figure 2.8.7: Food Price Index



Source: Stocker *et al.* 2013

Since the IPCC's 2007 Fourth Assessment Report (AR4), international food prices have reversed from the historical downward trend. **Figure 2.8.7** shows the history of FAO food and cereal price index compared to the crude oil index as tracked by the US Energy Information Agency. Vertical black lines represent events when a major producer or exporter of a crop had yields at least 25 per cent below trend line coinciding with a seasonal climate extreme.

Prices may have become more sensitive to weather-related supply shortfalls in recent years. At the same time, food prices are increasingly associated with the price of crude oil, making attribution of price changes to climate difficult. Thus, there is clear evidence, since AR4, that prices can increase rapidly, but the role of weather in these increases remains unclear. However policy decisions at high government levels may have significant influence on agricultural prices: the spike in food prices, and especially cereal and oil prices, in 2008 coincided with biofuel production mandates related to energy policies in the US and in the EU that were later moderated (World Bank 2012; Porter *et al*. 2014).

2.8.6 Stepping up with transformational adaptation

Recent literature on climate change solutions adopts an approach from management thinking and change theory by categorizing adaptation actions as incremental or transformational and exploring the nuances, dimensions, contradictions, and synergies the categories enable (McNamara *et al*. 2011).

Incremental adaptation is undertaken as an individual or autonomous adjustment reacting to a change in conditions and using knowledge and technology already at hand and well understood (Smith *et al*. 2011; Howden *et al*. 2010). Many options for adaptation are local and can build successfully on past climate risk management experience: labelled as climate change adaptation, they might be considered as practice adaptation, because the climate will continue to change over centuries. Therefore adaptation must become a way of life.

Meaningful long-term adaptation will require shifts in institutional arrangements and policies, approaches that nurture the design, exploration, and adoption of unprecedented intervention. Effective transformational adaptation must include social and financial investment in the unfamiliar: new technologies, creative partnerships, different infrastructure, and innovative engagement processes (Porter *et al.* 2014; Adger *et al.* 2009; Nelson *et al.* 2008).

Given the sporadic pace and inadequate efforts to mitigate the causes of climate change, communities on all continents, in every city, and at all scales need to adapt to the impacts of climate change. While incremental adaptation may suffice for initial response–as it has worked for coping with climate variability in the past–the inevitable, continuing, and likely intensifying impacts of climate change require transformational adaptation: and sooner rather than later (Porter *et al*. 2014; Bierbaum *et al*. 2013; Kates *et al*. 2012; Vermeulen *et al*. 2012).

A 2012 exploration of the approach suggests that transformational adaptation is essential in at least three situations: when an adaptation intervention must be significantly scaled up, when the intervention is introduced to a new region or resource system, and when the intervention will transform places and shift locations (Kates *et al*. 2012). Two conditions in particular call for transformational adaptation to climate change: severe vulnerability in certain regions, populations, or resource systems; and severe impacts that overwhelm even robust human systems.

2.9. The energy transition

2.9.1 Introduction

North America is at a crossroads where policies, infrastructures, and innovation can accelerate transitioning to a cleaner, low carbon energy system. At the international level, the Paris Agreement and Sustainable Development Goal 7 send a strong signal that the global economy is moving towards a decrease in the carbon intensity of the energy system. However, implementation of these milestone international agreements will require stakeholder involvement complementary to actions outside of the agreements by sub-national governments, businesses, innovators and entrepreneurs (The White House 2015; Trudeau 2015).

Although uncertainty exists in any market forecast, business as usual will likely result in increased development of unconventional fossil fuel sources such as those recovered by hydraulic fracturing (fracking) of underlying rock (US EIA 2016g). Past fossil fuel usage has contributed significantly to the historic increases in atmospheric greenhouse gas concentrations (IPCC 2011). North America, with abundant renewable energy resources, a culture of innovation, strong financial institutions and a highly skilled workforce is in an excellent position to lead the transition to a sustainable energy system (IRENA 2015). The choice of energy pathways is significant and will affect future global climate, human health and sustainability.

The energy sector in North America is transitioning, and shifting patterns of supply and demand are affecting air, land, and water resources. Technological developments have reduced the costs and increased the efficiency of solar, wind and other renewable energy sources, resulting in wider use (IEA 2015). Other technological advances have increased the development of unconventional fossil fuels. Decreasing costs, volatility of petroleum and natural gas prices, levelling of consumer demand, shifting policy priorities and the desire for consumer choice are all driving these changes. Data show that shifts in the North American energy landscape are affecting emission pathways, patterns and locations of land development, and water use associated with energy production and use–all with consequences for ecosystems and human health. This section examines the transformation in primary and secondary energy, along with changing patterns in energy demand.

Key messages: The energy transition

The energy system in North America is undergoing rapid changes, which provide challenges and opportunities.

- Challenges arise from the negative externalities associated with aggressive hydrocarbon extraction methods. These externalities include the potential for increased air emissions, water use and induced seismicity.
- Several opportunities also exist in the energy sector, driven by ongoing trends in renewable energy, rising efficiencies, and energy storage technologies. These clean energy trends show the potential that exists to achieve a sustainable energy system
- Ongoing shifts in the consumption and production of energy in North America have affected cities and rural areas, fostering alliances to both promote and deter particular forms of energy development.
- Integrated planning and robust governance are necessary to examine energy choices in a world of increased systematic risks and climatic change.

2.9.2 Primary energy sources

Primary energy resources are heterogeneously distributed across Canada and the US. Canada has vast oil resources, and is currently developing oil sand deposits. The US had large conventional oil resources that were rapidly developed from 1920 to 1985 (National Energy Technology Laboratory 2014) but are now in decline, as well as shale oil and gas, which are now being extracted at increasingly rapid rates. Canada also has shale gas formations; however, the development of these resources has not been as extensive as in the United States (National Energy Board 2009).

Since the oil and gas reserves that were easiest to access have been produced first, continuing on the fossil fuel path now requires more complex activities such as fracking, extracting energy from oil (bituminous) sands and drilling in more difficult locations. These new practices are more complex than conventional means and may increase water use, water contamination, greenhouse gas emissions, land impacts and wastes, although the magnitude of these effects are still being studied (Nicot and Scanlon 2012; Webb 2015; Jackson 2014; US EPA 2014; Jordaan 2012; Brandt 2012). Meanwhile, renewable energy sources such as wind and solar are now economically competitive with electricity sourced from fossil fuels (Wiser 2015). While choices between energy pathways have always existed, today the options are far more economically competitive, with the consequences having far-reaching effects on the economy, climate, ecology and society.

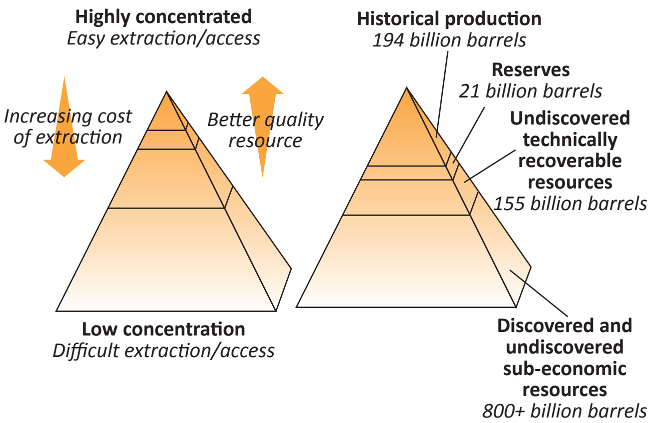
There have been changes in patterns of the consumption of oil, gas, and electricity in North America over the past 40 years. The US and Canadian economies have decoupled energy use from GDP and other measures of economic growth (EIA 2015a; EC 2011a). This decoupling also includes a reduction in petroleum consumption, mainly due to increased transportation efficiency (US EPA 2014). With predictions of increased petroleum production, the influence of international oil and gas developments and no concomitant increase in demand across North America, the fossil fuel industry has recently experienced severe price

Box 2.9.1: The resource pyramid concept

Oil, gas and other resources are not evenly dispersed geographically and also occur in differing concentrations. Higher concentration resources that are easily accessible are the most lucrative and are typically produced first. Lower concentration resources are developed later; even though they usually exist in greater quantity, they are more difficult and energy intensive to extract and may require new technological development. Conceptually, these resources may be placed in a pyramid, with easily accessible, lower volume, higher concentration resources at the top and lower concentration, more abundant resources at the bottom (Whitney *et al*. 2009).

In North America, most fossil fuel resources at the top of the pyramid, such as shallow onshore oil and gas, have already been produced and consumed. If the demand for oil continues, exploration and production will continue to move down the pyramid under the influence of price and the availability of technology to access these resources. Moving down the pyramid, the techniques used to develop the less concentrated resources, such as fracking, oil sands production and mountain top removal mining techniques may also increase environmental costs (Whitney *et al*. 2009).

Figure 2.9.1: Resource pyramid concept



Source: Adapted from Whitney *et al*. 2009

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declines. Since 2012, gasoline prices in the United States have dropped while petroleum production has increased, since 2010, driven by horizontal drilling, the fracking of tight shales, and enhanced recovery techniques deployed in conventional approaches (EIA 2015a; EIA 2015b; EIA 2015c). Canada exports much more oil than it consumes, a trend that is expected to continue, even as production increases and North American growth in oil demand decreases (EIA 2015). Despite the increasing share of Canadian oil in the US's import mix, these trends call into question the long-term economic viability of increasing petroleum production in North America.

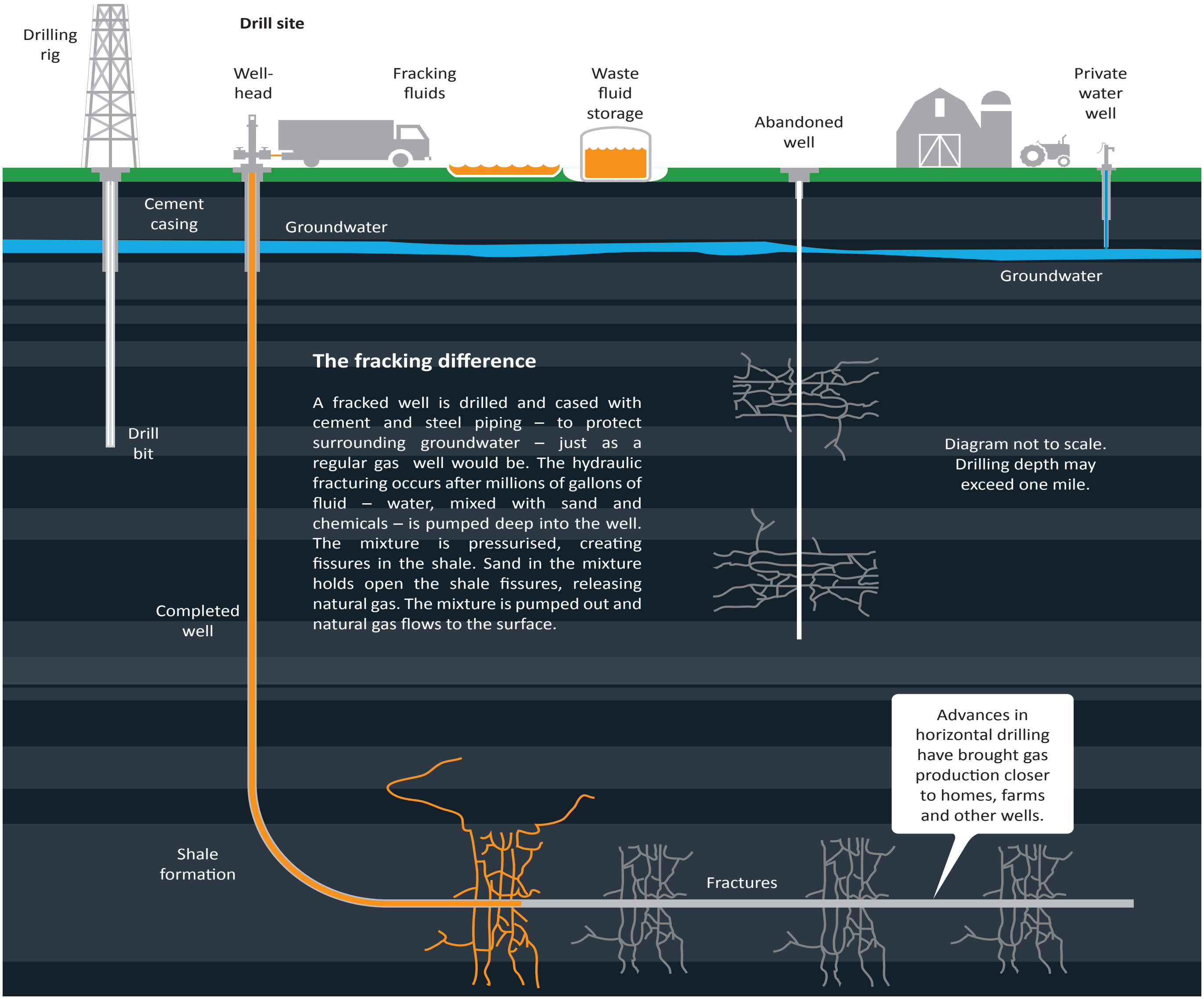
The extraction technologies driving the North American oil and gas boom depend on higher water usage than the amount required for conventional extraction (Gallegos *et al*. 2015) (See Section 2.4.2). These methods also require more energy for production and, in the case of oil sands in Canada, more energy to refine. As a result, some oil produced from oil sands has a higher GHG impact per barrel of crude than oil produced from other sources around the world (OCI 2015; Schneising *et al*. 2014; California Air Resources Board 2014). Despite these elevated greenhouse gas emissions, the Canadian government has not imposed any national greenhouse gas regulations on the oil sands (McCarthy 2014, 2015; EC 2013); however, the province of Alberta has announced an economy-wide carbon price, a cap to oil sands emissions, and a target to reduce methane emissions (See Section 3.2.6).

Over the past 30 years, fracking has become widely used across North America and is responsible for an increase in oil and gas production in the US (AEO 2015). While fracking is not a new technology, its use in combination with directional drilling is. By pumping a slurry of fresh water, sand and chemicals under high pressure into shale or other oil or gas bearing formations, previously inaccessible deposits become available.

While significantly reducing North American imports of oil, fracking has created new political conflicts over land use, waste disposal, climate change, concerns over potential human health impacts and economic development (EIA 2015d; Boudet *et al*. 2014; Davis 2014; Warner and Shapiro 2013; Fry *et al*. 2012). Like more traditional petroleum production, fracking produces many tonnes of associated brine that must be managed. In addition, any fresh water used to fracture the rock is contaminated by the chemicals and must be disposed of or reused. Often, these waste products are forced into porous rock formations through deep injection wells. Reusing contaminated water can decrease the use of freshwater in fracking operations in some cases, although freshwater use remains high (Nicot and Scanlon 2012). Lastly, some fracking chemicals (such as diesel fuels) contain carcinogens and toxins (Loh and Loh 2016; US EPA, 2015). With the increase in fracking, cities, counties and states across the US, as well as some provinces in Canada, have required disclosure of fracking fluid chemicals or have restricted, or even placed a moratorium, on the process (Jackson 2014; Howarth *et al*. 2011).

Another growing concern associated with fracking is the disposal of oil and gas production wastewaters in injection wells. The disposal of these fracking brines is responsible for increased seismic activity in certain areas (Farahbod *et al*. 2015; Weingarten *et al*. 2015; Folger and Tiemann, 2014). Recent earthquake intensities in Oklahoma have reached as high as 5.1 on the Richter scale (USGS 2016; see **Figure 2.9.3**). The increase in the volume and rate of injections is associated with the increase in seismic activity in areas where disposal occurs (Keranen *et al*. 2013; Holland 2013; Keranen *et al*. 2014; Weingarten *et al*. 2015). For example, in Oklahoma, the rate of seismic events in 2010–2013 was more than five times the rate in 1970–2000 (USGS 2016). In some cases, structural damage has been associated with these seismic events. In Western Canada, recent studies have indicated that instead of wastewater disposal inducing seismicity, there may also be a direct link between fracking and induced seismicity (Atkinson, *et al* 2016). Recently, a seismic event of magnitude 4.4 on the Richter scale was reported by British Columbia's Oil and Gas Commission to have been directly linked to hydraulic fracturing (Trumpener 2015; Atkinson *et al*. 2016).

Figure 2.9.2: How gas drilling could affect the environment



The US EPA has undertaken a three-year study of the impacts of hydraulic fracturing or "fracking" on drinking water amid complaints of water contamination. While some industry leaders insist there has never been a case of tainted water due to fracking, several states have begun requiring companies to monitor groundwater quality near their gas and oil wells.
Source: US EPA 2014; Bloomberg Research 2015

Box 2.9.2: Exploiting Arctic fossil fuel resources

- With the United States becoming the largest contributor to global liquid energy supplies, the increase in the use of fracking techniques has increased oil supplies and led, in part, to decreased prices for oil and natural gas (US Bureau of Labor Statistics 2013; US EIA 2016; Barbé 2015; Baumeister and Kilian 2015). These recent decreases in prices have led to a reassessment of areas where costs for mineral exploration are elevated relative to the onshore shale oil and gas regions, such as offshore and Arctic areas. In the case of the Arctic region, the USGS estimates the region to hold approximately 30 per cent of the world's undiscovered natural gas, as well as 13 per cent of its oil with 85 per cent of these resources located offshore (Wilson Center 2013). With this region becoming increasingly accessible, analysts have estimated that over USD 100 billion could be invested over the next decade (Emmerson and Lahn 2012).
- North American resources in the Artic are located on the North Slope of Alaska, in the Beaufort and Chuckchi Seas, and on the Mackenzie Delta. In the US, the government released a five-year plan for 2012-2017 that pursued a cautious approach to medium term leasing by planning for potential lease sales. However, recently the US Department of the Interior cancelled two potential Arctic offshore lease sales under the 2012-2017 programme and denied requests for lease suspensions that would have extended the expiration date of existing leases. The Interior Department cited the recent results of exploration in the area and current market conditions as reasons for these cancellations (US Department of the Interior 2015).
- In Canada, leases were granted in the Beaufort Sea, following a review of the potential safety and environmental impacts of offshore Arctic drilling in the aftermath of the Deepwater Horizon disaster (Wilson Center 2013; National Energy Board 2015; Indigenous and Northern Affairs Canada 2015). However, similar to the US, several exploration companies have also recently suspended Arctic exploration programmes (Davidson 2015) and the west coast of Canada is subject to a policy-based moratorium on development (Fletcher-Johnson, 2015). Canada is also currently reviewing the Canadian Petroleum Resources Act, which allocates the rights to explore and develop on frontier lands (Indigenous and Northern Affairs Canada 2015).
- The difficulty in accessing these resources results in relatively elevated costs and, in combination with recent fossil fuel price decreases and policy shifts, appears to be contributing to a hold on some development activities in the offshore Arctic. Recent analysis has shown the need for Arctic resources to remain undeveloped to achieve the globally agreed goal of limiting warming to less than 2°C (McGlade and Ekins 2015). As a result, the current pause may afford the time necessary for assessing the need to develop the resources in conjunction with current climate commitments and recent scientific findings.

Box 2.9.3: Oil sands exploitation in North America

- Canada is home to about 15 per cent of the world's proven oil reserves, second only to Saudi Arabia, with 98 per cent in the form of oil sands (NRCan 2014). In Alberta, landscapes have been transformed to extract, process, and transport bitumen, which is thicker than crude oil and occurs naturally mixed with sand.
- Bitumen can be extracted in two ways. The first is open-pit mining that involves removing forests and bogs from the surface, scooping out a mixture of bitumen and sand using heavy machinery, and separating the bitumen from the sand. The second involves injecting high-pressure steam deep underground to separate sand from bitumen below the surface. Either way, extracting bitumen is an energy- and water-intensive process.
- The development of oil sands is associated with a range of environmental impacts. In addition to the greenhouse gas emissions linked to extracting, refining and transporting bitumen, the strip mining approach results in significant land-cover change, though regulations require industry to return disturbed land to a biologically productive state. Water contamination (Frank *et al*. 2014) causes health concerns, especially for downstream indigenous communities. Air pollution is also a concern: mining and upgrading bitumen releases more sulphur dioxide than annual forest fires in Canada, contributing to the 25 per cent of Canada's sulphur oxide emissions that come from the oil and gas industry (Howell *et al*. 2014; Environment and Climate Change Canada 2016).
- Exploiting the oil sands has encountered resistance from indigenous groups, environmental advocates and others. In addition to activities in and around the production of the oil themselves, the expansion of pipelines has provoked controversy. Networks of pipeline opposition have spread across North America in a spatial pattern similar to that of the region's pipeline infrastructure itself (Veltmeyer and Bowles 2014). Resistance is driven by concerns over land rights, habitat fragmentation, acute risks from spills and long-term exposure to pollutants near refineries, as well as solidarity with indigenous people directly affected by the extraction of bitumen at its source (Grant 2014; Scott 2013). Some affected communities have responded to the development of the oil sands and associated infrastructure by hosting tours to present their perspective on the local impacts of this development (Dinshaw 2015).
- As Canada's top oil importer and refiner, the US energy industry is inextricably tied to Canada by pipelines and trains. Given the volume of bitumen available in Canada, and globally, North American governments are confronted with political decisions about whether to prioritize support for petroleum or renewable energy development and efficiency gains. A recent study concludes that most of the oil sands must remain underground if global warming is to be limited to 2ºC (McGlade and Elkins 2015).

Fracking techniques have raised concerns over the potential for increased methane emissions from the oil and gas sector (US EPA 2014). Recent research indicates that methane leaks from natural gas production and transportation may offset the benefits of greenhouse gas reductions from natural gas electrical generation compared with coal-fired generation, despite lower GHG emissions from natural gas (Howarth *et al*. 2011; Miller *et al*. 2013; De Gouw *et al*. 2014; Petron, *et al.* 2014; Brandt *et al.* 2014). The integrity of some retired oil and gas wells has also been called into question and may be sources of errant methane releases (Jackson 2014). Research has indicated that, for specific areas in the US, the range of increase of methane from unconventional development may be as high as 6.2–10.1 per cent (Schneising *et al.* 2014). In the United States, draft regulations have recently been issued to require monitoring and reduction of these emmissions (US EPA 2015).

Roads and natural gas well-pads crisscross the Pinedale Anticline gasfield, just outside of Pinedale, Wyoming, US
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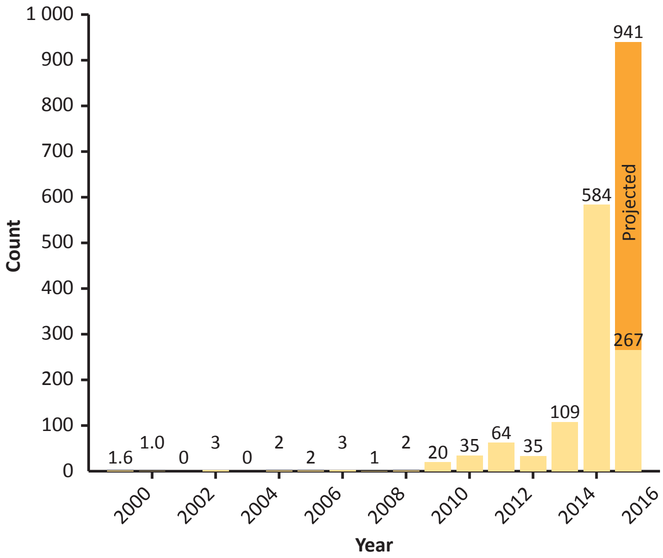
2.9.3 Secondary resources

Traditionally, coal deposits in the US supplied the fuel for generating electricity, though coal production and use is now shrinking. Electricity generation from natural gas and renewable sources have increased in the United States to fill the gap created by decreasing coal-fired generation (US EIA 2016a). In 2014, approximately 38 per cent of electrical generation came from coal, 27 per cent from natural gas, 19 per cent from nuclear and 13 per cent from renewables (US EIA 2016g). In contrast, Canada produces over 60 per cent of its national electricity from renewable hydroelectric resources. Nuclear resources provide approximately 13 per cent, conventional steam provides 14 per cent, combustion turbines produce 7 per cent, with the remainder coming from renewable resources (Statistics Canada 2012). Thus, the Canadian electrical sector is largely decarbonized. Despite differences in supply, the two countries share some trends: electricity generation from renewable sources and natural gas is increasing. Large investments in the natural gas generating sector have come at a time when a slowing in the growth of demand for electrical power is seen across developed countries and production from renewables has increased (US EIA 2015).

In the US, the two traditional forms of electric generation that emit no GHGs–hydroelectric and nuclear—have had relatively stable output since 2001 (US EIA 2016b; 2016d). Large shifts have occurred in two forms, coal and natural gas. Coal generation has fallen by almost 25 per cent (US EIA 2016c), while natural gas generation has increased by over 50 per cent (US EIA 2016e). Despite the lack of change in hydroelectric and nuclear, the change in the mix of coal and natural gas is significant. Natural gas fired generation emits lower GHG emissions per unit of electricity than coal. Therefore, the change from coal to natural gas in the US, along with increased renewable deployment and efficiency has contributed to lowered GHG emissions from electricity generation (US EIA 2014). In Canada, increases in nuclear and hydroelectric power generation of 22 per cent and 6 per cent occurred between 2000 and 2012 (US EIA 2016f). Total fossil fuel generation during this period fell slightly, by approximately 16 per cent (US EIA 2016f).

Figure 2.9.3: Oklahoma, US, earthquakes over time



Source: USGS 2015

Renewable energy technologies have matured to an extent that they can now be deployed at significant scale and be cost competitive in North America (Wiser 2015; IPCC 2014b). Recent decreases in wind and solar energy prices illustrate this trend: wind energy prices have fallen to an all-time low, pushed in part by improvements in technology and increasing production (Wiser 2015), while solar energy prices have also fallen, with solar photovoltaic (PV) module prices in 2014 around 75 per cent below their levels at the end of 2009. Between 2010 and 2014 the total installed costs of utility-scale PV systems fell by 29–65 per cent, depending on the location in North America (IRENA 2015).

For other renewable energy technologies, the story is similar to wind and solar, with electrical power generation costs competitive under many circumstances. Biomass, geothermal and hydropower provide electricity competitively with fossil fuel-fired power generation (**Figure 2.9.4**). These trends encourage forecasts of increasing renewable energy deployment and decreasing fossil-fuel electricity generation (IRENA 2015; BNEF 2015).

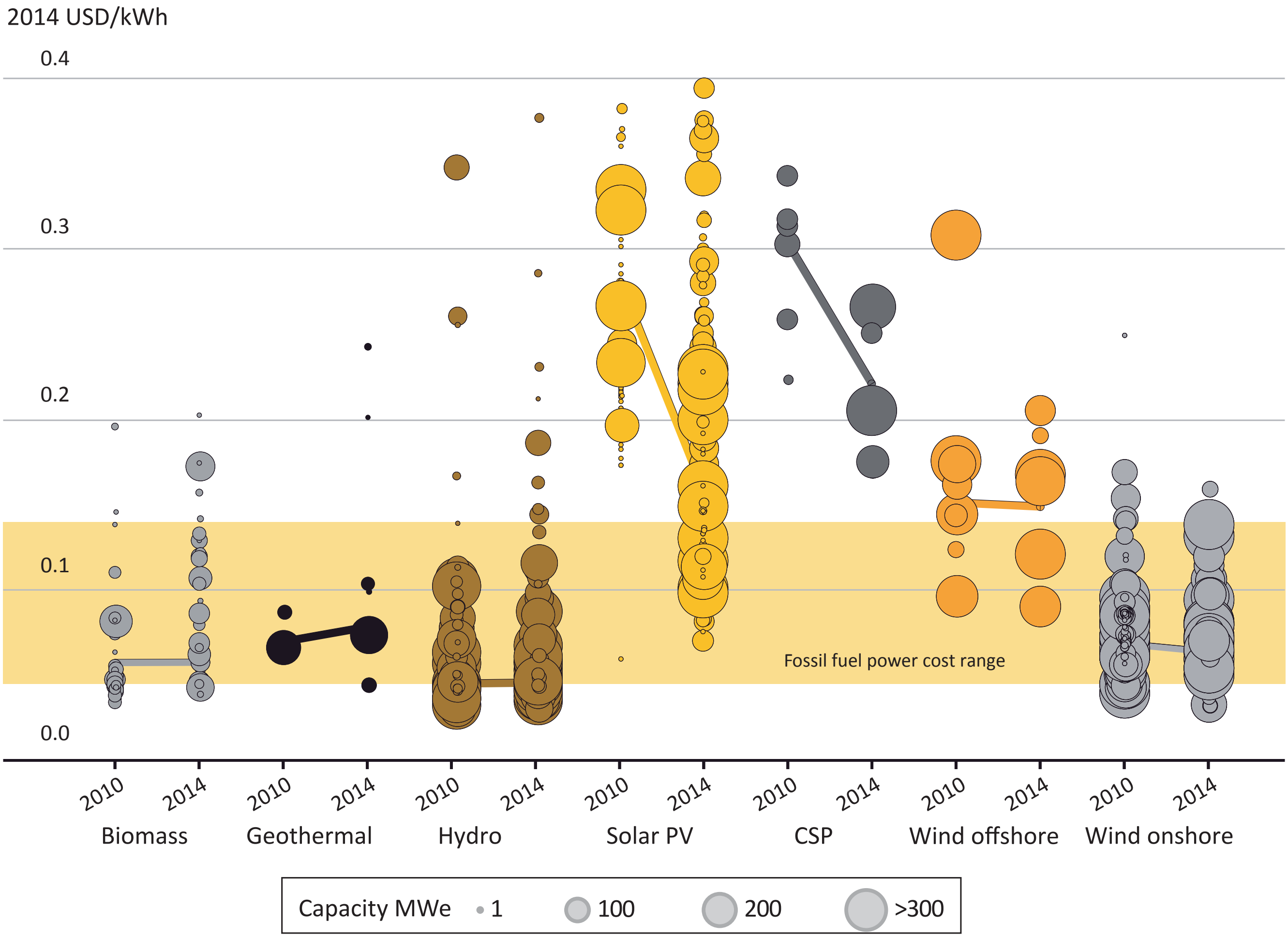
The ongoing transition to renewable energy has been dramatic in the US, where wind energy now provides about 5 per cent of total electricity demand and powers more than 17.5 million homes (EIA 2015a). However, the most striking change is that the price of wind-generated electricity is at historic lows and is lower than the wholesale price of electricity across many parts of the US (Wiser 2015).

Canada has also experienced a large increase in wind energy deployment. With more than 10 gigawatts of installed capacity, wind power in Canada can now supply 4 per cent of national electricity demand and power about 2 million homes (CanWEA 2015). In many instances, community resistance based on perceived human health risks has presented an obstacle to the further development of wind energy, not only in Canada, but also in the US (Songsore and Buzzelli 2014; Walker *et al*. 2014).

A mix of supportive policies, technological improvements and, increasingly, consumer choice, drives the growing rate of wind power installation. Technological improvements and increasing returns to scale contribute to price declines in wind energy, explaining why many technology firms are specifically requesting wind energy to power data centres. A key to technological improvement is the development of larger and taller turbines. Since higher wind energy is available at higher wind speeds and larger rotors capture more energy at lower wind speeds, these turbines produce more energy at lower costs. This trend has resulted in wind energy capturing a one-third share of all new electricity generating capacity built since 2007 in the US (EIA 2015a).

Solar deployment has also increased dramatically, capturing 40 per cent of the market for new electric generating capacity in the US in the first half of 2015. During the second quarter of 2015 alone, solar installations in the US were 1 393 megawatts and solar capacity now has reached 22.7 gigawatts nationwide. Solar now powers 4.6 million homes and individual homeowner and utility-scale installations are becoming more common (SEIA 2015; EIA 2015).

Figure 2.9.4: The levelized cost of electricity from utility-scale renewable technologies, 2010 and 2014



Source: Adapted from IRENA 2015

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Modernizing the energy grid in the US is necessary to improve load balancing for renewable energy resources, to increase efficiency and to decrease costs. Both wind and solar are variable resources and thus require load balancing, either through other generation sources, energy storage or a well-diversified portfolio of renewable assets to maintain supply. Research has shown that electricity supply and demand can be balanced with nearly 80 per cent renewable resources, including 50 per cent from variable resources, such as wind and solar (Mai *et al*. 2012). These levels of penetration do require additional investments in transmission and require greater system flexibility (Mai *et al*. 2012). Modernization also includes further implementation of grid-connected energy storage through battery systems and pumped-storage hydro. In 2013, the US had about 24.6 gigawatts, or 2.3 per cent, of grid storage, 95 per cent of which was pumped hydro (DOE 2015; Sandia National Laboratories 2013).

Battery storage capacity in the US has expanded to 62 megawatts in 2014, but two-thirds of all batteries deployed were located in one grid balancing area. This rapid expansion in one area was the result of restructuring that provides a market for rapidly-responding resources to balance the grid (Xiao *et al*. 2014). The use of smart market incentives has resulted in a growth in storage and improved grid stability. In addition, the smart use of storage has reduced the total amount of peak electricity procured, resulting in lower costs for consumers (Lueken and Apt 2014). Therefore, the development of smart-grid systems, additional transmission, and storage should allow for greater deployment of renewables, leading to reduced greenhouse gas emissions and water use in electricity generation.

2.9.4 Energy conservation ('Negawatts')

Energy conservation is accelerating, driven by increasing conservation as a result of technologies, regulatory requirements, public private partnerships and changes in consumer behaviour. This multifaceted approach is showing great promise with energy efficiency increasing across multiple sectors. Conservation decreases demand, thus allowing greater production per unit of energy and lowers the requirement for additional energy sources. This results in savings for consumers and decreases the emissions of greenhouse gases per unit of production.

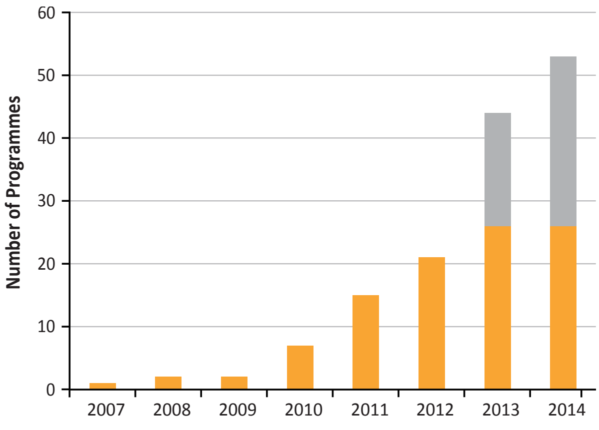
Box 2.9.4: Generational changes in energy use

Millennials, or those that came of age during the early 2000's, are increasingly turning to bikes, urban living, and public transportation as eco-friendly alternatives across Canadian and US cities. Early research into this area, indicate shifts in lifestyles, demographic, macro-economic, and housing market preferences (Moos 2015).

The rise in alternative commuting practices is evident in the number of bike sharing programmes that have been put in place in the US since 2007. The bike-share programmes encompass two aspects of a sustainable future for cities, an eco-friendly transport option combined with a sharing economy. In these programmes, bikes are stationed at key points throughout a city, available for use with the swipe of a card. Cyclists can take advantage of use for a period of time and leave bikes at the station nearest their destination. This eliminates the need for maintenance by the users and allows for casual use between destinations. These programmes are increasing as well across Canada and show promising results (Shaheen 2014). Bike-sharing has resulted in lowered personal automobile use by 50 per cent for programme members and as a result, decreased carbon emissions in cities with these programmes (Shaheen 2014).

Commuters are not only using bikes, but, in the case of younger commuters, are often walking to work. In fact, workers aged 16–24 have the highest rates of walking to work – 6.8 per cent in the US (McKenzie 2014). The rate of walking and cycling has been influenced in part by actions by cities and local government agencies to increase participation in these forms of travel. The initiatives these agencies have taken not only include the bike share programmes, but changes in the infrastructure and travel options that people have. As a result, participation rates for biking to work have almost doubled in the United States from 2008–2012 (McKenzie 2014).

Figure 2.9.5: Bike-sharing programmes in the US, 2007–2014



Source: Adapted from Earth Policy Institute 2015

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Efficient transportation has resulted from regulatory requirements that have driven changes in technologies. Average fuel economy of new light-duty vehicles has increased dramatically, by more than 25 per cent between 2005 and 2014 (US EPA 2014). For light duty vehicles, the targets set by US and Canadian regulators should enable this trend to continue and in turn decrease oil consumption (Salisbury *et al*. 2015). In this case, regulatory requirements have driven large improvements in the vehicle fleet.

Not only have light duty vehicles achieved reductions, but so have heavy trucks. These are responsible for 26 per cent of US on road fuel consumption, and therefore account for a large portion of the greenhouse gas emissions from the US transportation fleet (Wiser and Bolinger 2015). The US Department of Energy in conjunction with private partners set a goal for increasing the efficiency of these large vehicles by 50 per cent between 2009 and 2015. This public/private partnership not only met the target, but achieved an improvement of 115 per cent. Canada has harmonized its vehicle emissions regulations for both cars and trucks with those of the US.

New technologies are starting to transform the way that buildings use energy and respond to varying patterns of occupancy. Smart building technologies, such as smart thermostats and smart electricity meters are increasing comfort while saving energy. These new devices are often self-configuring, communicate and track patterns of usage across floor spaces to optimize energy use. Companies are recognizing that by implementing these smart devices, the savings are substantial, with an average savings of 55 per cent per unit, resulting in short-term returns on investment with long-term savings. In many cases these smart devices allow for electricity grid operators to reduce output and decrease the need for peak power and additional power plants (Wiser and Bolinger 2015).

In California, the Energy Commission's energy efficiency standards for buildings have also resulted in savings for consumers. These initiatives have saved more than USD 74 billion in electricity costs since 1977. The savings add up over time as new buildings with greater efficiency replace outdated buildings, and higher efficiency equipment and appliances replace older, less efficient ones. California's per person electricity use has remained stable over the last 40 years, and this is often attributed to these standards (Levinson 2014; California Energy Commission 2014).

The State of California has been at the forefront of environmental stewardship within North America and globally (e.g. the California co-founded Subnational Global Climate Leadership MOU) — which collectively represents more than 572 million people. In 2007, the State set an ambitious goal of reaching zero net emissions (ZNE) by 2020 for residential buildings and by 2030 for commercial construction. ZNE will be achieved through a combination of energy efficient building codes and on-site renewable energy generation. In 2015, California enacted legislation to substantially update building codes which will result in a 28 per cent reduction in residential energy use (Levinson 2014; California Energy Commission 2014). The California Energy Commission estimates that CO_2 emissions will be reduced by 160 000 tonnes/year.

The shifts in consumption and production of energy have affected cities and rural areas, fostering alliances to both promote and deter particular forms of energy development. These partnerships have pointed out the trade-offs, barriers and impacts incumbent in the development of energy resources. Integrated planning and robust governance are necessary to examine these choices in a world of increased systemic risks and climatic change.

See links for Chapter 2

See references for Chapter 2

CHAPTER 3

Policies, goals and objectives: review of policy responses and options

Key messages

Environmental conditions in North America have significantly improved over time due to investments in policies, institutions, data collection and assessments, and regulatory frameworks.

- Air quality, water quality, biodiversity protection and waste management are areas where significant progress has been made. In each of these areas, however, there are regions and communities that have not benefited fully from the overall success.
- Recently environmental challenges have emerged that are proving harder to manage within existing policy frameworks. These challenges are the result of interactions across complex systems involving multiple pressures. They pose risks to human wellbeing and ecosystems that are novel in form and magnitude.
- Climate change, contaminants of emerging concern, non-point source pollutants, and transforming the energy system are examples of issues that are harder to manage using conventional policy tools.
- Environmental change in the Arctic is an example of a problem that combines hard-to-manage issues with rapid, multiple pressures in a single region, creating major policy challenges.
- Approaches to managing these problems that reduce systemic risk and steer sustainable transformations have emerged, generating evidence of their potential to respond to these new challenges.
- Natural Capital Accounting is receiving growing levels of attention and moving toward higher levels of feasibility and acceptance. By providing quantitative metrics on the value of environmental assets and ecosystem services, it enables broad improvements in conservation and management.
- Sustainable consumption and production is increasingly embraced as a policy framework, and has shown an ability to reduce pressures on the environment by triggering changes in procurement and manufacturing processes.
- North America is driving environmental improvements by embracing data-driven innovation, using environmental informatics, analytics and data to transform behaviour and outcomes. Advances in open data architectures, sensor technology, interoperability standards, and modelling and visualization tools are making more information more accessible to more people.
- Multiple approaches to adaptive governance are proving capable of helping communities tackle complex, difficult problems with impressive results. These approaches combine pluralistic approaches to problem framing and solution identification; strong commitments to evidence-based decision-making and results-oriented management; and flexible, iterative processes aimed at maximizing learning.
- Cities in North America are experimenting with new approaches to managing sustainable development challenges, proving in many instances to be capable of levels of innovation and integration beyond that of the federal government

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3.1 Introduction

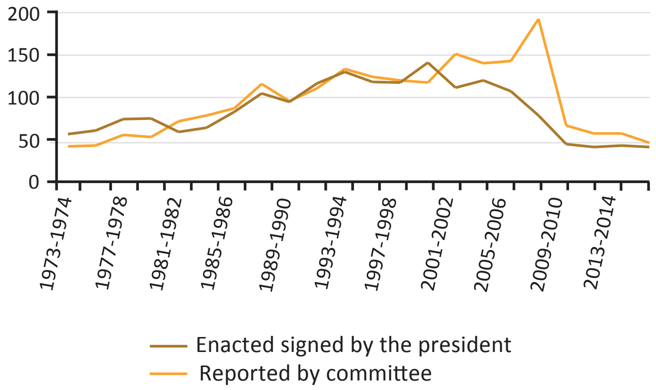
It is a challenging time for environmental policy makers in North America. While the Paris Agreement and the pledged NDCs provide a cause for optimism, climate change continues to loom as a formidable problem, with the severity of impacts rising. Some new issues, such as contaminants of emerging concern, are entering the policy agenda without clarity on how they can be effectively managed. Others, such as hydraulic fracturing, are triggering polarization and discord. In different ways, Canada and the US are experiencing a transitional period in environmental policymaking.

However, the US is finding that its historical policy strengths may be less reliably sufficient. In the past a series of landmark laws that served as the blueprint for federal regulation of the environment were passed. The Clean Air Act (1963), the establishment of the Environmental Protection Agency (1970), the Clean Water Act (1972), the Endangered Species Act (1973), and the Safe Drinking Water Act (1974) have served as models for national and subnational legislation across the globe. This legislative and policy infrastructure has been responsible for decades of progress towards environmental sustainability, ecosystem protection, and public health improvement.

In addition, there are signs that environmental policy has been subjected to heightened degrees of polarization in past decades. In the US, after a shared high in 1990, support for public spending on the environment began to sharply split between people self-identifying as Democrats and Republicans (McCright *et al.* 2014).

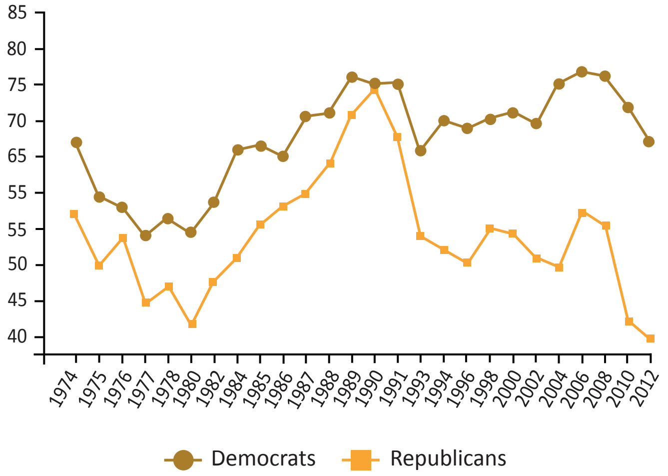
Canada also experienced sharp breaks from its traditional style of environmental policymaking. A 2014 Auditor General report identified several areas in which environmental policies were becoming less effective, including regulation of greenhouse gas emissions, monitoring of oil sands and application of environmental assessment requirements (CESD 2014).

Figure 3.1.1: US national environmental legislation, 1973-2015 (number of Congressional Bills)



The number of national environmental laws enacted in the US has decreased from an average of 71 per year in the 1980s and 1990s to one per year since 2009.
Source: govtrack.us 2015

Figure 3.1.2: Percentages of US Democrats and Republicans reporting that national spending on the environment is "Too Little," 1974-2012



Source: McCright *et al.* 2014

Despite these factors, response across North America has been far from stagnant, with considerable innovation and enthusiasm. What has emerged is a complex landscape of responses that leverage adaptive governance, new uses of data, and city-based innovation. Physical infrastructure and legal frameworks that were designed for a past era have been re-formed in pursuit of new goals and outcomes. Provincial and state governments, businesses, municipalities and counties, community organizations, and religious institutions have all taken the lead in developing new projects, initiatives, and laws that often address multiple environment-related goals. Coalitions among unlikely partners have formed on a project-by-project basis, including an effort with farmer, environmentalist, and military support for renewable energy development and preservation of agricultural lands.

3.2 Policy: state and trends

This section presents a broad survey of policy developments in Canada and the US, focused on issues presented in this assessment's state and trends coverage.

3.2.1 Air

Canada and the US have demonstrated effective air quality management strategies and roles for local, regional, and national governments, as well as for bilateral arrangements such as the Canada-US Air Quality Agreement. Canada and the US have successfully used a range of regulatory and non-regulatory policy approaches to significantly decrease emissions from a variety of air-polluting sources. It has been shown that protecting public health and building the economy can go hand-in-hand. Some persistent air quality problems, however, remain.

Common air pollutants

Both Canada and the US have implemented systems for management of key common air pollutants, such as ground-level (or tropospheric) ozone and fine particles, through which provinces and states develop regulatory programmes to achieve uniform national standards for ambient air quality. The efforts of provinces and states are supported by regulations and guidelines established at the national level. In the US, this federated approach is specified by the Clean Air Act of 1970 and its amendments in 1977 and 1990, which give the national government authority to set the National Ambient Air Quality Standards (NAAQS) and require states to develop plans to achieve those standards. The Canadian Ambient Air Quality Standards (CAAQS) are established under the Canadian Environmental Protection Act of 1999 and implemented through an Air Quality Management System developed under the Canadian Council of Ministers of the Environment (CCME 2012).

Canada and the US have required dramatic reductions in emissions from new motor vehicles and non-road engines—such as those used in construction, agriculture, industry and marine vessels—through harmonized industry-wide standards that require a combination of cleaner engine technologies and cleaner fuels. Canada and the US worked together to establish a North American Emissions Control Area for marine vessels under the International Maritime Organization, establishing emission limits and fuel requirements for ships operating near North American coasts (IMO 2010).

Regulatory approaches in the region aim for incorporation of the highest practical pollution control technologies in new industrial facilities. As cleaner facilities are built, the region's industrial base becomes cleaner overall and public health is protected as economic growth proceeds. Under the US Clean Air Act, new and modified large plants and factories must apply the best available technology considering cost, and avoid causing significant degradation of air quality or visibility in areas that are already in attainment of the NAAQS. If the area is not attaining the NAAQS, the new or modified source must meet the lowest achievable emission rate, a more stringent standard. To help meet the requirement, facilities can obtain offsetting emission credits from other sources that emit below their allowable limit. Authority to administer these permitting requirements is delegated to state, local, tribal or national authorities, as appropriate.

The US continues to make extensive use of economic instruments in achieving its air quality goals. A 2011 Cross-State Air Pollution Rule (CSAPR) provides an updated framework for implementing tradable permits for sulphur dioxide emissions, initiated by the 1990 Clean Air Act Amendments, and adds similar provisions for nitrogen oxides. Following a series of legal challenges culminating in an October 2014 decision in the District of Columbia Circuit Court, the US EPA began implementing CSAPR in 2015 (US EPA 2016a).

The development of robust regulatory systems to address air pollution sources has provided the impetus for technology innovations that reduce emissions and control costs. Examples include (US EPA 2010):

- selective catalytic reduction and ultra-low nitrogen oxide burners for nitrogen oxide emissions;
- scrubbers which achieve 95 per cent and greater sulphur dioxide control on boilers;
- sophisticated new valve seals and leak detection equipment for refineries and chemical plans;
- low or zero volatile organic compound (VOC) paints, consumer products, and cleaning processes;
- chlorofluorocarbon- and hydrochlorofluorocarbon-free air conditioners, refrigerators, aerosol sprays and cleaning solvents;
- water- and powder-based coatings, as opposed to liquid paint, to replace petroleum-based formulations;
- vehicles far cleaner than believed possible in the late 1980s due to improvements in evaporative controls, catalyst design, and fuel-control systems for light-duty vehicles;
- treatment devices and retrofit technologies for heavy-duty engines;
- idling-reduction technologies for engines, including truck stop electrification efforts;
- market penetration of gasoline-electric hybrid vehicles and clean fuels;
- routine use of continuous monitoring technology that provides data more quickly; and
- multi-pollutant monitors that help to better understand the complex nature of air pollution.

Other toxic air pollutants

In addition to ozone and fine particles, both the United States and Canada have developed policies to decrease emissions of other air pollutants that pose acute or chronic health risks. Under the 1990 Clean Air Act Amendments, the US has established technology-based emissions standards for 174 major source categories and 68 categories of small-area sources, which represent 90 per cent of emissions of 30 priority pollutants in urban areas. The US EPA has conducted numerous residual risk assessments and technology reviews to assess whether more restrictive standards are warranted and has updated them as appropriate. Additional residual risk assessments and technology reviews are currently underway.

Under the 1999 Canadian Environmental Protection Act, Canada has implemented Canada-wide standards for emissions of dioxins and furans from waste incineration (municipal solid waste, hazardous waste, sewage sludge and medical waste), pulp and paper boilers, iron sintering, and electric arc furnace steel manufacturing. In addition, Canada and the United States have implemented legislation and regulations to eliminate or limit lead, sulphur, and benzene content in fuels and establish stringent emission standards for diesel and gasoline vehicles, thereby significantly reducing emissions of toxic air pollutants from mobile sources.

In 2006, Canada adopted Canada-wide standards for mercury emissions from coal-fired electric power generating stations. By 2010, the implementation of these standards resulted in an approximately 70 per cent decrease in emissions of mercury from coal-fired power plants compared to 2003 levels (CCME 2014). In 2012, the US took similar action under the Mercury and Air Toxics Standards (MATS) for power plants, which require controls that will reduce risks from toxic pollutants such as mercury, arsenic, chromium, nickel and acidic gases.

Continuing air pollution challenges

Despite significant progress, challenges remain and additional technological and policy innovation will be necessary to address continuing air quality challenges in North America, including:

Adapting to global changes in climate and emissions. Climate change is likely to exacerbate existing air pollution problems, increasing some sources of emissions such as wildfires, and increasing the frequency of high temperature stagnation events that cause summertime smog episodes. Efforts to decrease greenhouse gas emissions are likely to lead to some co-benefits, including emissions reductions of other air pollutants. However, not all climate mitigation strategies significantly decrease traditional air pollutants. Lastly, development beyond North America and the associated emissions are becoming increasingly important contributors to air pollution within North America.

Integrated management of multiple pollutants. Air pollution regulations are typically developed for one pollutant at a time, an approach that can be economically inefficient. Air quality managers have been exploring multi-pollutant approaches to air pollution and greenhouse gas mitigation planning, but this remains a challenge. Moreover, as reliance on end-of-the-pipe controls has economic and technological limits, policy makers must seek to prevent air pollution generating behaviour by integrating air quality implications in broader areas of policy, including land use, transportation, energy and economic development.

Addressing elevated exposures of sensitive, vulnerable or disadvantaged sub-populations. Despite progress at the national level, some people in North America are exposed to high levels of pollution. These exposures can occur near industrial facilities, in urban centers, near major roads or transportation facilities, or in remote communities, such as in the Arctic where communities rely on stationary diesel engines for electricity. Indoor sources of air pollutants often add to or even dominate the cumulative exposures. In many cases areas of high exposure are also areas of low economic and social status, so that problematic access to health care and poor baseline health conditions increase vulnerability. Identifying hotspots, the factors affecting variability of and sensitivity to exposures, and appropriate mitigation measures have become air quality management priorities (Fann *et al.* 2011).

Protecting ecosystems from cumulative impacts. With the exception of the bilateral 1991 US–Canada Air Quality Agreement on acid deposition and associated regulations, most air quality regulations in North America are designed primarily to protect human health. Although the US Clean Air Act allows for a secondary standard to protect welfare, including adverse effects on ecosystems, the US EPA has only promulgated two secondary national ambient air quality standards (NAAQS), for sulphur dioxide and fine particulate matter ($PM_{2.5}$) that are distinct from the primary health-based standards. Prevention of significant deterioration regulations in the US limit incremental pollution from new air pollution sources being built in areas that have already achieved the NAAQS. However, this programme does not address the cumulative effects of multiple new pollution sources on a given ecosystem. Canada faces similar ecosystem protection challenges and has included principles of continuous improvement and "keeping clean areas clean" in its Air Quality Management System (CCME 2012). Canada and Alberta have enhanced environmental monitoring in the oil sands region in an attempt to assess the cumulative environmental impacts of resource development in the region (Canada-Alberta 2012). An area of common concern for the two countries is the potential impact of development in the Arctic.

Managing smaller, more diffuse emissions sources. As major power plants, industrial facilities and motor vehicle emissions become controlled, the relative importance of smaller, more diffuse sources has become more important. Such sources include oil and gas extraction sites, stationary diesel generators, woodstoves, and consumer product solvents. These sources are harder to quantify, control, and monitor, which creates challenges for traditional permit and enforcement approaches.

Greenhouse gases

Although both Canada and the United States have a long history of investing in clean energy research and development at the national level, the development of specific policies to mitigate greenhouse gas emissions and climate change began primarily at the provincial and state level in North America. In 2003, a group of northeastern US states and eastern Canadian provinces launched the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade system to reduce carbon dioxide emissions from power plants. Currently, nine northeast states are members and several other states and provinces participate as observers (RRGI 2016). A similar effort, the Western Climate Initiative, was started in 2007 by western US states and Canadian provinces. Currently, seven US states and four Canadian provinces are partners; and an additional 6 US states, 2 Canadian provinces, and 6 Mexican states are observers (Western Climate Initiative 2014).

In 2007, Alberta implemented mandatory controls on greenhouse gas emissions through its Specified Gas Emitters Regulation, the first of its kind in North America. A comparison of climate policy instruments implemented in some Canadian provinces is presented in Table 3.2.1; most of these schemes are too recent to be judged for effectiveness. California has taken the most aggressive stance on climate change mitigation with a stream of legislation envisioned to decrease greenhouse gas emissions to 40 per cent below 1990 levels by 2030. In 2013, Ontario, which gets the majority of its electricity from hydropower, passed the Ending Coal for Cleaner Air Act, which prevents new and existing facilities from burning coal for the sole purpose of generating electricity.

In 2015, Ontario closed its last coal-fired power plant. The closure of all coal-fired electricity plants in Ontario has eliminated more than 30 megatonnes of annual GHG emissions, equivalent to taking seven million vehicles off the roads (OMECC 2015). Although local, state, and regional programmes have been useful laboratories for developing management approaches, such a patchwork of programmes cannot be as effective or efficient as a systemic and strategic national approach.

In the United States, a coalition of 12 states and several cities ignited change in the national climate change policy framework when they filed a suit against the federal government for failing to regulate greenhouse gases, specifically from motor vehicles (US EPA 2016). The Supreme Court's 2007 decision opened the door to regulation of greenhouse gases under the Clean Air Act. Starting in 2009, the US EPA issued a series of findings and regulations that have brought greenhouse gases under the various reporting and permitting provisions of the Clean Air Act and established new emissions standards for motor vehicles, oil refineries and power plants. In 2014, the US EPA declared its intention to regulate greenhouse gas emissions under the provisions of the Clean Air Act. This move enabled the government to issue binding greenhouse gas emission targets without additional Congressional legislation and permitted the use of a broad range of implementation and enforcement mechanisms linked to the Clean Air Act, including emissions trading.

In 2010, the EPA and National Highway Traffic Safety Administration (NHTSA) issued national light-duty greenhouse gas and fuel economy standards, which apply to cars and light trucks. Starting with the 2012 model year, manufacturers had to meet tailpipe methane and nitrous oxide emissions, along with increasingly strict fleet standards for carbon dioxide up to the 2016 model year (US EPA 2016b). These standards have been extended for model years 2017-2025. The EPA and NHTSA have also recently adopted the first-ever GHG regulations for medium- and heavy-duty engines and vehicles, which would significantly reduce carbon pollution, cutting GHG emissions by ~ 1 billion metric tons (US EPA 2015a).

In 2015, after an extensive outreach and public engagement effort, the US enacted a set of requirements to reduce greenhouse gas emissions from existing power plants. The Clean Power Plan sets reduction goals for each state based on their existing energy sources and provides a variety of

Table 3.2.1: Key features of GHG reduction policy instruments in some Canadian provinces

	Carbon tax (British Columbia)	Specified gas emitters regulation (SGER), hybrid model (Alberta)	Cap-and-trade (Quebec)	Offsetting (British Columbia)
Coverage (sectors and level of emissions)	All combustion sources of carbon are included (fossil fuels). Applied to the purchase or use of fuels within the province. Excludes non-combustion sources such as methane released from natural gas processing and transmission.	Facilities emitting more than 100 000 tonnes carbon dioxide equivalents annually are required to reduce greenhouse gas emissions intensity by 12 per cent per production unit.	Applies to facilities emitting more than 25 000 tonnes of carbon dioxide equivalent per year (for example, in industrial and electricity sectors). All fossil fuel distributors.	Applied to public institutions, including government agencies, schools and hospitals.
Cost containment provisions (for example, credits and/or offsets)	The BC low-income climate action tax credit helps to offset the impact of carbon taxes paid by low-income individuals or families. BC also offers corporate tax cuts to business to offset their costs from the tax.	Verified Alberta offsets. Payment into the Climate Change and Emissions Management Fund (currently CAD 15/tonne, increasing to CAD 20 in 2016 and CAD 30 in 2017). No limit on the use of these for compliance.	Free allocation of allowances to trade-exposed sectors. The number of these units will drop 12% per year. Offsets (up to 8% of compliance). Quebec maintains a strategic reserve of allowances to be used in cases of price peaks to reduce impact for industry.	None
Administrative overhead	Carbon tax is applied and collected similarly to motor fuel taxes (except for natural gas which is collected from fuel distributors). This minimizes administration and compliance cost.	The administration of the SGER system is comparatively high; similar to a trading system as the same actions are required, plus the administration of the Climate Change Emissions Management Corporation (CCEMC) is an additional administrative layer.	Comparatively high administrative burden, but collaboration among jurisdictions can provide an opportunity to share administrative functions, reducing the costs of programme operation and enhancing consistency across jurisdictions.	Fairly low, although it implies the development of an offset system.

Source: IISD and University of Ottawa (in press) mechanisms for states to achieve these goals, including the implementation of a cap-and-trade system. The Clean Power Plan is one of the key elements of the US Climate Action Plan (and also a key element of the US NDC under the Paris Agreement) along with standards for motor vehicles and a strategy to reduce methane emissions from the oil and gas industry and municipal solid waste landfills. The Clean Power Plan is currently the subject of litigation (Herzog 2016).

In 2012, the Government of Canada published the Reduction of CO_2 Emissions from the Coal-Fired Generation of Electricity Regulations, which came into effect on July 1, 2015. These regulations effectively ban the construction of new traditional coal-fired generation plants as well as provide an accelerated phase-out schedule for existing plants and establish high efficiency gas as the standard for new plants. Federal, provincial and territorial governments have also developed measures to enhance efficiency and to reduce GHGs in the transportation sector. Federal GHG emission standards for on-road vehicles, engines and marine vessels are key to these efforts. Other measures include voluntary agreements to reduce emissions from aircraft and locomotives; measures related to biofuels; transit planning frameworks; and, policies to encourage electrification of vehicles.

The Government of Canada has also put in place the federal Renewable Fuels Regulations for diesel fuel, while several provinces and territories have also established incentive programmes and regulations targeting renewable fuels, including British Columbia, Alberta, Saskatchewan, Manitoba and Ontario. However, the 2014 Fall Report of the Commissioner of the Environment and Sustainable Development emphasized unsatisfactory progress of the federal government in their efforts to reduce emissions of greenhouse gases and the lack of a coordinated approach with the provinces and territories to achieve national emissions reduction targets (Office of the Auditor General of Canada 2014). In the Vancouver Declaration on Clean Growth and Climate Change (March 3, 2016), the First Ministers of the national, provincial, and territorial governments of Canada committed to the development of a pan-Canadian framework on clean growth and climate change and to implement the framework by early 2017.

Internationally, Canada and the US have been leaders in efforts to decrease emissions of short-lived climate pollutants, which include methane, ground-level (or tropospheric) ozone, black carbon, and hydrofluorocarbons. They are founding partners of the Climate and Clean Air Coalition to Reduce Emissions of Short-Lived Climate Pollutants (CCAC) and the Global Methane Initiative. Both countries have prioritized short-lived climate pollutant mitigation during their respective chairmanships of the Arctic Council and have worked for passage of an amendment to the Montreal Protocol to control hydrofluorocarbon emissions. Canada and the US also participate actively under the United Nations Economic Commission for Europe's (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) to address the long-range transportation of key air pollutants.

3.2.2 Land

A rich network of well-managed protected areas is in place that is helping to conserve biological diversity. Large-scale disruptive land use and land cover changes are largely kept in check by effective governance policies and regulations. However, natural landscapes are becoming more fragmented in some areas in response to both natural causes, such as wildfires and pest outbreaks, and decisions made about land management and development activities, particularly at the intersection of the forest, agriculture, and energy sectors.

Changes in Canada's land policies

There has been a long tradition of cooperation between the federal and provincial/territorial governments in forestry matters. The Canadian Council of Forest Ministers (CCFS) was established in 1985 to provide an important forum for fourteen federal, provincial, and territorial ministers to exchange information, work cooperatively, provide leadership and generate actions on forestry related matters of interests to all Canadians above and beyond the work

Box 3.2.1: Climate and Clean Air Coalition

The potential power of voluntary public-private partnerships is exemplified by the success of the Climate and Clean Air Coalition (CCAC) to Reduce Short Lived Climate Pollutants (SLCP). The CCAC's focus is on facilitating mitigation of emissions of methane, black carbon, and hydrofluorocarbons to complement and supplement, but not replace, global action to reduce carbon dioxide, in particular efforts under the United Nations Framework Convention on Climate Change (UNFCCC). Launched in 2012 by the United States, Canada, Mexico, Bangladesh, Ghana, Sweden and the United Nations Environment Programme (UNEP), the initiative has quickly grown to include 50 countries, 16 intergovernmental organizations, and 43 non-governmental organizations.

The CCAC is focusing on practical action in 11 key areas, chosen to ensure rapid delivery of climate and clean air benefits. The initiatives seek to promote near-term reductions of SLCPs at a substantial scale worldwide, and to engage high-level stakeholders. Seven initiatives focus on single sector activities: agriculture, bricks, cookstoves, diesel, hydrofluorocarbons, oil and gas, and waste. The remaining four initiatives cut across a variety of sectors: finance, health, regional assessments, and supporting national action plans.

The Coalition's objectives are to address short-lived climate pollutants by:

- Raising awareness of short-lived climate pollutant impacts and mitigation strategies
- Enhancing and developing new national and regional actions, including by identifying and overcoming barriers, enhancing capacity, and mobilizing support
- Promoting best practices and showcasing successful efforts
- Improving scientific understanding of short-lived climate pollutant impacts and mitigation strategies

done by individual governments. The secretariat for the Council is provided by Natural Resources Canada's Canadian Forest Service.

In its *A Vision for Canada's Forests: 2008 and Beyond* (CCFM 2008), the CCFM identified two issues that required immediate attention within the broad context of practicing sustainable forest management: the managing climate change impacts and forest sector transformation.

Climate change

CCFM formed the Canadian Climate Change Task Force (CCTF) to develop approaches to the climate issue. In phase 1, the CCTF assessed the vulnerability of Canadian tree species to climate change, laid out options for adaptation, and established a framework for forest management offset protocols. In 2010, two reports were published: Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation; and A Framework for Forest Management Offset Protocols. During phase 2, completed in March 2015, the CCTF addressed adaptation at the forest ecosystem and forest sector levels. The primary goal of this phase was to provide members of the forest sector with state-of-the-art tools and new knowledge that will allow them to assess the vulnerabilities, risks, and opportunities associated with climate change. In phase 3, initiated in 2015, the CCTF will focus on furthering inter-jurisdictional conversations on integrating climate change into national sustainable forest management criteria and indicators (C&I), enhancing integration of climate change considerations into CCFM Fire and Pest working group outputs, and continuing forestry adaptation networking through support of the Forestry Adaptation Community of Practice (FACoP) site. The CCTF's work is intended to catalyze and accelerate the transformation of sustainable forest management policies, planning, and practices in accordance with the needs of various forest management organizations across Canada.

There is increasing interest in carbon offsets as a way for changes to forest-related activities to contribute to climate change mitigation. A number of provinces are supporting the development of forest carbon offsets projects. In 2011, the Government of British Columbia developed a Forest Carbon Offset Protocol (FCOP) to guide the design, development, quantification and verification of carbon offsets from afforestation, improved forest management and avoided deforestation which is currently being updated. Also in 2011, the Government of Alberta made available an approved offset protocol that addresses the reduction in emissions that result from changes in forest harvesting practices. More recently, as part of their cap and trade systems and their involvement in the Western Climate Initiative, the Provinces of Ontario and Quebec have announced plans to work together on a carbon offset system that will be linked with that of California and would include forest-related offset projects.

The Federal, provincial, and territorial governments have been cooperating on the establishment of the Canadian Wildland Fire Strategy (CWFS). The CWFS will seek to balance the social, ecological, and economic aspects of wildland fire to deal with both the root causes and the symptoms of current and potential fire management issues.

Forest Innovation Programme

The Forest Innovation Programme (FIP) was established to support research, development and technology transfer activities in Canada's forest sector. Together, these activities are intended to help the sector pursue its ongoing transformation through the adoption of emerging technologies.

The FIP directly supports the Transformative Technologies Programme and the work of the Canadian Wood Fibre Centre (CWFC). The Transformative Technologies Programme supports pre-commercial research and development and technology transfer for innovative technologies and processes in the forest sector. This research, which is delivered by FPInnovations, Canada's not-for-profit forest research institute, is focused on four key areas: (1) next-generation building systems, (2) bio-product development, (3) integrated value maximization, and (4) innovation deployment.

The CWFC works with FPInnovations to increase the economic return of Canada's forest resources by ensuring a coordinated, transformation-oriented approach to research and innovation along the entire forest value chain (e.g., from seedlings to value-added consumer products). The CWFC's forest and wood fibre research is aimed at two core areas:

- ***Resource characterization***: research activities focused on developing forest inventory and evaluation tools and techniques that enable the main fibre attributes of Canada's forests to be more accurately quantified, assessed and understood
- ***Resource production***: research activities focused on developing and using genetics, genomics, biotech and silvicultural approaches to add value to future forests

Forest in Mind Programme

The Forest in Mind Programme is a collaborative market intelligence and advocacy programme of the CCFM supported by Canadian missions abroad to position Canada as a world leader in sustainable forest management and environmental stewardship to protect and enhance market access for Canadian forest products.

Repeal of the 1992 Canadian Environmental Assessment Act

In 2012 the Government of Canada repealed the Canadian Environmental Assessment Act (CEAA), established in 1992 to evaluate and mitigate negative environmental effects caused by industrial projects. The Act had served as a model for environmental assessment standards and legislation around the world. Following its repeal a new law subjected a much smaller range of projects to assessment, expanded ministerial discretion and narrowed the scope of assessments (Doelle 2012). Approximately 95 per cent of projects that would have required assessment under the old CEAA are now exempt, and 3000 on-going assessments were cancelled immediately after the change (Kirchhoff and Tsuji 2014).

Among the types of projects no longer assessed are those related to groundwater extraction; heavy oil and oil sands processing; industrial mining for salt, graphite, gypsum, magnesite, limestone, clay and asbestos; milling of pulp, paper, steel, and textiles; metal smelting; leather tanning; and the manufacturing of chemicals, pharmaceuticals, pressure-treated wood, chemical explosives and lead-acid batteries. While open-pit extraction of bitumen is subject to assessment, in situ extraction that injects steam below ground is not (Gibson 2012). In addition to private sector activities, nearly all the federal government's own projects are now exempt from assessment, and no mechanism remains for considering the cumulative effects of multiple projects (Gibson 2012). The new Trudeau administration has pledged to review these changes in environmental legislation and restore "lost protections" and credibility to environmental assessments and ensure that decisions are based on science, facts, and evidence and serve the public's interest. As part of the review, the plan will be to modernize and rebuild trust in the National Energy Board, which will consist of broad regional representation and sufficient expertise in fields such as environmental science, indigenous traditional knowledge and community development (Liberal 2015).

Changes in US land policies

Agricultural Act of 2014

The Agricultural Act of 2014, commonly known as the "Farm Bill," was signed into law on February 7, 2014. It resulted in major changes in farm commodity programmes, added new crop insurance options, streamlined conservation programmes, modified some aspects of supplemental nutrition programmes, and expanded programmes for specialty crops, organic farmers, bioenergy feedstock producers, rural development, and assistance to beginning farmers and ranchers (Claassen 2015).

Conservation programmes are focused on working farms, ranches, and forests. There is a cap on the number of acres covered by the Conservation Reserve Programme, which will gradually decrease over five years from 12.9 to 9.7 million hectares. The area enrolled has been dropping for the past five years, so the impact of the cap reduction is likely to be modest. The real shift within the programme has been from enrolling entire fields to enrolling only parts of fields, such as stream-side buffers, field-edge filter strips, grassed waterways, and wetlands. These are areas where conservation benefits are high, and costs on a per-acre basis are also higher than for entire fields. However, by only enrolling the critical and sensitive parts of fields, crop production is sustained. The new bill encourages the shifts underway. The bill also re-linked crop insurance premium subsidies to conservation compliance—protecting highly erodible land and wetlands—for the first time since 1996. The conservation aspects in the bill also include (Claassen 2015):

- Funding was provided for long-term easements for restoration and protection of on-farm wetlands and to protect eligible agricultural land from conversion to nonagricultural uses.
- The Environmental Quality Incentives Programme (EQIP) will continue to assist producers to install and maintain conservation practices on eligible agricultural and forest land. The bill also transfers functions and funding formerly in a separate wildlife habitat

incentives programme into EQIP, and requires that at least 5 per cent of EQIP funding be targeted on practices benefitting wildlife habitat.

- The bill continues to fund the Conservation Stewardship Programme, to help producers who meet stewardship requirements on agricultural and forestlands. Annual enrolment is capped at 4 million hectares, down from 5.2 million hectares for the previous five years.
- The bill created two major research initiatives affecting farms and forests:
  1. The Forestry Products Advanced Utilization Research Initiative, authorized at USD 7 million per year, for improving wood quality, creating new products and renewable energy, for improving the management of timberlands (forests where wood harvesting occurs), and creating "green products" from forest products, such as multi-story buildings using new laminated wood structural members.
  2. The Foundation for Food and Agriculture Research, authorized at USD 200 million the first year, was created. The Foundation will coordinate projects across public and private institutions, and seek additional matching funds from individuals, corporations, charitable foundations, and other sources. The public will benefit from long-term studies, multi-disciplinary teams, and specialized research facilities.

Improved forest certification standards

The American Forest Foundation released improved "Standards of Sustainability for Forest Certification" on 6 January 2015. The improvements were the result of a rigorous, multi-stakeholder process and based on international guidelines for sustainable forest management and conservation. Major revisions included expanding best management practices to encompass water, air, and soil and clarifying the management needed to protect threatened and endangered species and forests of recognized importance (ATFS 2016).

The American Forest Foundation operates the American Tree Farm System (ATFS), a programme to keep family-owned forests well-managed, and provide clean water and air, wildlife habitat, wood products, and recreational opportunities. AFTS is the largest certified programme for family-owned forests in the world (ATFS 2016).

New planning rule for national forests

The US Forest Service adopted a new planning rule (regulation) for national forests on April 9, 2012. The new regulation shifted the focus of planning to ecological sustainability and placed strong emphasis on using science to understand the links between management activities and outcomes for forest health and productivity. The new rule, replacing a 30-year old regulation, was designed to enable flexible, rapid, and effective responses to a range of increasing challenges (USDA 2012). The new rule provides a planning framework that provides a more efficient and adaptive process for land management planning, allowing national forest managers to respond to changing conditions more easily. It has provisions to maintain and restore ecosystem services, to provide for multiple uses, and to provide for public involvement in planning.

The new rule was not greeted with uniform praise. Although some major non-governmental organizations welcomed the new rule, a number of interest groups brought lawsuits seeking to suspend implementation or completely overturn the new rule. But so far, the new 2012 rule has withstood legal challenges.

Approaches to counteract land fragmentation

Governance responsibilities regarding land use in the US and Canada are primarily a responsibility of local governments (counties, cities, towns), provincial, territorial, or state legislatures or agencies, or tribal or First Nations governments. The federal governments play smaller and more indirect roles. In the US, federal roles include, adjusting federal tax policies to encourage better management, setting water or air quality standards, and providing funding for technical assistance and financial incentives.

Box 3.2.2: Montréal process working group

In today's world of fast-paced changing land use, a common, shared framework using internationally agreed-upon criteria and indicators helps scientists, managers, and policy makers evaluate relevant information when making local, regional, national, and global-scale decisions about sustainable forest management. The Montréal Process Working Group (MPWG) was formed in 1995 to test the hypothesis that a voluntary, non-legally binding process could make more and faster progress towards sustainable forest management than a legally-binding convention.

In 2015, this initiative celebrated 20 years of continuous membership from all 12 member countries who together have 49 per cent of the world's forests and 31 per cent of global population. Over its first two decades, collaboration among Montréal Process member countries and engagement with other forest-related processes has led to major improvements in national forest inventories and three cycles of national reports containing data that are credible and robust, more useful for multiple reporting requirements, more accessible to a larger audience, and more robust for improving management practices and addressing emerging policy issues. Results and recommendations in the national reports have led to management and policy decisions that have demonstrably improved sustainable forest management, with results documented in subsequent forest inventory and national reporting cycles.

Today, the Montréal Process framework of criteria and indicators:

- Is embedded into national reporting processes
- Informs the development of national policies and programmes
- Is referenced in national legislation and forest law in many member countries
- Is aligned with national forest inventory programmes
- Informs the development of national forestry standards

See Montréal Process for more information

The reliance in North America on local and state or provincial governments to enact, regulate, and engage with local landowners creates a different policy context than found in many other countries. The leading role of sub-national and local governments means that parties interested in making policy changes to manage development must make their case to local and state or provincial governments—legislatures and agencies—one at a time. Thus, making policy changes happen over broad landscapes is slow and difficult. The result can be substantial differences in policies to manage land use and deal with fragmentation in different parts of Canada or the US, and even amongst different local governments. It can also mean that counter-pressures pop up locally too. As suburban development expands into areas formerly intact forests, farms, or ranches, newly arriving occupants unfamiliar with normal management activities may object to the smells and sounds of farming or forestry operations or mud on roadways from tractors or trucks. The newcomers may try to influence local governments to regulate more tightly these operations, leading to political squabbles between long-time residents and the newcomers that threaten the economic and social fabric of local communities.

The shifting political situation in the US is also creating uncertainties about the effectiveness of government programmes to keep working forests and farms intact and sustaining the protection of ecological values. Some interest groups advocate private property owner rights and limits on government programmes that provide incentives for active management. Efforts to launch broad-based public dialogue about these issues are emerging from groups operating at various spatial scales. Examples include the Forest Trends Association internationally; Solutions from the Land alliance nationally and regionally; and the Malpai Borderlands Group regionally.

Climate change mitigation and sustainable land management

There are two aspects to this issue. The first is how crops produced on croplands and in forests can be used to help mitigate carbon emissions. The second is how altering crop production practices can help reduce emissions from production activities and make crop production more resilient in the face of changing climates.

Mitigation through different crop production methods and forest management practices

Adapting crop production methods and forest management practices are leading to major changes in land and water use, different crops, and better management of production inputs. There are significant opportunities for adaptation measures to limit climate change impacts in agriculture and forestry Malcolm *et al*. (2012). These include tools to guide seed selection, planting decisions, and management practices; identification of plant varieties and management practices well-suited to changing pest risks; and development and adoption of new technology.

Management practices on public and private forests may also need to change. Hotter and dryer weather patterns are expected to lengthen the wildfire season in many areas and lead to larger and hotter wildfires. The US Departments of Agriculture and the Interior are also implementing the National Fire Plan, the President's Healthy Forests Initiative, the Healthy Forest Restoration Act and the Tribal Forest Protection Act of 2004 to address the risk of catastrophic wildfire and improve forest and rangeland health on federal lands by thinning biomass density. In addition, regeneration foresters are beginning to plant commercial tree species, such as genetically-improved loblolly pine (*Pinus taeda L.*), north of the species' historic range, in anticipation of changes in temperature patterns. Several tree seed and seedling suppliers are breeding 'super seedlings' with genes to take advantage of warmer climates and planning to introduce new species, such as Eucalyptus cultivars that are commonly grown in warmer countries, to the southern US because of their potential to increase fibre yields in altered future climates.

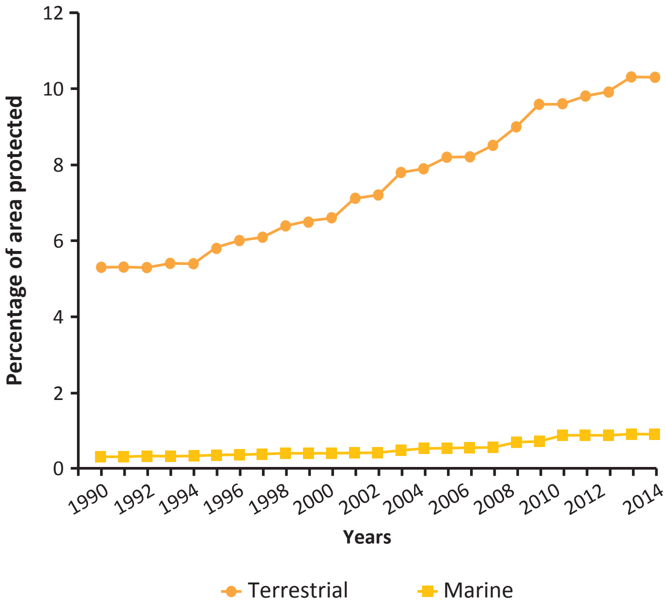
3.2.3 Biota

The accelerating decline of biodiversity is a serious global environmental threat (Leadley *et al*. 2014). In North America, positive and progressive plans and approaches are underway that are geared towards biodiversity conservation and sustainable use of living resources.

Canadian policies have shifted over the last ten years towards deregulation, making it easier for developers to implement various projects that might have a compromising impact on wildlife and ecosystems. Some degree of reversal is anticipated with the election of the new government in Ottawa in the fall of 2015. In the US, political opponents of the Endangered Species Act have largely failed to weaken its impact, though several legislative proposals or bills that remain pending (Clark 2015; Schlickeisen *et al*. 2011). Ideological divides over the proper approach to biodiversity conservation are palpable in both countries, and reflect broader perspectives on the roles of government, the private sector, civil society, and human-nature relations.

Recovery plans for species at risk in Canada have made considerable strides in recent years. By early 2015 there were 521 animal and plant species classified as endangered, threatened, or of special concern under the Species at Risk

Figure 3.2.1: Trends in proportion of area protected, Canada, 1990-2014



The upper line of the chart shows the percentage of terrestrial area that has been recognized as protected in Canada between 1990 and 2014. The lower line of the graph shows the percentage of marine area protected between 1990 and 2014

Source: EC 2015

Act; 307 had recovery strategies or management plans in place (Canada 2016). There has also been a noticeable rise in protected areas across North America in recent decades. In 2014–2015, as part of its National Conservation Plan, the federal government renewed the Natural Areas Conservation Programme for another five years, investing an additional USD 100 million. However, marine protected areas remain very far below the national target of 10 per cent, and not all terrestrial biomes are protected at the international target of 12 per cent (EPI 2016).

Canada has established a set of biodiversity goals and targets for 2020 that focus on Canada's biodiversity priorities for the coming years. These goals and targets complement the Canadian Biodiversity Strategy and the Biodiversity Outcomes Framework. The objective is to guide further action on the conservation and sustainable use of living resources in Canada and provide a base for measuring and reporting the progress. Canada's goals and targets are in line with the global Strategic Plan for Biodiversity 2011-2020 adopted by Canada and other Parties to the Convention on Biological Diversity in 2010. The Canadian Biodiversity Strategy reiterates that governments in Canada must create the policy and research conditions for leading the conservation of biodiversity (Biodivcanada 2016).

In the US, Biodiversity Information Serving Our Nation (BISON), a unique, web-based Federal system developed by USGS is supporting policy-making activities by making it easier to find the location of US species. This tool offers more than 100 million mapped records of nearly every living species across the nation and promotes data-driven science for decision-making that supports a rapid response to emerging natural resource issues. BISON acts as the US node of the Global Biodiversity Information Facility (GBIF) and forms an important part of EcoINFORMA, the information delivery strategy in *"Sustaining Environmental Capital: Protecting Society and the Economy."* Hundreds of thousands of citizens and professional scientists have contributed to the data collection in BISON. In fact, NGOs, universities, and state and local governments have also participated in this undertaking (USGS 2016).

Canada and the United States cooperate on the management of invasive alien species and migratory species (Temby and Stoett 2015). Canada, the US, and Mexico are cooperating on the North American Waterfowl Management Plan, aimed at wetland conservation. On both sides of the border, governmental collaboration with NGOs such as the Nature Conservancy and Ducks Unlimited has enhanced wetland conservation efforts. Beyond their decades-old collaboration on sea lamprey eradication, the two countries are co-ordinating ballast water policy, regulations, research and enforcement actions through annual meetings of the authorities responsible for vessel discharges under the Great Lakes Water Quality Agreement. The US-Canada Regulatory

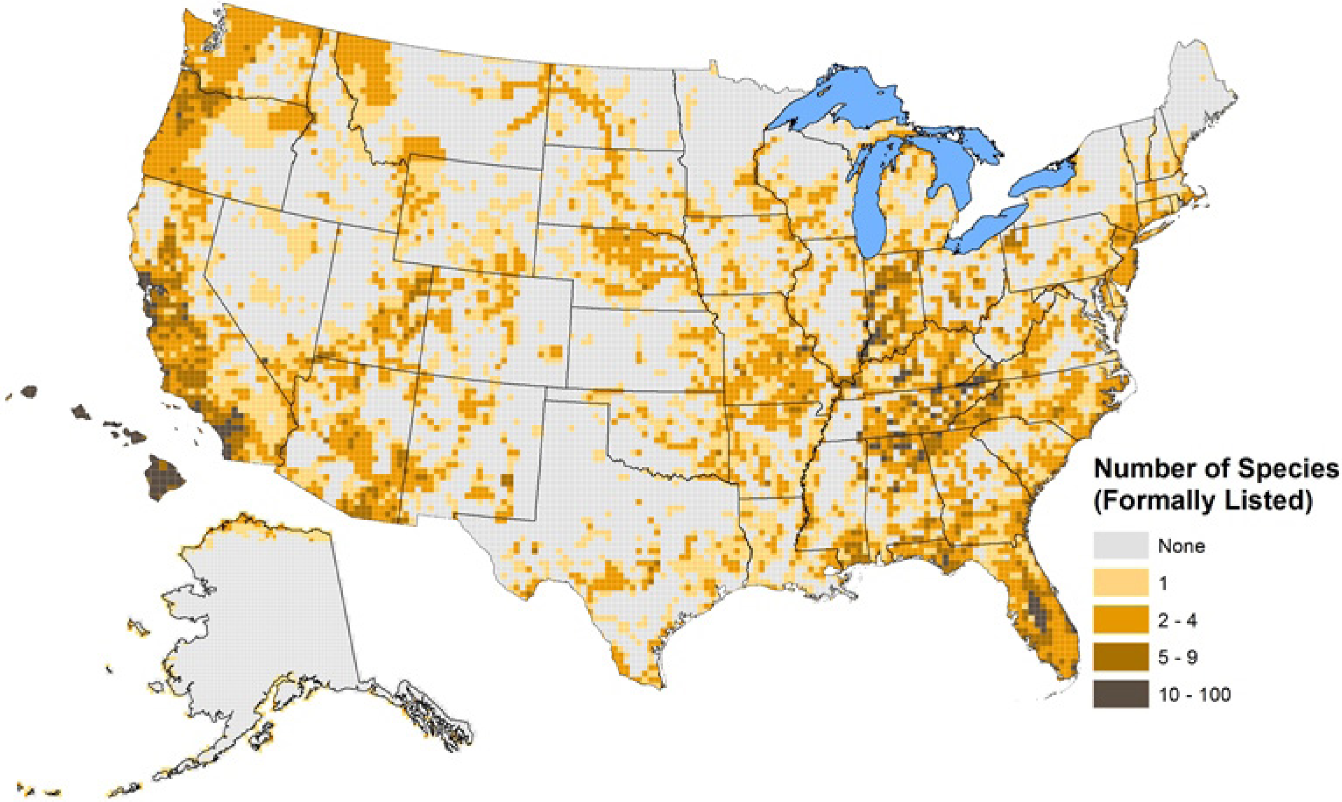
Cooperation Council is taking joint action on efforts to co-ordinate policy in areas such as invasive species management and the regulation of the aquaculture industry.

Monarch butterfly conservation: adaptive governance and big data in action

An example of a circumstance where cooperation among national governments is key to species wellbeing is the monarch butterfly (*Danaus plexippus*), which is threatened by destruction of milkweed, the key plant that monarch caterpillars eat. Since some monarch populations undergo a remarkable migratory journey that spans Canada, Mexico and the US, effective conservation requires complex cooperation (see **Figures 3.2.3** and **3.2.4**).

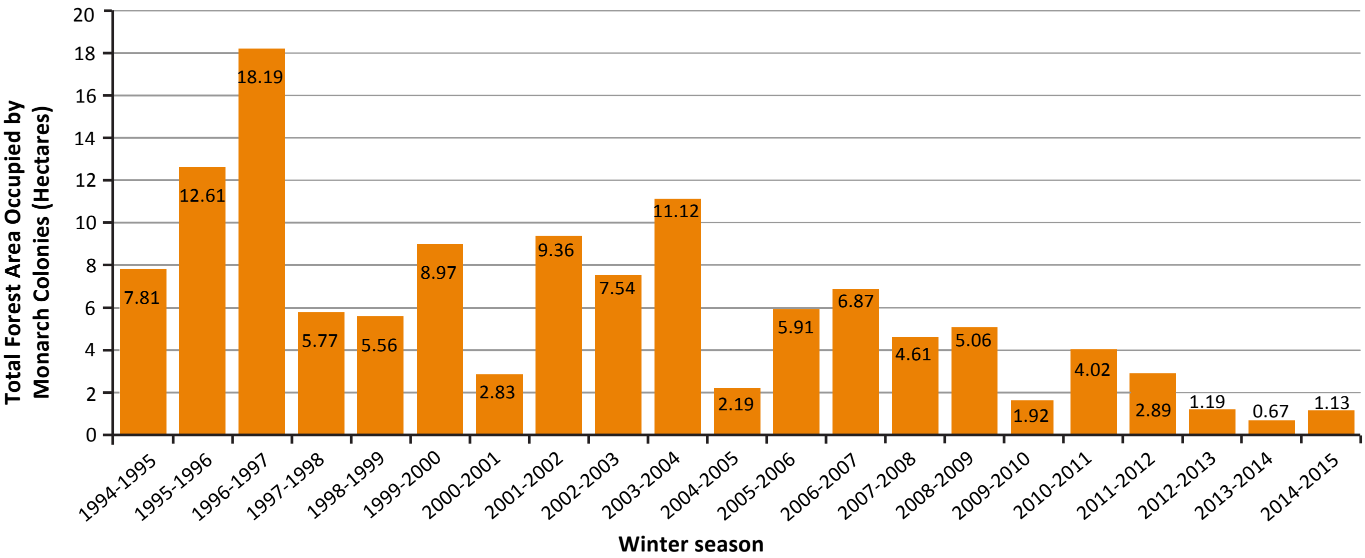
The Trinational High Level Working Group for the Conservation of the Monarch Butterfly Migratory Phenomenon was established in 2014, following a conservation plan developed through the trilateral CEC in

Figure 3.2.2: Distribution of species formally listed as threatened or endangered under the ESA, 2014



Notes: US Alaska and Hawaii are displayed on a different scale for presentation purposes. Data from 1994-2003 were collected by personnel of the Monarch Butterfly Biosphere Reserve (MBBR) of the National Commission of Protected Natural Areas (CONANP) in Mexico. Data collected from 2004-2016 were collected by the WWF-Telcel Alliance, in coordination with the Directorate of the MBBR.
Source: Evans *et al.* 2016 .

Figure 3.2.3: Total area occupied by monarch butterfly colonies at over-wintering sites in Mexico, 1994/1995–2014/2015

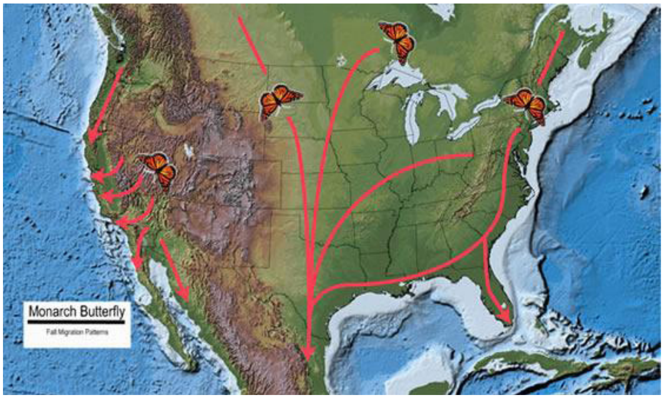


Source: Monarch Joint Venture (2015)

2008. The Working Group promotes communication across several layers of governance (federal, state, provincial, and municipal) as well as industries, non-governmental organizations, indigenous communities, and civil society. The migratory route of the Monarch includes crop fields, forest patches and wintering habitat. It is also noteworthy that indigenous communities "*will play a crucial role…as the traditional ecological knowledge related to the monarch flyway will be gathered and synthesized*" (CEC 2015).

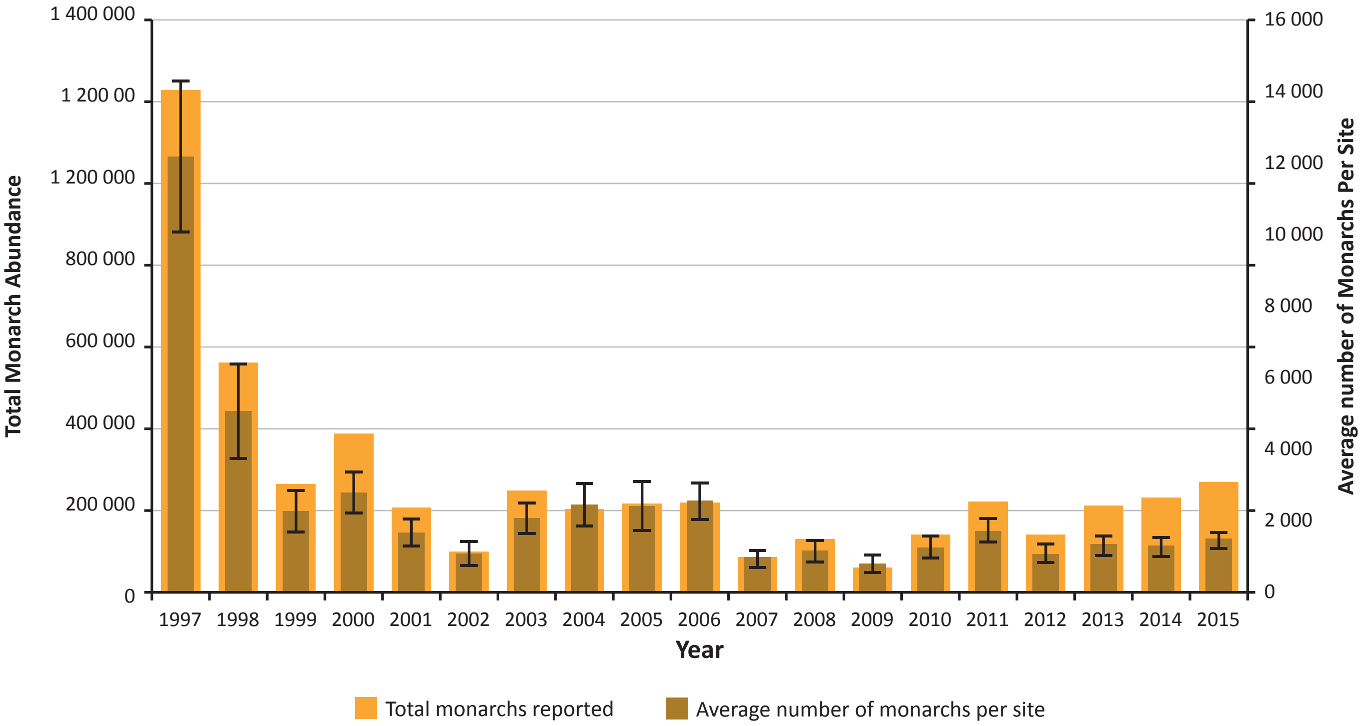
The CEC conservation plan will help to coordinate efforts between the US, Canada, and Mexico. In the US, the Obama Administration's Pollinator Health Task Force has initiated a National Strategy to Promote the Health of Honey Bees and Other Pollinators. Included in this strategy is a commitment to work with the US Department of Transportation, the Federal Highway Administration, and the US Fish and Wildlife Service to rehabilitate a 2 400 kilometre butterfly corridor alongside Interstate 35, which runs from the Texas-Mexico border to Duluth, Minnesota. Collaboration with hundreds of local communities and organizations, including schools and NGOs, as well as individual farmers and groundskeepers, will be essential to its success. This national

Figure 3.2.4: Monarch butterfly fall migration patterns



Source: USDA 2016; Base map source: USGS National Atlas

Figure 3.2.5: Total and average monarch abundance estimates with standard error of the means at 76-187 over-wintering sites, 1997-2015



Source: Xerces Society (2016)

strategy was developed by ten federal departments. It is premature, however, to gauge its success.

Indeed, a Pollinator Research Action Plan is an integral component of the national strategy, and it will provide funding for related advances in population trends and basic biology, environmental stressors, land management, habitat restoration and knowledge through data sharing, interoperability and informatics, from the genome to population level.

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) deemed the monarch butterfly to be of importance as early as 1997. Even prior to this, Canada had reached an agreement with Mexico to establish a network of monarch reserves, which evolved into a Trilateral Monarch Butterfly Sister Protected Areas Network in 2006 that includes the Long Point National Wildlife Area and the Point Pelee National Park in Ontario. A proposed management plan was circulated in 2014, and addressed both the eastern and the smaller western populations. It called for increased cooperation among international partners, monitoring of monarch populations through research and citizen science, conducting awareness activities and the conservation of existing staging and breeding areas (Environment Canada 2014a).

3.2.4 Water

In 2012, Canada and the US amended the Great Lakes Water Quality Agreement (GLWQA), first signed in 1972, to build on previous commitments and to expand the agreement to new issues of mutual interest. The overall purpose of the GLWQA 2012 is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes. The GLWQA 2012 includes 10 annexes on issues that affect water quality: areas of concern, lakewide management, chemicals of mutual concern, nutrients, discharges from vessels, aquatic invasive species, habitats and species, groundwater, climate change impacts, and science (GLWQA 2012).

Broad changes to Canadian water policy since 2010

In Canada, federal, provincial, and municipal governments share water governance. The federal government is responsible for navigation, transboundary waters, and fisheries and fish habitat protection. The provinces have jurisdiction over most aspects of water quantity and quality, including the allocation of surface water and groundwater.

Canada's first national standards on wastewater systems effluent, the culmination of collaboration between the federal and provincial/territorial governments, were put into place in 2012 (Canada 2012). At this time, numerous changes were made to federal legislation—the Fisheries Act, the Navigable Waters Protection Act (now the Navigation Protection Act) and the Canadian Environmental Assessment Act (CEAA; now the CEAA 2012)—that have implications for water, arguably weakening certain aspects of the protection of freshwaters related to, for example, fish habitat, navigation, and the scope of federal environmental assessments (Gibson 2012; Olszynski 2015). However, following the 2015 election, the new federal government announced its intention to conduct a review of these legislative changes and restore lost protections, as well as to engage in a collaborative, inter-governmental approach on freshwater protection (Canada 2015). Although no specific changes to federal water policy or legislation can yet be attributed to these statements, they signal a renewed commitment to freshwater protection at the federal level.

At the provincial level, one key new piece of water legislation is the province of British Columbia's Water Sustainability Act (British Columbia 2014) that provides for the ability to manage surface water and groundwater together, establishes water management rules during times of scarcity, and provides greater certainty with respect to water rights, although many of the details and implementation have yet to be finalized (British Columbia 2015a, b).

Broad changes to US water policy since 2010

Differences in US regional water policy stem from a relative abundance of water east of the 100th Meridian, and variable, but generally drier, conditions in the West. Challenges posed by water scarcity and, more recently, drought in the Southwest US, have caused federal and state agencies to initiate new regulatory efforts to mitigate the immediate effects on urban and agricultural communities. In addition, integrated water resources management (IWRM) and climate change adaptation planning have gained momentum since 2010, although implementation of the resulting plans continues to lag. Important large-scale IWRM planning efforts include the Colorado River Basin Plan and the Yakima Basin Water Plan (USBR 2012a, b).

While the general population in the US has good water security, the contamination of municipal water supplies (such as in Flint, Michigan) and the lack of water (such as in some California communities) have highlighted the potential fragility of the situation.

The Clean Water Act and Safe Drinking Water Act continue to be implemented and enforced across the US to protect and restore the biological, chemical, and physical integrity of the nation's waters. There have not been any major changes in these underlying regulatory tools since 2010. The US EPA has identified nutrient pollution as the biggest water quality priority for the nation and progress continues to be made at the state level to reduce these nutrient loads (US EPA 2015f).

In 2015, the US EPA finalized the Clean Water Rule, which identifies waters of the US that are protected under the Clean Water Act. Previously, individual determinations

Table 3.2.2: History of Great Lakes Water Quality Agreement, 1972 – 2012

1972	1978	1983	1987	2012
Limit phosphorus inputs to control algal growth.	Introduction of ecosystem approach to management. Call for virtual elimination of toxic pollution.	Further limit phosphorus discharges.	Lakewide Management Plans developed and implemented for each lake to reduce toxic pollutants. Remedial Action Plans to clean up Areas of Concern.	Continue to support work on existing threats to water quality. Prevent environmental threats before they cause harm. Establishment of annexes on specific environmental issues that affect water quality.

Source: Binational.net 2016

of jurisdiction were required for more than 60 per cent of the nation's streams and millions of acres of wetlands. The largest effect of the Clean Water Rule is the implementation of Section 404 of the Clean Water Act, which established a programme to regulate the discharge of dredged or fill material into waters of the US, including wetlands. The release of the rule has resulted in a sharply divided water community. Environmental advocates and some local and state governments have found the rule to provide clarity and consistency in implementation of Clean Water Act programmes, but the agricultural community has raised concerns about the potential for additional regulation to the agricultural sector. Multiple states have filed lawsuits against the EPA that claim that the rule illegally expands federal jurisdiction.

Lastly, in an attempt to provide transparency on water availability and quality, and raise public awareness at a time when many areas are affected by water shortage, the Water Survey of Canada and the US Geological Survey collaboratively launched the North America WaterWatch in 2014, a website that maps real-time riverflow conditions for both countries (NAWW 2014; USGS 2014).

Climate change adaptation and water management

Since 2010, there has been a growing interest in understanding community vulnerabilities to climate change as well as development of adaptation plans that protect communities from the impacts of climate change. By 2012, 13 federal agencies in the US and 13 states had completed climate change adaptation plans, most of which included plans to mitigate the impacts of climate change on water resources (Bierbaum *et al*. 2013). Increasingly, local municipalities are also planning for the effects of climate change on the supply and quality of future water resources. Although such efforts to analyse risks indicate positive momentum in policy changes, very few of the adaptation plans are being implemented in the US (Bierbaum *et al*. 2013). Adaptation planning in the US has accelerated since President Obama signed Executive Order 13653 directing federal agencies to assist communities to strengthen their resilience to climate change. The Executive Order also established a task force on Climate Preparedness and Resilience made up of state, local, and tribal leaders.

In 2015, the task force delivered a progress report with recommendations to improve resilience of communities, infrastructure, and natural resources (White House 2015). Recommendations include measures to support and incentivize climate-resilient water resources planning and management including: federal investment in water and related land resources; support for innovative financing; integrating climate change considerations into the Clean Water Act and Safe Drinking Water Act programmes; and development of a toolkit for climate resilience (White House 2015). Adaptation of water systems to climate change varies across the region. In the Southwest, the need for water conservation and efficiency, in the urban and agricultural sectors, will become more important as water resources dwindle. In some cases, agricultural production may need to shift to less water intensive crops and/or fewer hectares may be put into production. In the Intermountain West, the shift from snow driven water supplies to rain driven water supplies could result in the need for innovative solutions to sustain communities through the dry late-summer period. In other parts of the country, extreme events including increased flooding and wild fires require changes in planning for development and flood control. Coastal areas are planning for rising sea levels and salt-water intrusion in coastal aquifers.

While seasonal reductions in water quality and quantity are expected in all parts of Canada, the specific causes and policy responses will be different. For example, a Canadian climate change adaptation report notes that changes to water treatment infrastructure or processes may be required to address taste and odour problems that can result from increased turbidity or contamination due to flooding, enhanced precipitation events, legacy impacts from wildfires, or from increased water temperatures (Andrey *et al*. 2014). In northern parts of Canada, increased freeze-thaw cycles could result in ice blockages in water intakes and also in reducing the efficacy of water treatment as a result of cooler temperatures of water needing to be treated (Andrey *et al*. 2014).

Box 3.2.3: Integrated water resources management: adaptive governance in conservation

Although there are significant US legal and jurisdictional barriers to IWRM implementation, there are several successful examples in North American basins. In 2012, the US Bureau of Reclamation completed a Colorado River Basin study that predicts a gap of 3.2 million acre-feet (~3.9 billion m^3) between water supply and demand for the 2041–2060 period. The report identifies key complexities, uncertainties, and vulnerabilities that will need to be considered in addressing projected water shortages (USBR 2012a). Efforts are ongoing to develop decision support tools for IWRM in the Colorado River Basin (Alexander *et al*. 2013).

The Yakima Basin Water Plan provides another recent example of large-scale IWRM planning. The water supply in the basin does not meet the needs of dependent communities, which include irrigation demand, municipal supply, and the in-stream flow requirements of fish and wildlife. As climate change and population growth threaten to further shrink the snowpack and associated water supply, the water deficit is projected to worsen. A comprehensive planning effort was launched in 2009 that included representatives from: the Yakama Nation; irrigation district; environmental organizations; and federal, state, county, and city governments. The plan was finalized in 2012 and addresses fish habitat, modifications to the operation of existing structures, surface water storage, market-based reallocation of water, groundwater storage, and enhanced water conservation (USBR 2012b; see **Figure 3.2.6**).

Implementation of other variants of IWRM planning efforts is advancing in parts of North America, including the Great Lakes, Ontario, and British Columbia (Conservation Ontario 2015; Gregory *et al*. 2006). In Ontario, for example, there is some evidence that watershed planning and land-use planning are being integrated to help protect sources of drinking water supplies (Plummer *et al*. 2011).

Figure 3.2.6: Yakima Basin Integrated Water Resource Management Plan

Source: Adapted from Mankin *et al.* 2015

Water quality: nutrient reduction

In 2009, the US EPA identified the control of nutrient pollution as the nation's primary water quality issue, emphasizing the need to make near-term progress on nutrient reductions through partnership with states. One key policy aimed at nutrient load reduction is the development of numeric nutrient criteria, which provide the basis for nutrients in discharge permits, as well as realistic targets for nutrient reduction planning. The number of states that have adopted numeric nutrient criteria has increased from 16 to 24 between 2008 and 2015.

More progress has been made in addressing the public health and environmental aspects of harmful algal blooms in Canada and the US. In May 2015, the US EPA released the first drinking water health advisory values for the most common algal toxins, microcystin (0.3 milligrams per litre) and cylindrospermopsin (0.7 milligrams per litre) (US EPA 2015). The US is now working towards implementing these standards to ensure safe drinking water supply. The US EPA plans to release recreational guidelines in 2016. Canada has had guidelines on microcystin in drinking water since 2008 but in 2015, Health Canada updated its guidance on microcystin to recommend that an alternate source of drinking water should be used to make infant formula if an algal bloom or microcystins are detected in the water supply, even if the levels fall within Canada's drinking water guidelines (Health Canada 2015).

Water quality: microbeads

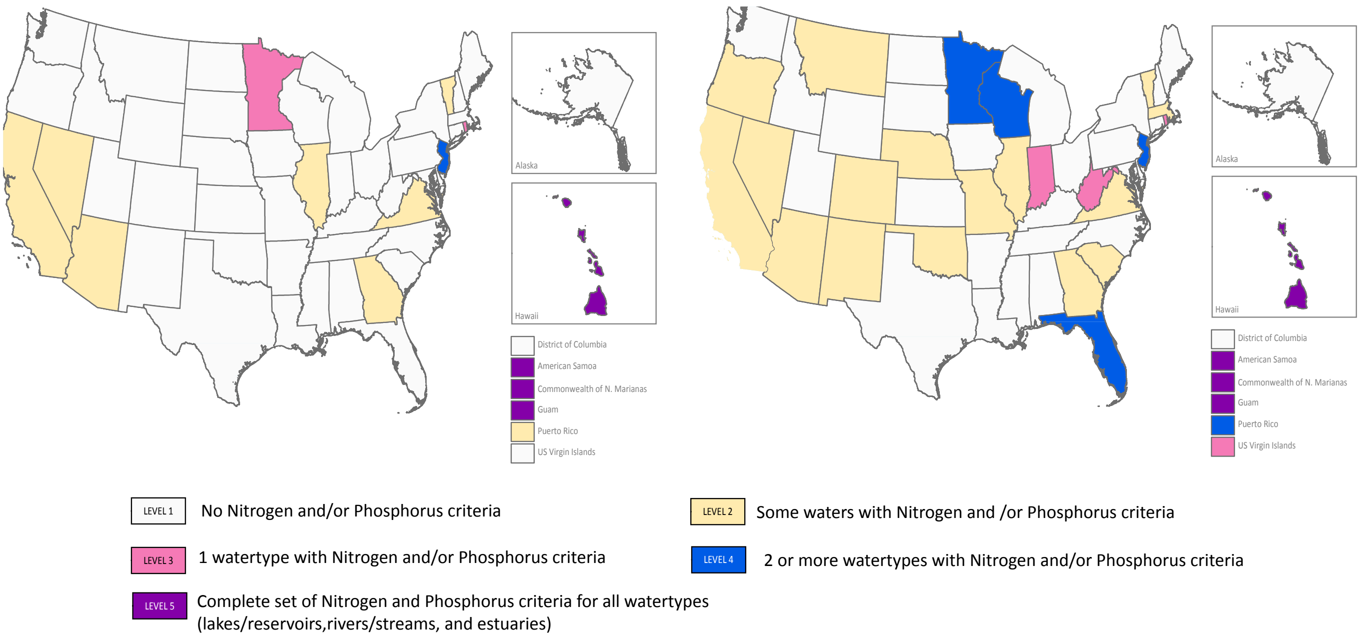
North American governments and manufacturers are starting to take precautionary action against some contaminants of emerging concern such as microbeads. Several sub-national jurisdictions in North America, including seven US states (Illinois, Colorado, Connecticut, New Jersey, Maine, Maryland and Wisconsin) have recently regulated or banned microbeads (Rochman *et al*. 2015). The US passed a federal law in 2015 that will ban the production of person care products with microbeads starting in 2017. In Canada, the province of Ontario has made efforts to control microbeads in personal care products (Ontario 2015) while the federal government declared microbeads toxic in 2015 (Environment Canada 2015a) and is in the process of developing regulations that would phase out the use of microbeads in personal care products (Environment Canada 2015b).

Water quality: nonpoint sources

Nonpoint source projects continue to be implemented voluntarily by willing landowners using funds available from a variety of state and federal programmes. In 2015, the US EPA allocated 158 million dollars for nonpoint source projects, a 21 per cent decline in annual spending since 2010 (US EPA 2015g). These efforts have resulted in notable success stories in many parts of the country (US EPA 2015h). Most states have nonpoint source funds that match the federal dollars allocated through the federal Clean Water Act 319 programme. The State of Minnesota became the envy of the country when it established a Clean Water Fund through a sales tax allocation in 2008 valued at tens of millions of dollars per year (approximately 56 million dollars in fiscal year 2014–2015). Such contributions to the fund have allowed Minnesota to achieve widespread implementation of nonpoint source projects across the state (Minnesota Pollution Control Agency 2015).

Despite these efforts, the control of nonpoint sources remains limited to actions that are implemented voluntarily and incentivized with federal and state funds. The paradigm, that nonpoint source pollution cannot be regulated under the Federal Clean Water Act, is being challenged for the first time by the City of Des Moines, Iowa. The Public Utilities Department filed a lawsuit against several upstream agricultural drainage districts that release large quantities of nitrogen into the streams through tile drainage systems. Des Moines claims that the discharge of water through drainage pipes is no different than regulated point sources, including wastewater and stormwater that discharge pollution into streams and rivers. After years of trying to keep drinking water for residents in Des Moines and surrounding areas clear of contaminants from upstream farms, the Des Moines Water Works board is suing three counties. The suit aims to

Figure 3.2.7: State development of numeric criteria for nitrogen and phosphorus pollution, 1998–2016



Source: Adapted from US EPA 2015c,d

hold the three counties responsible for the high nitrate levels in the Raccoon River, which is a primary water source for Des Moines.

Infants younger than 6 months are particularly at risk of becoming seriously ill from high nitrate levels. Drainage districts were established to help move water out of farm fields so they can be more productive. Northern Iowa has the most extensively drained farmland in the country, estimated at 9 million acres. The targeted counties have about 1.2 million hogs, over a million turkeys and 96 000 cows, according to US Department of Agriculture statistics. Manure and fertilizer are rich in nitrogen, which can wash into rivers and streams as nitrates. The Water Works claims that the water is polluted because of agriculture, which should be considered a point source like a factory.

Agricultural runoff is now exempt from the Clean Water Act. The utility wants the drainage districts — and, indirectly farmers — to be required to meet federal clean-water standards, similar to those governing factories, cities and other "point-source" polluters. The EPA has set a safe limit of 10 milligrams per litre for city water systems. The Raccoon River was recently tested at 14 mg/l. The treated water distributed by Water Works was just under 8 mg/l, due to expensive equipment that removes nitrates. The utility says it struggles to meet federal drinking water limits on nitrate concentrations. This winter it spent USD 540,000 to run nitrate removal equipment.

This is an example of how existing regulations are being used for different purposes than they have been historically. If the lawsuit is successful, it could affect the reach of the

Clean Water Act and the ability of states to take meaningful regulatory action in controlling nonpoint sources (Eller 2015a, b; Schneider 2015).

Innovative approaches have been initiated in the private sector to encourage improved nutrient use efficiency in agriculture, but it is too early to assess the impacts of these efforts. For example, Field To Market®, an alliance of private and public sector institutions, has produced a Fieldprint® Calculator that helps farmers visualize and assess how efficiencies of nutrient use and environmental impacts of nutrient losses fluctuate based on various management decisions (Field to Market 2015). Designed as an easy-to-use tool, farmers can also compare their performance against local, state, and national averages developed using publically available data. Since about 2003, Canada has undertaken several federal governmental initiatives to promote the use of beneficial management practices (BMP) in agricultural areas; about 30 different BMPs are commonly eligible for funding. Evaluation of these BMPs has been ongoing (Council of Canadian Academies 2013). Effective watershed management to control nonpoint sources requires better integration of policies and BMPs water quality, water quantity, and ecosystem management. This will be achieved through better integration across agencies and tools and mandates that provide for comprehensive evaluation of costs and benefits.

Water quality trading

Water quality trading is another trending approach to achieving water quality goals using market-based principles. Much like the cap-and-trade programmes used to reduce air emissions in the 1990s, water quality trading also permitted discharges to negotiate equal or greater pollution reductions from unregulated sources. Although trading has been permissible under the Clean Water Act for some time, there are increasing examples of well-established and monitored trading programmes in the US. The National Network on Water Quality Trading has been focused since 2013 on bringing multi-stakeholder groups together to promote trading programmes that are credible, transparent, and of consistent high quality. In 2015, the National Network on Water Quality Trading published options and recommendations for water quality trading between point and non-point sources in the US context (Willamette Partnership *et al*. 2015).

Responses to drought and water scarcity

Water rationing

Although there are examples of water use restrictions across the region, the most dramatic recent example of water rationing was the Emergency Conservation Regulation implemented when California Governor Brown issued an executive order in April 2015 directing the State Water board to achieve a state-wide 25 per cent reduction in potable urban water usage through February 2016 (CAWB 2015).

Water efficiency is a multi-faceted concept generally aiming to increase water productivity such that more value can be gained per volume of water used. Aspects of efficiency include productive efficiency, allocative efficiency, technical efficiency and managerial efficiency along the life cycle (UNEP 2013). It is important to consider water-use efficiency at a basin scale recognizing multiple sectors and the complete water cycle.

Desalination

In view of shrinking surface and groundwater supplies, desalination is being promoted in some areas of the US. For example, California is turning to desalination as one solution. The Carlsbad Desalination Plant will be the largest in the Western Hemisphere. It occupies part of the 388 acre ocean-front site of the Encina Power Station that for has run on oil and natural gas, releasing emissions, and requiring a large lagoon to hold sea water for cooling and to receive effluent. The adjacent desalination plant will use a reverse osmosis process with its source water coming from the generating plant cooling supply, treated and pumped under pressure through membranes to remove salt and other microscopic impurities. This association allows the new plant to share the power station's water lines, which reduces its cost and its impact on marine life (Little 2015). Built in collaboration with the San Diego County Water Authority and Poseidon, a private developer of water infrastructure, the plant is in the early stages of startup. Nearly a tenth of the San Diego County's total water supply will come from this facility. A hundred million gallons of ocean water will be pumped through the plant daily; half will become drinking water, the other half will flow back into the ocean as brine, carrying the removed salt. Poseidon is planning to build another fifty-million-gallon-per-day desalination plant in Huntington Beach, which will supply the Los Angeles area. Fourteen other mid- and large-scale plants have been proposed along the state's coast. A plant in Santa Barbara, California, which had been unused for more than two decades, is planned to be refurbished and opened. The reason it had not been used initially is that the drought that prompted its construction ended and the water shortage abated. The question remains whether the current drought will end and make the Carlsbad plant unnecessary, or if the current drought it associated with worsening climate change (Little 2015).

Most new plants, including Carlsbad, use reverse osmosis, which removes salt and requires enormous pressure to push the saltwater through the filter (National Research Council 2008).

There is some opposition to desalination, based in part on its huge energy demands. However, advances in reverse-osmosis technology have cut the amount of energy used in desalination by about half in the past two decades. In addition, almost all of the freshwater used by the twenty-two million people of Southern California is imported, much of it pumped long distances from Northern California, which also requires significant energy. Southern California also obtains freshwater from the Colorado River, the waterway that supplies six other US states and Mexico. Additional environmental concerns involve impingement and entrainment of marine organisms into the inflow, but since the Carlsbad plant is co-located with an existing power plant, additional impacts are minimized. At the other end, the salt extracted from seawater forms a heavy brine that is pumped back into the ocean, and can affect physiology, development, and behaviour of marine organisms, potentially destabilizing the ecology around the outflows (Jenkins *et al.* 2012). Although the brine is sprayed in an upward direction, since it is denser than water, most of it settles onto the bottom, affecting benthic organisms.

Water re-use

Through the natural water cycle, the earth continually reuses water. More recently people have used technology to speed up natural processes. Increasingly, communities are exploring ways to beneficially reuse water before it is put back into the natural water cycle. Reused water is most commonly used for nonpotable purposes, such as agriculture, landscape, and park irrigation. Other uses include cooling water for power plants, industrial process water, and to enhance natural or artificial lakes and wetlands. Some projects use recycled water indirectly for potable purposes such as recharging ground water aquifers and augmenting surface water reservoirs with recycled water (EPA 2016c). Such uses become more urgent during droughts. In addition to providing a dependable, locally controlled water supply, water reuse can provide other environmental benefits by decreasing the diversion of water from sensitive ecosystems, reducing wastewater discharges, and reducing pollution. However, in water systems that have over allocated water rights, water reuse can sometimes result in reduced in-stream flows (Sacbee 2016).

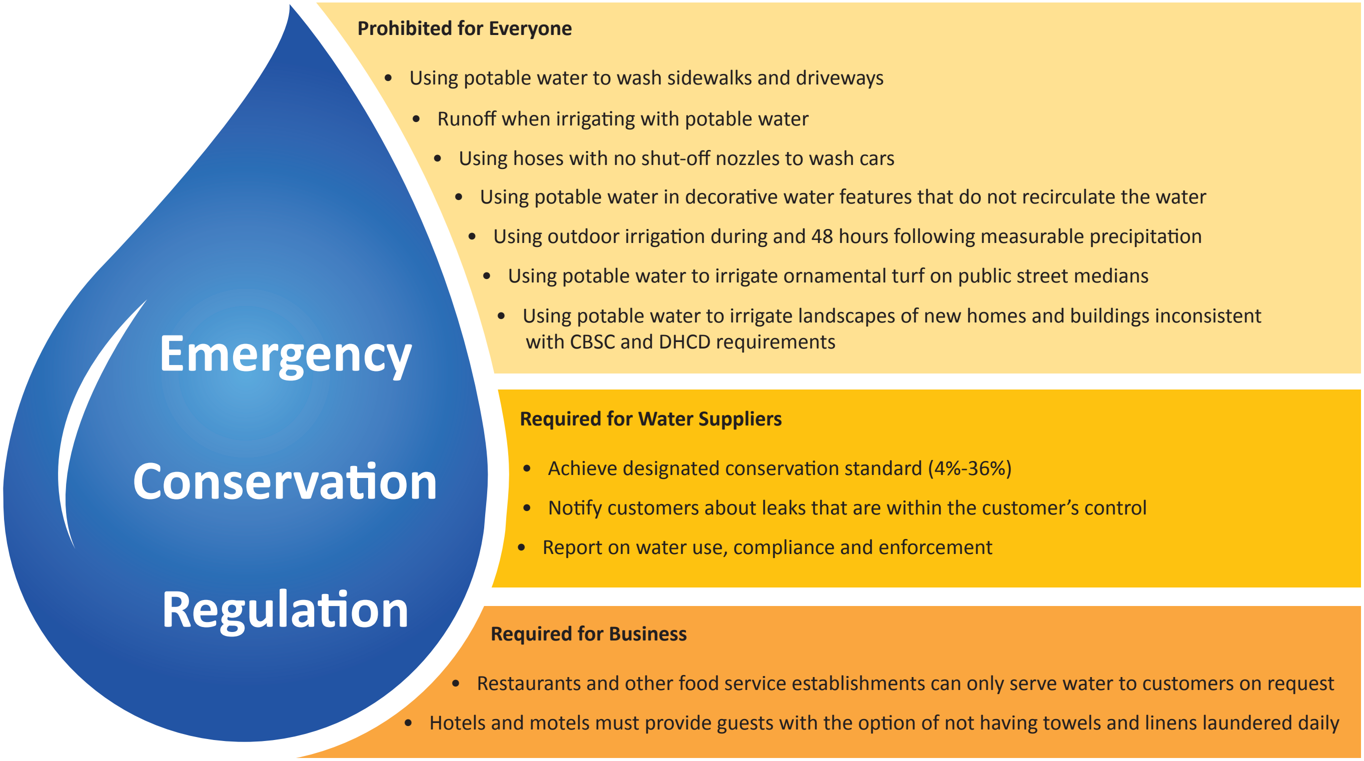
Groundwater governance

Groundwater governance in North America is decentralized and highly variable. In the US, state reliance on groundwater ranges from about 5 per cent of withdrawals (West Virginia, Virginia, Connecticut, Montana) to 95 per cent (Hawaii), with western states generally relying more heavily on groundwater (Megdal *et al*. 2015). There are also great variations in legal frameworks related to, for example, the recognition of connectivity between surface and groundwaters, and the protection of groundwater quality (Megdal *et al*. 2015). However, a recent survey of state officials reported that despite these variations in groundwater governance, common priorities include water quality, conflict and declining water levels (Megdal *et al*. 2015).

Similarly in Canada, governance of groundwater remains unclear due in part to decentralized and fragmented jurisdiction between water quality and quantity, surface and groundwater, as well as a lack of clarity in divisions of responsibility between orders of government (federal, provincial/territorial, municipal) for groundwater specifically (Council of Canadian Academies 2009).

In addition, organizations that play roles in water management are not applying similar programmes of reporting of water quality to groundwaters as they do for surface waters (Rivera 2015). However, there are signals that groundwater is gaining prominence, both internationally (e.g., to date ten Transboundary Aquifer Systems shared between Canada and the US have been identified as part of the Internationally Shared Aquifer Resources Management Initiative (ISARM) of UNESCO; the International Joint Commission published a report on groundwater in the Great Lakes Basin in 2010) and within various provinces and states (Rivera 2015).

Figure 3.2.8 : Summary of California Emergency Conservation Regulation



Source: CAWB 2015

3.2.5 Waste

In North America, effective waste reduction has largely been driven by policies and legislation in combination with appropriate technologies and economic measures. The North American approach to waste management has evolved over the years from open dumping of solid waste to integrated waste management in a shift towards holistic and proactive approaches (Hettiaratchi 2007).

All levels of government in Canada, primarily through the Canadian Council of Ministers of the Environment and the Federation of Canadian Municipalities, work together to improve the management of waste. In October 2009, the federal, provincial and territorial Ministers of the Environment approved a Canada-wide Action Plan for Extended Producer Responsibility (CAP-EPR) aimed at diverting products from landfills and increasing recycling (CCME 2009). EPR shifts the burden for diversion and recycling away from general taxpayers, and onto manufacturers, importers, retailers, and consumers of these products. Through the CAP-EPR, jurisdictions committed to work towards the development of EPR legislation and/or regulations and to promote a harmonized approach to EPR programme and policies. All provincial and territorial jurisdictions have mandatory and/or voluntary EPR or product stewardship programmes in place or under development for a wide range of products including packaging, printed materials, electronics and electrical equipment, used oil, and tires. Federal, provincial and territorial governments support the shared Vision for Waste Management adopted by Canadian Council of Ministers of the Environment (CCME) in 2014 to make Canada a world leader in waste management (CCME 2016).

Since 2006, Canada's Green Procurement Policy has aimed to "advance the protection of the environment and support sustainable development by integrating environmental performance considerations into the procurement decision-making process," including: reducing waste hazardous waste, and toxic and hazardous chemicals and substances; supporting reuse and recycling; promoting more environmentally responsible planning, acquisition, use and disposal practices in federal government; and promoting healthier work environments through the purchase of environmentally preferable goods and services (Government of Canada 2016).

Although many municipalities across Canada have implemented landfill bans to improve waste diversion, two provinces (Prince Edward Island and Nova Scotia) have utilized province-wide landfill bans for materials including, a long list of recyclable materials and organics (food, leaf and yard waste) from the residential and industrial, commercial and institutional sectors (Giroux Environmental Consulting 2014).

The US also has a diverse portfolio of policy instruments to manage waste in a sustainable manner. A few examples highlighted include green procurement, user-pay systems, disposal bans, carbon credits and food-waste treatment (US EPA 2015e). The Resource Conservation and Recovery Act (RCRA), enacted in 1976, is the primary federal US law that governs solid and hazardous waste disposal (Andersen 1978; Stander and Theodore 2006; USEPA 2015i). The general purpose of the RCRA is to reduce waste, conserve energy and natural resources, and protect the environment and human health from waste disposal hazards.

In the US, the cost of household solid waste management is covered by taxes, which guarantees the service to virtually all citizens. However, there can be a negative externality in the form of excess waste if the service is perceived as free. The concept of user pay or user fees is a solution that involves applying a variable charge to homeowners for solid waste collection and disposal according to their usage of the service – this is known as 'pay-as-you-throw'. This system makes the cost of waste more visible and targeted so as to incentivize homeowners to reduce their waste generation (FCM 2004).

Currently, it is estimated that over 97 per cent of food waste is discarded in landfills. A growing number of policies and programmes at both the state and local level demonstrate interest in the re-use and composting of food waste. Source-separated organic (SSO) waste collection programmes segregate organic compostable materials from other types of waste in order to produce renewable energy and compost via aerobic or anaerobic treatment (Levis *et al.* 2010).

Energy-from-waste

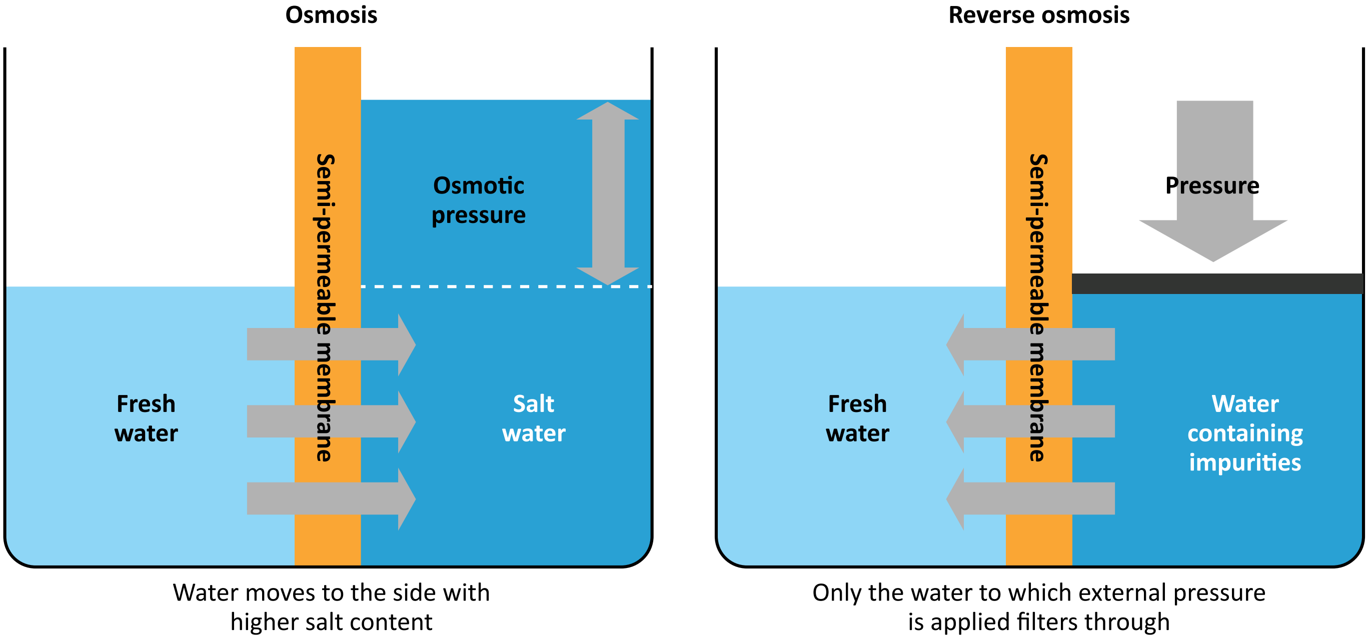
Energy-from-waste (EfW) facilities—also called waste-to-energy (WTE) facilities—offer an alternative solid waste management option that reduces GHG emissions that would have been emitted from fossil-fuel power plants and landfills and generates electricity that can then be sold to utilities and distributed to residential, commercial, and industrial consumers (Kasper 2013; **Figure 3.2.10**).

Waste problems remain a complex issue in North America—especially in the US and moving to a "zero-waste" policy will require significant changes in municipal and state programmes to manage waste, new investments in establishing waste processing facilities and major changes in consumer behavior at the level of households as well as firms. The programmes cited are all positive steps, but as yet, too small to demonstrate impact at a level to address the scale of the problem.

Hazardous waste

In 1980, the US Congress enacted the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). More commonly known as Superfund, CERCLA authorizes the US EPA to identify, prioritize, and clean uncontrolled hazardous waste sites. Sites determined to be the most threatening to adjacent communities and the environment are placed on the National Priorities List (NPL),

Figure 3.2.9: Mechanism of osmosis and reverse osmosis



Source: Hitachi 2016

which "is the list of national priorities among the known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories" (US EPA 2016d). NPL sites are eligible for federal funding through Superfund to perform clean up.

The Columbia University Superfund Research Programme "NPL Superfund Footprint: Site, Population, and Environmental Characteristics" Mapper is an interactive online tool that makes it possible "to better visualize and understand the characteristics of vulnerable populations, built and natural features, and environmental exposures near the National Priorities List sites" in order to inform decision making and "to help improve the evaluation of Superfund sites and more effectively address related environmental health concerns" **(Figure 3.2.11)**.

CERCLA authorizes US EPA to hold private and federal government parties responsible for cleanup or for reimbursing the EPA when it uses federal funding through Superfund to carry out cleanup. Enforcement of the Superfund programme is based on the "polluter pays" principle, which requires the party responsible for the contamination to pay for cleanup. Since 1980, US EPA has secured more than USD 35.1 billion in commitments from potentially responsible parties (PRPs)

to cleanup contaminants under the Superfund programme (US EPA 2015j). Limitations, inequities, and failures in the implementation and enforcement of the Superfund programme have been examined and reported by Daley and Layton (2004) and O'Neil (2007).

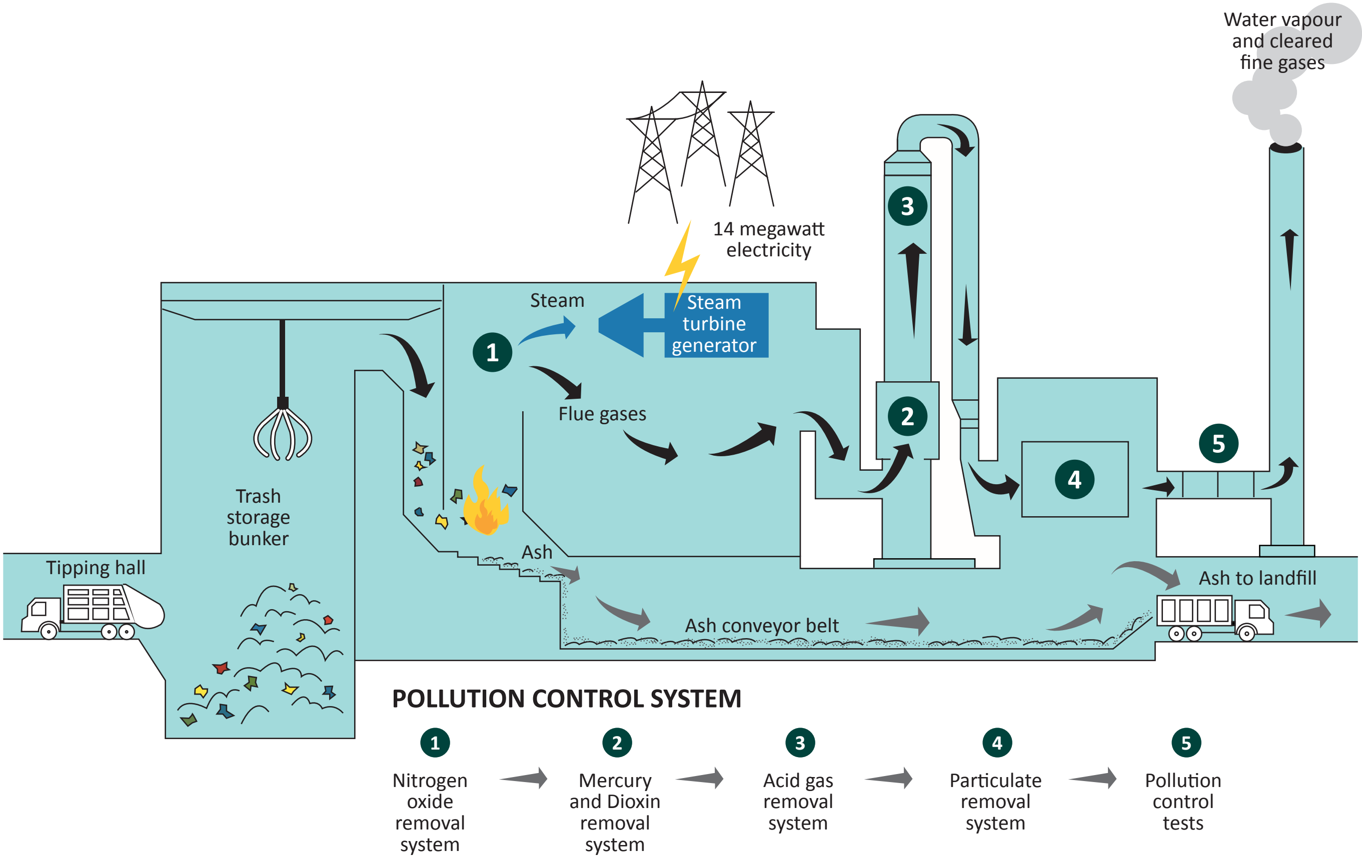
Under the Canadian Environmental Protection Act, 1999 (CEPA 1999), the Government of Canada regulates the use of chemical substances in products. Environment and Climate Change Canada controls the international and interprovincial movement of hazardous waste and hazardous recyclable materials. Similar to Superfund in the US, Canada's Federal Contaminated Sites Action Plan (FCSAP) was established in 2005 to reduce environmental and human health risks from known contaminated sites. In Phase I (2005-2011), federal departments and agencies completely remediated and assessed 650 and 6 400 sites, respectively. The focus of Phase II (2011-2016) was to continue this work and remediate the highest priority sites. During Phase I the programme totalled USD 1.6 billion, including USD 1.3 billion for remediation activities and an estimated 13 000 jobs were created (Government of Canada 2014a).

3.2.6 Climate change adaptation

The impacts of human-induced climate change are increasing nationwide (Mellilo *et al*. 2014). These effects are felt on our geography, health, livelihoods and security. The probability of these impacts to continue to worsen is making this issue a priority for the region. In December 2015, COP21, also known as the 2015 Paris Climate Conference, aimed to achieve a legally binding and universal agreement on climate, with the objective of keeping global warming below 2°C. Canada and the US have a significant role in curbing emissions. Both countries partook in the Paris negotiations where the next step of implementation will be crucial.

Canada is taking a firm approach to climate change issues. The Government of Canada plans to set ambitious targets and provide national leadership by joining with the provinces and territories to reduce carbon pollution and put a price on carbon. In order to protect Canada's communities and

Figure 3.2.10: Energy-from-waste plant diagram



Source: Ecomaine 2016

grow the economy, Canada's strategy is to make significant investments in green infrastructure and clean technologies. This commitment includes the phase out of subsidies for the fossil fuel industry and the creation of a Low Carbon Economy Trust to fund projects that reduce carbon (Environment and Climate Change Canada 2016).

There has been more activity on climate change adaptation in the US. For example, the President's Climate Action Plan 2013 established the case for action and outlined a wide variety of actions to cut carbon pollution, prepare the US for the impacts of climate change and lead international efforts to combat global climate change and prepare for its impacts. With abundant clean energy solutions available, the goal is to double renewable electricity generation by 2020. The Obama Administration in partnership with states, local communities, and the private sector are committed to achieving this goal (House 2013).

To achieve the Paris conference objectives, it will be necessary to keep the private sector engaged on climate adaptation. The private sector was visible and active at COP21 where CEOs from major industries made their own commitments to decrease their carbon footprints, engage in sustainable resource management and adopt renewable energy (IFC 2015). The private sector moves fast and is in a position to rapidly innovate and produce new technologies for combatting climate change. Key decisions in both countries by governments and businesses will be required to ensure that the Paris Agreement comes into effect quickly and is fully implemented.

More advancements on the climate change adaption front in the US and Canada is elaborated in the proceeding sections.

Climate change adaptation in the US

In 2010, the US National Research Council's Panel on Adapting to the Impacts of Climate Change produced a comprehensive list of 314 adaptations to specific climate impacts in seven sectors: agriculture and forestry, coastal areas, ecosystems, energy, health, transportation, and water resources (NRC 2010).

A recent report titled *A comprehensive review of climate adaptation in the United States: more than before, but less than needed* documents existing and planned adaptation activities of federal, Native American, state and local governments, and the private sector in the US (Bierbaum *et al*. 2013). Primary sources of review included material officially submitted for consideration in the 2013 US National Climate Assessment and supplemental peer-reviewed and grey literature. Although substantial adaptation planning exists in various sectors, levels of government, and the private sector, few measures have been implemented and even fewer evaluated. Most adaptation action to date appears to be incremental rather than transformational (Bierbaum *et al*. 2013).

Thus, adaptation to climate change in the US is at an early stage. The federal government is beginning to develop the institutions and practices necessary to cope with climate change, including efforts such as regional climate centres within the US Department of Agriculture, the National Oceanic and Atmospheric Administration (NOAA), and the US Department of the Interior. Approaches include working to limit current institutional constraints to effective adaptation, funding pilot projects, and providing useful and usable adaptation information, including disseminating best practices and helping develop tools and techniques to evaluate successful adaptation (Bierbaum *et al*. 2014).

President Obama established the State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience in 2013 to provide his Administration with recommendations on how the federal government could respond to the needs of communities nationwide. In 2015 his Administration responded to the Task Force recommendations (White House 2015).

The development of three cross-cutting national adaptation strategies focused on integrating federal efforts with those of state, local, and Tribal groups on adaptation in key sectors:

The National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate describes the major climate change risks to freshwater resource management and summarizes current federal agency activities to reduce them (ICCATF 2011).

The National Fish, Wildlife and Plants Climate Adaptation Strategy: This focuses on preparing for and reducing the most serious impacts of climate change and related non-climate stressors on fish, wildlife, and plants. It prioritizes addressing impacts for which there is enough information to recommend sensible action that can be taken or initiated over the next 5–10 years in the context of climate change projections through the end of the current century. Further, it identifies key knowledge, technology, information and governance gaps that hamper effective action (NFWPCAP 2012).

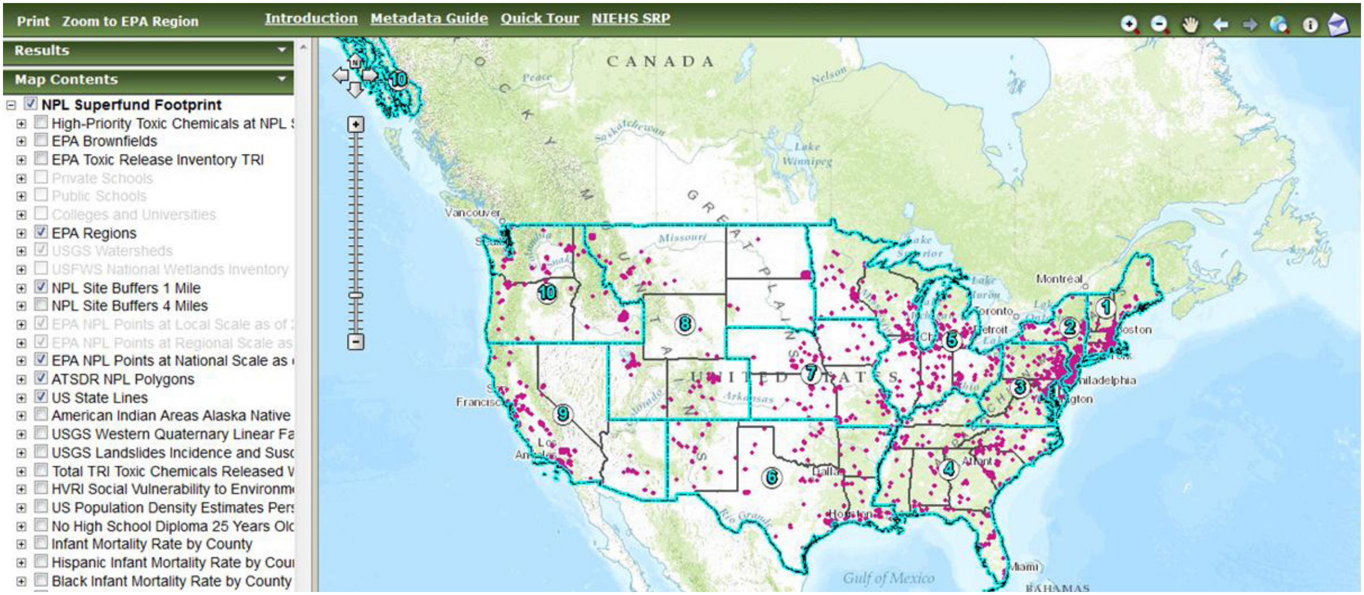
National Ocean Policy Implementation Plan: The need for a statutory framework to manage valuable marine resources in the US is highlighted by problems such as fragmented ocean governance and increasing conflict over the use of ocean spaces. On 19 July, 2010 President Obama signed Executive Order 13 547 to create a National Ocean Policy (NOP) for the US. A subsequent implementation plan, released in 2013, set up hundreds of actions to be accomplished between 2013 and 2025 to address economic, community, scientific and other issues. However, progress implementing the NOP appears to have stalled (Torres *et al*. 2015).

Climate change adaptation in Canada

In 2006, the Commissioner of the Environment and Sustainable Development (CESD), an officer of Parliament mandated to scrutinize the federal government's environmental performance, released an audit report about climate change adaptation (Auditor General of Canada 2006). The report was critical, asserting that the government had not developed appropriate objectives and timelines for adaptation, that it had made little progress in working with the provinces, and that it had not presented its own adaptation efforts at the policy and programme level. The report focused on the national adaptation framework, noting that it had not been officially approved and that the lead department, Natural Resources Canada, had not been granted authority to negotiate an action plan with the provinces (Henstra 2015).

The government's response suggested that the national adaptation framework would be forthcoming, and Environment Canada and Natural Resources Canada were directed to formulate an implementation strategy by the

Figure 3.2.11: The Columbia University Superfund Research Programme "NPL Superfund Footprint: Site, Population, and Environmental Characteristics" Mapper



Source: CIESIN 2016

end of 2008. However, in 2010 the CESD reported, "there is still no federal adaptation policy, strategy, or action plan in place" (Auditor General of Canada 2010). In response, Environment Canada committed to work with federal partners to develop a policy framework that would set out the vision and objectives for adaptation, define the federal role and set criteria for identifying priorities.

In 2011, Environment Canada released the federal adaptation policy framework, which it described as a guide to domestic adaptation action by the Government of Canada (Government of Canada 2011).

As of 2015, the federal adaptation policy is spearheaded by Natural Resources Canada, now the hub of a collaborative adaptation platform (Henstra 2015). Through this, Natural Resources Canada serves as the central node in a network of senior government officials, industry, professional associations and researchers who combine resources to generate information and tools to support adaptation decision-making (NRCan 2014).

The federal election in October 2015 brought a new government to power. The newly revamped Department of Environment and Climate Change promises to emphasize climate solutions. In April 2016, a symposium called Adaptation Canada 2016 took place, advertised as the first national symposium in ten years on the preparation for and management of risks associated with climate change. The symposium was organized by the Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR), the Ouranos consortium on regional climatology and adaptation to climate change, and, as of December 2015, Natural Resources Canada (Adaptation Canada 2016).

3.2.7 Energy

Energy policymaking in North America is facing an ever more complex set of interrelated issues. Over the past 40 years, growing environmental concerns over air quality, climate change, and sustainability have become intertwined with the affordability and social acceptability of energy sources and technologies. The North American energy sector, which is the most integrated in the world, has traditionally relied on market-based relationships between the US and Canada (Gattinger 2012). However, it now faces the increasing governance challenge to integrate environmental issues with socio-economic interests. Entering this mix of issues, renewable energy technologies have rapidly evolved in the last 15 years, becoming cost competitive, while much of North America's energy infrastructure is reaching the end of its life cycle and must be replaced (Gattinger 2012).

A recent lag in environmental policy enactment at the US national level is a reflection of the energy sector's complex interests and issues. Lack of action has not only left policies in place that support greenhouse gas emissions but has also allowed promising policies that support a low carbon future to periodically expire (Marsh 2012; Bast *et al*. 2015; OAG 2012. In Canada as well, a 2014 Auditor General report identified several areas in which environmental policies were becoming less effective, including the regulation of greenhouse gas emissions and monitoring of oil (CESD 2014). New techniques, such as hydraulic fracturing (fracking), create societal and governmental polarization, along with discord and conflicts in the face of uncertainty and risk (State of Colorado 2015; Elliott 2015; Minor 2014; Sreeja 2013; Schwartz and Gollom 2014).

Policy by subsidy, or not

In North America, subsidies exist for fossil fuels and renewable energy. Both Canada and the US have committed to phase out subsidies for fossil fuel production (Bast *et al*. 2015; OAG 2012). However, such action has been lagging and is politically difficult. In the US subsidies for renewables have been subject to periodic expiration and renewal that increases policy uncertainty. In Canada, subsidies for renewables were extended from 2000 to the present.

Fossil fuel subsidies in the US are provided not only at the federal level but also by the states, and come in the form of tax exemptions, deductions and credits. For example, the federal corporate tax exemption for master limited partnerships applies to activities related to the production, processing and transportation of oil, natural gas and coal and provides almost USD 4 billion in tax exemptions per year. Other US federal level annual subsidies include the USD 2.5 billion deduction for intangible oil and gas drilling, the offshore deep water royalty relief of USD 1.38 billion, and the USD 1.0 billion subsidy to the coal producing region of Powder River Basin in Wyoming. Also, the last-in, first-out accounting method allows companies to assume that the oldest, and presumably cheaper, barrels of oil remain in inventory, thereby reducing their tax burdens. State level subsidies also exist in Alaska, California, Kentucky, Louisiana, Montana, Oklahoma, Texas, West Virginia and Wyoming, which create powerful incentives for the continued use of fossil fuels. They are also part of the permanent tax code, thereby making it even more difficult to phase out fossil fuel production.

Renewable energy resources have also been subsidized in the US; however, the magnitude of the subsidies is far less than those received by the fossil fuel industry (Adeyeye 2009, Pfund and Healy 2011). Unlike federal fossil fuels subsidies that are written into the tax code, renewable energy subsidies are not permanent and must be periodically renewed (Klass 2013). Despite recent re-authorization, renewable energy subsidies are subject to future expiration, unlike their fossil fuel counterparts.

Two principal US federal instruments have supported wind and solar energy, the Production Tax Credit (PTC) and Investment Tax Credit (ITC) (DSIRE 2015). Originally enacted in the Energy Policy Act of 1992, the PTC is a tax credit based on the production of electricity from renewable resources. The policy was initially set to expire in July 1999 but was extended through 2001, until it expired again at the end of 2003. The policy was not reauthorized until October of 2004, almost expired again in 2012, before actually expiring in 2013 and 2014 (Klass 2013; Union of Concerned Scientists, N.p). In December 2015, the PTC for wind was extended for five years, with a phase-down in later years (Mai *et al*. 2016). The ITC for solar will continue through 2018 and taper off to a set rate in 2022. Industry representatives lauded the increased certainty provided to industry (Cusick 2015).

The pattern of deployment of wind energy facilities is consistent with the expiration of the PTC (**Figure 3.2.12**). Scholars have often cited this pattern to argue that policy uncertainty decreases the implementation of low carbon energy, particularly wind (Bolinger and Wiser 2009). Considering the pattern of deployment and the time that the PTC was in force, evidence certainly supports the argument that the wind industry is responsive to this federal tax incentive and that longer periods of policy certainty, as afforded to the fossil fuel industry, would be beneficial. Thus, tax incentives are an important factor in the transition to a lower carbon electricity sector.

Growth in US non-hydro renewable energy since 2000 supports the contention that the PTC is an effective instrument for supporting wind energy, which has experienced a 22 per cent average annual growth capacity from 2002-2011 (EIA 2015). Growth for all other non-hydro renewables over the same period was 3 per cent. When compared, wind's share of the total non-hydro renewable electricity generation capacity increased from 28 per cent to 77 per cent (EIA 2015). From 2008–2014 when the PTC was in effect, 31 per cent of all new US electricity infrastructure was for wind energy (EIA 2015).

While wind has expanded greatly and benefitted from policy stability, solar energy has experienced growth for similar reasons. The Solar Investment Tax Credit (ITC) is a 30 per cent corporate tax credit that applies to expenditure on solar energy that generates electricity or heat. This credit was extended in 2008 to 2016 and therefore provided an eight-year period of policy certainty. This level of policy support and period of time allowed the solar industry to gain a substantial foothold in the US while increasing returns to scale associated with higher production of photovoltaic solar panels and substantially decreasing the cost of materials necessary for solar energy systems. This combination has led to large-scale development of solar energy, particularly in California. Overall, utility scale solar installations grew by 68 per cent in 2014 and 99 per cent of all systems have been built since 2008 (EIA 2015):

"*Today, clean energy technologies are providing real-world solutions—not only do they reduce the carbon pollution that causes climate change, but they also drive a domestic energy economy with technologies that are increasingly cost-competitive with existing conventional technologies, even without accounting for the climate benefits. Clean energy manufacturing and installations have also become major opportunities for American workers in the 21st century*".

Canada also provides a number of tax exemptions and deductions at the federal and provincial levels for fossil fuels. Examples of federal policies include development expense measures of approximately CAD 785 million, and accelerated capital cost allowances for bituminous sands projects estimated at CAD 122 million annually (Bast *et al.* 2015). There are also provincial policies in Alberta and British Columbia – the Alberta Crown Royalty reductions alone provided an estimated USD 578 million in 2014 (Bast *et al.* 2015).

Renewable energy policies in Canada consist of development support for renewable technologies, alternative fuels and carbon sequestration along with market incentives and federal renewable power purchases. The Purchase of Electricity from Renewable Resources (PERR) programme started in 2000 and ended in 2012. It consisted of C$25 million to encourage Canadians and Canadian organizations to purchase renewable energy. The federal power purchase requires 20 per cent of the power for federal operations to come from wind or solar. For businesses investing in renewable energy systems, the Government of Canada also provides an accelerated capital cost allowance under Class 43.2 in Schedule II of the Income Tax Regulations, to encourage investments in specified clean energy generation and energy conservation equipment. This provision allows the capital cost of eligible equipment acquired after February 22, 2005 and before 2020 to be deducted at a rate of 50 per cent per year (declining balance basis), thus providing for a greater deferral of taxation in the first years of a project's life. In addition, certain intangible start-up costs associated with renewable energy projects (qualifying for Class 43.2), such as feasibility studies, engineering and design work are eligible for 100 per cent tax deductions or can be transferred to investors using a flow-through share agreement under the Canadian Renewable and Conservation Expense provisions in the Income Tax Regulations (Natural Resources Canada 2015a).

Canada has also provided renewable energy production incentives. For example, from 2000 to 2007, there was a 1 cent per kilowatt-hour incentive to produce wind energy (max of 1,000 MW) (Natural Resources Canada 2016a). In 2007, Canada enacted the ecoEnergy for Renewable Power programme, which encourages the generation of electricity from wind, low-impact hydro, biomass, photovoltaic and geothermal energy by providing a one cent per kilowatt production incentive during the first ten years of operation (Natural Resources Canada 2016b). The ecoEnergy programme is set to expire in 2021 (Natural Resources Canada 2016b).

The decline in policy responses in North America is illustrated by the relatively high number of subsidies that exist for fossil fuels. Legislative action to remove these policies has been lacking, despite international commitments by the G20 nations to phase them out (Bast *et al*. 2015; OAG 2012). However, incentives for renewable energy have propelled a revolution in the energy sector, leading to lower rates of greenhouse gas emissions and new job opportunities. This economic transition has the potential to continue to decarbonize the energy sector and lead the way to a future of renewable energy.

Energy efficiency policies

In the United States, a number of energy efficiency policies have reduced energy consumption. For example, the Corporate Average Fuel Economy (CAFE) Standards are designed to increase the fuel economy of cars and light trucks (US National Highway Traffic Safety Administration 2016). Proposed Phase 2 fuel efficiency and GHG emission standards for 2018-2027 are expected to result in a 1 billion metric ton reduction in CO_2 emissions and reduced oil consumption of up to 1.8 billion barrels during the lifetime of the programme. Similarly, certain appliances and equipment have been subject to minimum energy conservation standards. These standards have been estimated to save consumers over USD 63 billion in 2015 alone and should reduce GHG emissions by the equivalent of 1.5 billion cars from the time the programme was initiated in 1987 to 2030 (US Department of Energy 2016).

Another programme for energy efficiency, the Energy Star programme, is a voluntary programme that promotes energy efficient products and home energy savings, along with energy efficiency for new homes and buildings. From 1992 to 2013, this programme resulted in an abatement of 2 198 million metric tons of CO_2 equivalents (US EPA 2016e). In addition to these programmes, the US has utility sector energy efficiency programmes, energy efficiency requirements for state buildings, and federal tax incentives for home and building energy efficiency improvements.

Canada also provides a number of incentives and programmes for energy efficiency. For example, fuel economy standards for cars have been matched to those of the United States. These Canadian standards are projected to result in a decrease of fuel consumption by up to 50 per cent less than 2008 vehicles and reduce GHG emissions by 174 million metric tons of CO_2 equivalents (Government of Canada 2014b).

Canada also has efficiency standards for buildings, housing, equipment and industry through the ecoENERGY Efficiency programme. The programme includes not only standards, but tools to assist in improving buildings, encourages energy retrofits in buildings and accelerates energy-saving investments in industry. The programme is anticipated to reduce emissions by 6.5 million metric tons of CO_2 equivalents per year (Canadian Department of Finance 2015). Additionally, through the ecoEnergy Programme for Renewables and the Clean Energy fund, there have been reductions in CO_2 emissions of 6.2 and 2.8 million metric tons per year, respectively (Canadian Department of Finance 2015).

The American Council for an Energy Efficient Economy (ACEEE) examines a country's national effort to improve energy efficiency in buildings, industry, and transportation (2016). The national effort consists of the overall or cross-cutting indicators of energy use at the national level. Based on the ACEEE's assessment, energy efficiency improvements could be made in the industrial and transportation sector in Canada (ACEEE 2016). In particular, there is potential to implement more public transit, which would reduce the number of vehicle miles travelled per person. In the US, the ACEEE claims that there is still room for improvement in energy efficiency in all areas, including buildings, industry, and transportation and at the national level (ACEEE 2016).

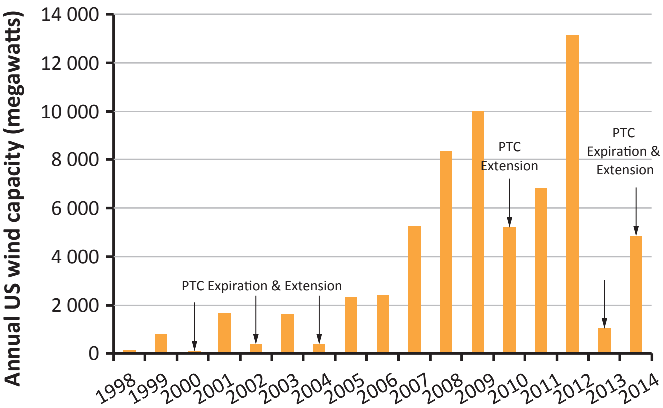
With room for additional energy efficiency improvements, countries should consider the 25 energy efficiency recommendations that were developed in consultation with experts and the International Energy Agency (IEA) member states (IEA 2011). The cross-sectoral measures include data collection, development of strategies and action plans, along with monitoring, enforcement, and evaluation. Other recommendations are aimed at buildings, appliances and equipment, lighting, transport, industry and energy utilities. When these recommendations were made, they were estimated to have the potential to decrease global emissions by as much as 7.6 gigatonnes of CO_2/year (IEA 2011). Thus, there is great potential for countries to reduce GHG emissions through energy efficiency improvements.

Emerging and promising policies: reducing greenhouse gas emissions from electrical generation

With a lack of specific environmental legislation in the US, existing instruments and authorities are being utilized; one example of this is to advance greenhouse gas emission reduction standards in the US. In 2015, US EPA finalized the Clean Power Plan, which established a new set of carbon dioxide emission standards for electrical power plants (US EPA 2015k). This new policy, the first-ever national standard to address carbon dioxide pollution from power plants, was informed by years of collaboration, including stakeholder outreach and public engagement. Rather than using subsidies, the plan sets targets for each state, but allows states to select how to achieve these targets, either within the state itself or in combination with other states. Thus, the plan itself encourages collaborative efforts between states to determine how to achieve greenhouse gas emission reduction goals. If the plan survives legal challenges and is successful, total power sector emissions will be reduced by 32 per cent compared to 2005 levels (Climate Central 2015; C2ES 2015) (See Section 3.2.2, Air).

Canada has also passed regulations to address emissions from power generation. The Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity regulations was published in 2012 and came into force in 2015. The regulations are expected to result in a cumulative reduction of 214 million tonnes of greenhouse gas emissions and CAD 4.2 billion in cumulative health benefits by 2035 (Environment Canada 2014). The Canadian standard is 420 tonnes of carbon dioxide per gigawatt-hour for new coal-fired units, which also apply to existing units once they reach a defined period of operating life (generally 50 years). Comparatively, the US standard for new power plants is 454 tonnes per gigawatt-hour for natural gas-fired power plants and 635 tonnes per gigawatt-hour for coal-fired units.

Figure 3.2.12: Impact of production tax credit expiration and extension on US annual installed wind capacity



Source: USC 2016

The province of Alberta recently updated the Specified Gas Emitters Regulation. This regulation—which applies to large industrial emitters, including oil sand extraction companies—increased stringency in 2015 from 12 per cent emission reductions to 15 per cent by 2016 and 20 per cent by 2017. In addition, under the Climate Leadership Plan recently announced in Alberta, GHG emissions will be addressed in several ways. First, oil sands will transition to a CAD 30/tonne carbon price and be subject to a legislated maximum emissions limit of 100 million metric tons per year. Second, a target has been set to decrease methane emissions by 45 per cent from oil and gas operations by 2025. Finally, coal-fired sources of electricity will be phased out completely by 2030.

North American policies are evolving providing more certainty to renewable energy industries, but continue to subsidize fossil fuels. Some states have regulated public action against fracking while others have made efforts to ban fracking. Yet, new policies, such as the Clean Power Plan in the US and the Clean Energy Fund in Canada and the Alberta Climate Leadership Plan, are emerging, leading to optimism that decarbonization and commitments to international goals will be honoured. Policies represent choices that have implications for future sustainability of the energy sector and affect achievement of the less than 2°C anthropogenic temperature increase. The path to transition to a sustainable energy sector is becoming clear and North America has the resources, entrepreneurship and capital to play a pivotal role in leading the way (IRENA 2015, Jacobson *et al.* 2015; Torrie *et al.* 2013; Clean Energy Canada 2014).

3.2.8 Sustainable consumption and production

Once a process, product, or service becomes easier to use or more accessible through efficiencies, the user decides to consume more. Although many consumers in North American and other OECD countries report their intention

Box 3.2.4: Fracking: emerging citizen science, data gathering, and responses

Hydraulic fracturing or "fracking" in Canada and the US has led to conflicts between citizens and developers over land and mineral rights. In some cases, developers obtain legal authority to drill, frack, and extract natural gas where people work and reside-areas not accustomed to widespread oil and gas production. In the US, some of these conflicts occur in rural communities and urban areas, such as the greater Dallas-Fort Worth and Denver metro areas. The map of North American Shale "plays" demonstrates the locations of shale gas reserves, where conflicts between developers and residents may arise in the future (**Figure 3.2.13**).

Cities, states, and rural communities have therefore become the focus of fracking-related conflicts. Responses include citizens investigating fracking impacts and initiating processes at the local, state, or federal government level to address their concerns. For example, citizens participated in the first of a kind community-based study to determine the impact of fracking on human health and air quality. Results showed elevated concentrations of hazardous air pollutants in areas near unconventional oil and gas sites (Macey *et al*. 2014). Armed with this information, citizen groups proposed ballot initiatives that provide local control over decisions related to shale gas drilling.

In the Energy Policy Act of 2005, Congress amended the Safe Drinking Water Act to largely eliminate wells used for fracking from regulation by the US EPA under the injection well provisions of the SDWA, making such regulation primarily within the purview of the states (Soraghan 2015).

Figure 3.2.13: North American shale plays

Source: EIA 2011

In the State of Colorado, for example, three municipalities imposed five-year fracking suspensions in 2013, and two imposed bans (Minor 2014, Sreeja 2013), while in Texas, the city of Denton voted to ban fracking within city limits as part of a citizen-led initiative (Fry *et al*. 2015). The response to these citizen initiatives has varied across states. The State of Texas implemented new laws to restrict municipal regulation of oil and gas and the State of Colorado formed a task force to attempt to arrive at harmonious state and local regulations (*Texas, House Bill 40*, 2015, Colorado 2015; Elliott 2015). Similar conflicts have been seen across Canada, with First Nation members raising concerns about the failure to consult with aboriginal people (Schwartz and Gollom 2014).

In the State of New York, the approach to fracking was to initially place a moratorium on the activity. The state followed this moratorium with a study of public health effects. The study transmittal letter states:

"Absolute scientific certainty regarding the relative contributions of positive and negative impacts of high volume hydraulic fracturing (HVHF) on public health are unlikely to be attained. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health" (NYSDOH 2014).

As result of the findings of this study, New York state regulators have banned fracking (NYSDEC 2015). The uncertainty over the benefits and costs of this activity remain an open question and continue to fuel conflicts across the region.

to consume in more environmentally sound ways, when their actual behaviour is examined, an 'attitude–behavioural intention' gap is often found (Peattie 2010; Vermeir and Verbeke 2006). Thus, it is critical to understand why this gap exists and how to ensure that attitudes, intentions, and behaviours are aligned to sustainable outcomes. To limit the effect of behavioural rebound, users' needs and perceptions should be considered and integrated into design and innovation decisions at an early stage (Stevens 2010).

Innovative designers are exploring how to influence consumer behaviour through concepts such as user-centered design, persuasive technology, behavioural psychology, and social practice theory (Bloks *et al*. 2015). Some progress in this sphere includes increasing the use of behavioural economic approaches for policy making (Sunstein and Thaler 2012). The Swedish Environmental Protection Agency has explored the use of 'nudging' to gently lead people in a desirable direction (Mont *et al*. 2014).

Innovations are essential to catalyze and support progress and improvements for advancing sustainable production (Leach *et al*. 2012). New assessment technologies and techniques are needed that effectively document inefficient and unsustainable aspects of production and consumption, so replacements can be designed and implemented (Rotmans 2006).

Businesses and corporations responsible for the design and production of many goods and services are increasingly sensitive to reputational risks related to corporate social responsibility and are engaging with sustainability to an increasing degree, both internally and in their supply chains (Kolk *et al*. 2008; Kovacs 2008).

A large and growing number of manufacturers is realizing substantial financial and environmental benefits from sustainable business practices. Sustainable manufacturing is the creation of manufactured products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community and product safety (US EPA 2013).

Only two decades ago, 'environmentally-sound technology' was considered a separate sector by the governments of both the US and Canada. That put the whole approach in competition with industrial sectors—such as forestry, mining, manufacturing, agriculture, and pharmaceuticals and medical devices—for consideration, promotion and subsidies. By 2015, some practitioners in each of those sectors considered sustainable production simply to be best practice (Epstein and Buhovac 2014).

Canadian progress on SCP

The Canadian Green Procurement Policy of 2006 influences purchasing worth more than USD5 billion annually (UNEP 2015). The Federal Sustainable Development Act, passed by Parliament in 2008, requires the government to develop a Federal Sustainable Development Strategy every three years. Many producing sectors are overseen by Industry Canada. In its 2013 contribution to the strategy, Industry Canada pledged a number of commitments relevant to sustainable consumption and production (Industry Canada 2014):

- continue to support the development and promote the use of corporate social responsibility management tools by industry and the use of related standards in the Canadian marketplace in support of sustainable consumption and production, innovation and competitiveness;
- continue to work with key stakeholders to ensure that consumers have the information and tools needed to protect their interests, while engaging in and supporting research and policy development on consumer issues such as sustainable consumption;
- continue to promote sustainable manufacturing practices to Canadian businesses recognizing that the adoption of technologies and processes that support innovation and competitiveness can also increase environmental sustainability;
- continue to advance environmental sustainability through support to cooperatives as businesses with economic, environmental and social sustainability goals by identifying and addressing barriers and opportunities to cooperative growth, and enabling access to emerging market opportunities;
- continue to support the growth of business services to manufacturing, including those which integrate innovation into product design and development and into the supply chain, and can result in environmental sustainability benefits;
- continue to collaborate with partners to enhance Canada's competitive advantage in hydrogen and fuel cell technology development and commercialization;
- continue to implement the Automotive Innovation Fund through to 2018 in support of strategic, large-scale research and development projects leading to innovative, greener and more fuel-efficient vehicles;
- provide scientific expertise, guidance and advice to decision makers, and develop and apply models for social, cultural and economic valuation of ecosystem services to support sustainable development decision making so that ecosystem information and environmental effects of development proposals can be factored into decisions;
- support research efforts to develop and apply models for economic valuation of natural capital to improve the understanding of natural capital productivity and productivity in general in Canada and to support sustainable development decision making;
- in accordance with mandated responsibilities, provide environmental and/or other information to reduce the risk of, and advice in response to, the occurrence of events such as polluting incidents, wildlife disease events or severe weather and other significant hydro-meteorological events as applicable; and
- continue to cooperate with partners across Canada to implement the Computers for Schools programme to divert electronic equipment from landfills thus protecting nature, preventing water pollution and providing economic and social benefits to Canadians.

US progress on sustainable consumption and production

The US EPA serves as the National Focal Point for the global 10-year Framework of Programmes on Sustainable Consumption and Production (10YFP), and it leads interagency participation in the activities of this effort, including leading an interagency contact group to promote cross-government inputs to, and distribution of, key 10YFP materials. The US EPA currently focuses on three key areas in continuing support of the 10YFP.

- The US EPA was involved in launching the Sustainable Public Procurement Initiative (SPPI), a UNEP-led

Box 3.2.5: Renewable energy and North American cities

Cities are increasingly driving the demand for clean energy through policy initiatives. States, provinces and federal governments have implemented clean energy goals and cities have also done likewise; however, cities have pushed this concept further, often implementing 100 per cent renewable energy requirements. In the US, fourteen cities have implemented 100 per cent renewable power requirements, while two Canadian cities have made the same commitment. These are not just small cities, but include large electrical load centres, such as San Francisco, San Diego and Vancouver.

For example, Vancouver's 100 per cent Renewable Energy Strategy was approved by the City Council in 2015 and includes three strategic elements:

- Reducing energy use
- Increase the use of renewable energy
- Increase the supply of renewable energy

Vancouver intends to facilitate these strategies through establishment of greenhouse goals for new buildings, enabling conversion of steam systems from natural gas to renewable energy, streamlining processes for installing rooftop solar panels, supporting car-sharing and renewably powered vehicles along with pricing carbon into the process for municipal decision making (City of Vancouver 2015).

Cities that are pursuing renewable requirements are not only providing benefits for the environment, but are also finding economic benefits as well. For example, Austin, Texas which has a 55 per cent renewable energy goal issued a request for proposal for solar energy supplies and received a record 1.2 gigawatts (GW) of bids for generation capacity at less than 4 cents per kWh in mid-2015. This price is only 25 per cent of the price of solar electricity purchased in 2008 by Austin Energy and is illustrative of the steep declines in solar energy pricing. However, the price decreases have not stopped there, but have continued. For example, the City of Palo Alto, California which is now 100 per cent carbon neutral, announced a power purchase price for solar at 3.67 cents per kWh in early 2016. As a result, these choices have made not only environmental but also economic sense for cities that are pursuing sustainable solutions.

Adoption of these goals by cities has been attributed to a variety of stakeholder outreach and community engagement efforts (Pitt and Bassett 2013). Surveys of small to mid-sized cities show that focusing clean energy programmes initially on incentives for local residents and business and integrating these programmes with collaborative planning can educate residents and facilitate adoption of these environmentally friendly clean energy initiatives (Pitt and Bassett 2013). Summing it up, these programmes are engaging citizens, providing environmental and economic sense and progressing communities forward to a sustainable energy future.

initiative at Rio+20, and serves on the Advisory Committee. The SPPI is expected to be the first officially adopted 10YFP programme.

- The Life-Cycle Assessment (LCA) Partnership is a touchstone feature of the 10YFP, and through this Partnership, the US EPA and Department of Agriculture are leading the effort to facilitate access to information and capacity building, develop tools that improve computer applications, build international interoperability of LCA databases, and reduce the costs of using LCA internationally.
- The US EPA houses the US dimensions of the Global LCA Partnership Sustainable Consumption and Production Clearinghouse. The Clearinghouse, which was launched in 2013, is the key information exchange and networking platform supporting the 10YFP.

Finally, the US EPA supports the Sustainable Business Clearinghouse that allows the searcher to examine hundreds of examples of private-sector, governmental and civil-society efforts to realize efficiencies and waste elimination in manufacturing, distribution, transport, clean-ups and restoration with benefits to health and safety as well as the bottom line (US EPA 2015l).

Sustainable consumption and production: complementary approaches

Circular economy

The idea of a circular economy has been part of the environmental discussion for decades, under a variety of names. As a government policy, the Chinese explored the potential benefits of a circular economy specifically in the 1990s and adopted the principles in 2006 (Zhijun and Nailing 2007). The concept gained popularity and has been elaborated to include many of the ideas inherent to sustainable consumption and production and other complementary systems (European Commission 2016; See **Figure 3.2.16**).

Industrial ecology

The focus issues of industrial ecology are a cluster of concepts and tools:

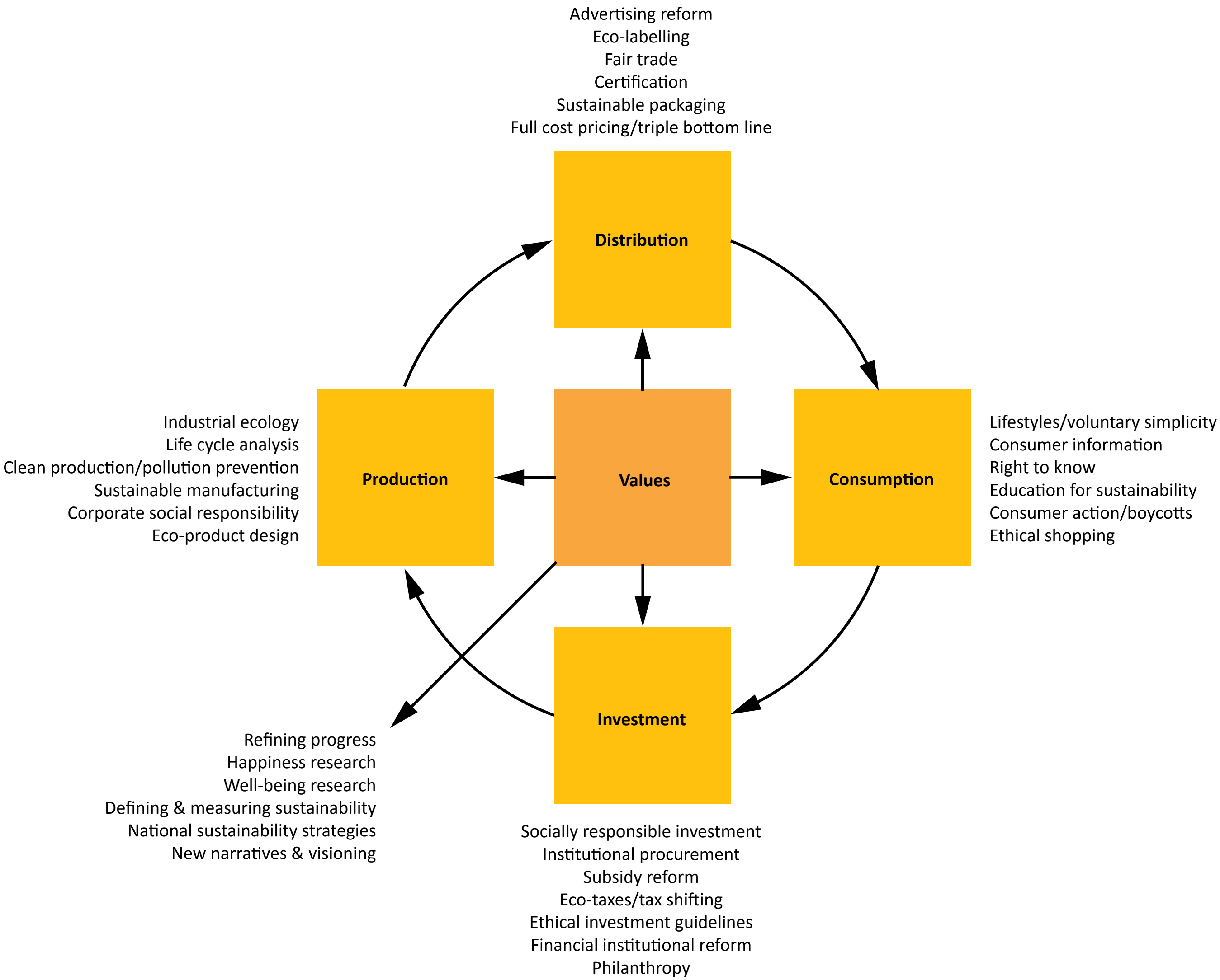
- the biological analogy, or biomimicry;
- life-cycle assessment (LCA);
- product-oriented environmental management and policy;
- material and energy flow analysis;
- industrial symbiosis;
- eco-efficiency;
- dematerialization and decarbonisation.

Uniting these elements requires attention to the flow of materials and energy at multiple levels and scales: products, supply chains, product life cycles, processes, facilities, firms, cities, regions, nations, and the globe. Through approaches such as LCA, design and management, and rigorous materials accounting, industrial ecology also pursues a comprehensive systems perspective (Lifset and Graedel 2002). In the early days of industrial ecology, the 1980s and 1990s, the field was dominated by investigation of the soundness and utility of biological analogy and efforts at eco-design. Since 2000, input-output analysis, studies of resource criticality, integration of social science, complexity modelling, urban metabolism, and long term socio-ecological research have become central to the field (Yale 2015).

Urban metabolism/socio-economic metabolism

The urban metabolism approach allows researchers to regard cities as organisms that consume raw materials, fuel and water and convert them into the built environment, human biomass and wastes (Decker *et al*. 2000; Wolman 1965). The approach combines analyses of ecological, social and economic processes to build broad frameworks accounting for urban development, energy production and waste emission. The accounts help to define interactions between the human and natural components of an urban system and, once analysed, demonstrate the input and output flows between cities and their environment (Zhang *et al*. 2015;

Figure 3.2.14: Elements of a sustainable consumption and production system



Sources: Adapted from Pike 2015; Barber 2014

Kennedy *et al*. 2007). Understanding urban metabolism can help planners design infrastructure and manage the reduction, treatment and repurposing of waste material in cities. Through the organism metaphor, advocates of this approach believe that the efficiency and stability of natural systems can serve as a model for urban management (Zhang *et al*. 2015).

In North America, the use of material and energy flow analyses for understanding how cities work allows city planners, urban geographers and other researchers to better manage small towns and megacities alike. Scores of examples can be found in reviews of urban metabolism theory and implementation and journals dedicated to the subject (Brattebø and Lifset 2015; Reyna and Chester 2015; Zhang *et al*. 2015).

Human appropriation of net primary production

Material and energy flow analysis has opened up new dimensions in tracking the effects that human activities have on Earth systems (Smil 2007). A prominent example is a metric called human appropriation of net primary production (HANPP), the aggregate impact of human land use on the biomass available each year in ecosystems (Krausmann *et al*. 2013; Haberl *et al*. 2007).

Addressing regional priorities

Adopting sustainable consumption and production practices will support the solutions necessary to address all of North America's regional priorities documented in this GEO-6 assessment. Applying principles of a circular economy, industrial ecology, urban metabolism, and material and energy flow analysis, as well as natural capital accounting, allows practitioners to include all the ecosystem goods and services required for human and ecological well-being. For instance, close material and energy flow analysis of fertilizer and power needs in agricultural production enables the kind of precision that leads to more efficient cultivation and more healthy crops (Pike 2015; Bowles 2011).

3.2.9 Implementing natural capital accounting in North America

Introduction

To assess the real wealth of a country and the value of an economy, many economists and policy makers posit the need to go beyond a simple measures of the economic like GDP, captured by the UN System of National Accounts (SNA). In support of this view, the UN Statistics Committee agreed to a System of Environmental and Economic Accounts (SEEA) Central Framework, as the initial international statistical standard, to be implemented in a flexible and modular way (43rd Session of the UN Statistical Commission (UNSC)), in 2012. The SEEA central framework is designed to serve as a satellite account to the SNA. The SEEA allows countries to capture both stocks and flows of natural resources in both physical and monetary terms. The SEEA also allows countries to track water and air emissions and waste, as well as, to track environmental expenditures. As a satellite to the SNA the information can be integrated with the basic economic accounts to track natural resources use, such as, water or energy to reveal resource use efficiency and productivity across sectors (UN DESA 2014).

In 2013, at its 44th meeting, the UN Statistical Commission welcomed SEEA – Experimental Ecosystem Accounting (SEEA-EEA) as a first step in the development of a statistical framework for Ecosystem Accounting. SEEA Experimental Ecosystem Accounting seeks to compliment the SEEA Central Framework so that together they have the potential to comprehensively describe the relationship between environmental, economic and other human activities. SEEA-Experimental Ecosystem Accounting measures: ecosystems; their condition; and, the flows of services from ecosystems into economic and other human activities. SEEA-EEA goes beyond standard measures of the economy and seeks to capture non-market activity and to integrate it with traditional market measures. It builds on a rich history of work in the environmental sciences on ecosystem services and seeks to link biophysical data to economic and social activities (UN DESA 2014).

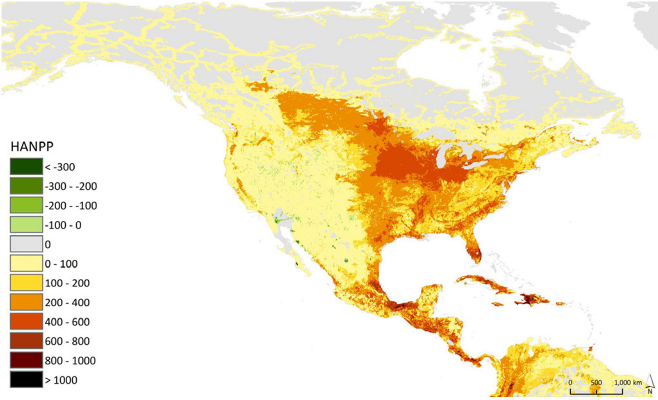
Finally, the business community has begun to embrace Natural Capital Accounting spurred by the book *"Natural Capitalism"* and a Harvard Business review article (Hawken *et al*. 1999a, b). These studies made a business case for efficient natural resource use, the opportunities for innovative new environmentally friendly products and the need to account for risks of resource shortages and costs throughout the supply chain. The Natural Capital Coalition brings together the many approaches to natural capital accounting for the private sector and is developing and encouraging the use of a standardized Natural Capital Protocol and sector guides, for the private sector. This efforts builds on the UNEP-private sector partnership on The Economics of Ecosystems and Biodiversity (TEEB), as well as, a North American history of investors and companies pursuing sustainability through advocacy groups, such as, CERES and the Business for Social Responsibility, numerous companies and financial institutions from Canada and the United States are members in these efforts and are exploring the application of Natural Capital Accounting to their enterprises.

Background

Natural capital comprises the planet's supply of air, land, water, biodiversity, and other natural resources including minerals and hydrocarbons, solar and wind energy, ecosystem interaction, and chemical reactions–and even the gravity that pulls rivers down from mountain lakes and drives the ocean's deep water conveyer system. While many concerned voices reject any attempt to commodify nature, the idea can facilitate responsible decision-making at the personal as well as at a global scale. At national scales, natural capital accounting can be a valuable tool for policy design and implementation (Guerry *et al*. 2015; Costanza *et al*. 1998).

Built, human, and social capitals are assigned monetary value according to the benefits of goods and services they provide. The benefits provided by the resources and processes supplied by natural capital are known as ecosystem goods and services, often shortened to ecosystem services (MA 2005).

Figure 3.2.15: Human appropriation of net primary production, excluding effects of human-induced fires

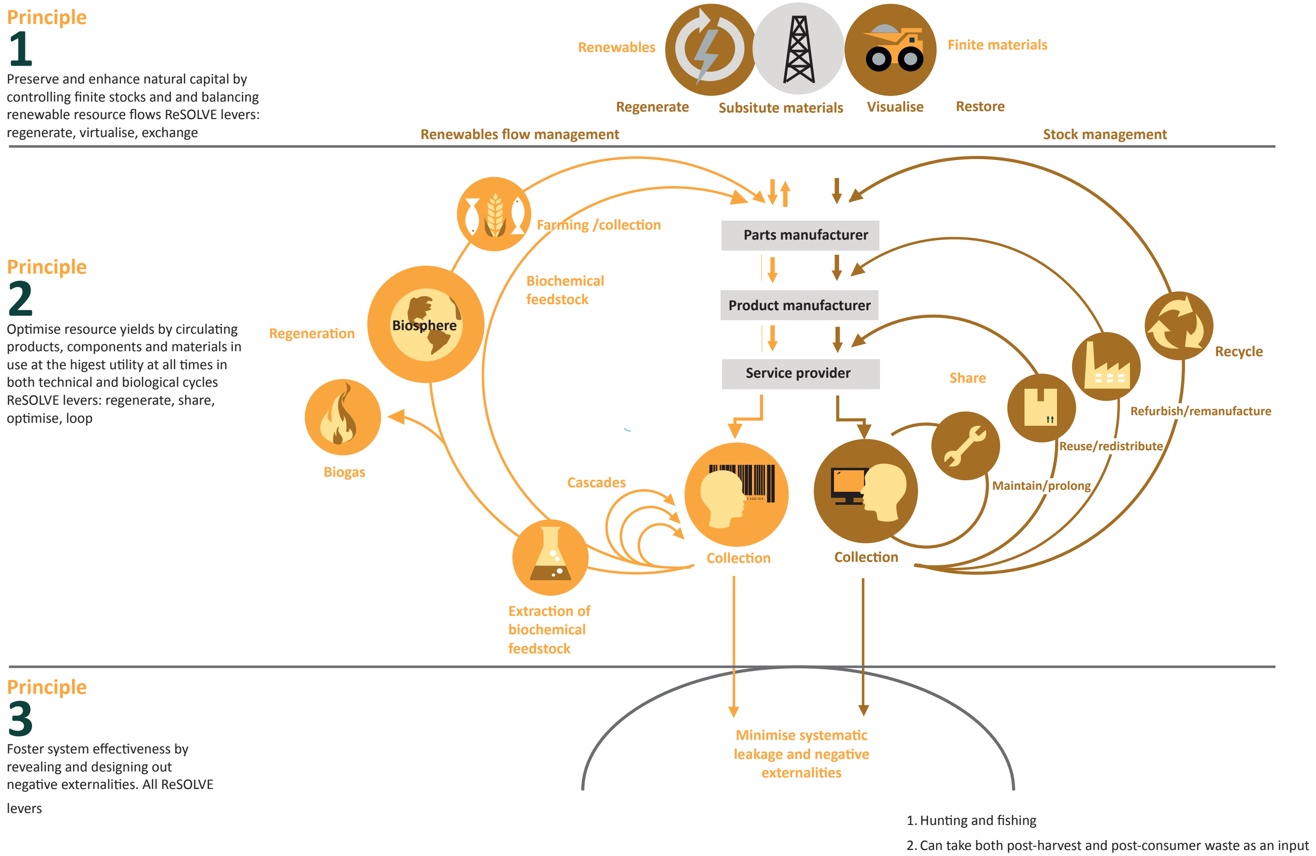


Source: Haberl *et al.* 2007
Note: Grams of carbon per metre squared per year

Traditionally these ecosystem services were not assigned a value when drawing up national accounts. However, if the value of the infrastructure that human societies would have to install to replace ecosystem services is assessed, the real value of natural capital begins to be comprehensible. So, should a city install an expensive water treatment network of ponds and pools churning 24/7 or should it protect the watershed from which it takes its water supply? The concern about honeybee vulnerabilities, for instance, has led to more robust evidence of the value of their ecosystem services: the estimated annual global contribution of managed honeybee pollination is USD 28-123 million, with only around USD 1.8 million actually being paid through commercial transactions. The contribution of wild pollinators ranged between USD 49 and USD 311 million with no direct payment by beneficiaries for the service (Allsop *et al*. 2008).

According to the Natural Capital Coalition, the top 100 environmental externalities cost the global economy around $4.7 trillion a year, while half of all existing corporate profits are at risk if the costs associated with natural capital were to be internalized through market mechanisms, regulation,

Figure 3.2.16: Outline of a circular economy



Source: Adapted from Ellen MacArthur Foundation 2013

or taxation. For instance, water scarcity would have a 'severe' or 'catastrophic' impact on 40 per cent of Fortune 100 companies (CIMA 2014). That is only one facet of complex natural capital estimations, which are the subject of emerging research by academics, governments, business firms, and organizations in North America.

Natural capital accounting in the United States

According to Nordhaus (2000), dedicated environmental accounting began in the US Bureau of Economic Analysis (BEA) of the Department of Commerce in 1992, and it published the first official environmental accounts for the US, known as the Integrated Environmental and Economic Satellite Accounts, in 1994. Shortly thereafter, 103rd Congress directed the Commerce Department to suspend further work in this area. An external review of environmental accounting was called for and a panel of the National Research Council's Committee on National Statistics was charged "*to examine the objectivity, methodology, and application of integrated environmental and economic accounting in the context of broadening the national economic accounts*" and to review "*the proposed revisions…to broaden the national accounts …*".

In 1992, the US vision for developing natural capital accounting used a phased approach. It proposed adding asset accounts in three iterations: first with minerals, already a commodity; second with renewable resources, which were beginning to prove themselves; and third with non-market public goods, such as clean air. It was assumed that if this phased approach were adopted, a useful initial step would be to refine the initial estimates of sub-soil minerals. Constructing forest accounts, focusing initially on timber, would have been a natural next step for integrated economic and environmental accounts. Other sectors that would be high on the priority list are those associated with agricultural assets, fisheries, and water resources (Nordhaus 2000).

However, the National Research Council panel urged the adoption of a more ambitious approach, in which a comprehensive set of near-market and non-market accounts would be developed. In addition to the environmental arena, significant extensions would include the value of home production and unpaid work, the value of research and development capital, the value of non-market time, and the value of informal and home education. This work was motivated by the idea that expanding accounting boundaries would provide a better estimate of the size, distribution, and growth of economic activity and economic welfare. The panel's central recommendation was that Congress should authorize and fund the BEA to recommence its work on developing natural-resource and environmental accounts and that it should be encouraged to develop a comprehensive set of near-market and nonmarket accounts (Nordhaus and Kokkelenberg 1999). Congress did not follow the National Research Council's advice and there are no categories for natural capital or ecosystem services in the BEA's 2015 mandate (BEA 2015).

Scientists and economists, are applying Natural Capital Accounting methodologies using federal data in an effort to promoting the establishment of natural capital accounting standards and methodologies by the central accounting system in the US national government (Fenichel *et al.* 2016; Muller *et al.* 2011). There is increasing interest in reorganizing data already collected by US federal agencies into an accounting framework as suggested in the SEEA which would provide greater comparability. In the meantime, natural capital accounting and ecosystem service approaches are widely used in federal agencies and efforts are underway to increase their value for decision making (Obama 2015). In 2015 the Proceedings of the National Academy of Science of the United States of America published a special issue to celebrate its centennial: Nature as Capital PNAS 100th Anniversary Special Feature (Guerry *et al.* 2015).

In the US, many parties including universities, non-governmental organizations and federal agencies are actively collaborating to develop and apply ecosystem service concepts. These efforts advance natural capital accounting at a national scale to achieve environmental and economic objectives. Numerous federal agencies have incorporated these concepts into land-use planning, water-resource management and climate change adaptation (Bagstad *et al.* 2014 Bagstad *et al.* 2013) Well-defined policy direction is needed to institutionalize ecosystem services approaches across federal agencies, and guide inter-sectoral and interdisciplinary collaborative research and implementation. In addition, the community of practice needs next generation decision support tools for the practical application of ecosystem service principles in policymaking and in commerce. These communities also need better performance metrics, as well as tools to monitor ecosystem service status and assess the environmental and economic impacts of policies and programmes (Schaefer *et al.* 2015).

Natural capital accounting in Canada

Statistics Canada (StatsCan) has introduced an environment and resource category into its National Economic Accounting practice, called the Canadian System of Environmental and Resource Accounts. Some data sets were initiated in the 1960s. The introductory material state that the category was collated was because the information existed and only needed to be collected to present as a whole. But the most important reason was that the statistical agencies in different ministries wanted to address long-standing environmental criticisms of the national accounts. The criticisms included neglect in measuring the contribution of the ecosystem goods and services to national wealth; treatment of receipts from natural resource depletion as current income rather than capital depletion; measurement of the benefits from the use of the environment but not the costs; and inclusion of expenditures to protect the environment as part of gross production (Statistics Canada 2015). StatsCan goes on to say *"many of these criticisms are controversial and not all are accepted as legitimate by all parties of the debate. Many countries including Canada have attempted to address one or more of them in their environmental and resources accounts".*

The ministry is thinking strategically. The wealth represented by these resources *"can make a very substantial difference in the economic position of the government that owns them. And because the prices of resource commodities fluctuate widely and are determined by market forces outside of Canada's control, this wealth can vary from one year to the next"* (Statistics Canada 2015).

Over the past decade Statistics Canada has also published an annual Human Activity and the Environment Report (HAE) highlighting a distinct area of environmental and economic accounts. In 2013 then HAER addressed " Measuring Ecosystem Goods and Services in Canada (Statistics Canada 2013). Canada has also taken a leading role as a chair of the UN Statistical Commission Committee on Environmental and Economic Accounts and the working group on environmental accounts called the London Group.

In both Canada and the US, government departments and ministries, civil society, and businesses are using natural capital accounting and ecosystem services approaches to revalue their natural resources.

3.3 Closer looks at synergies and cross cutting themes

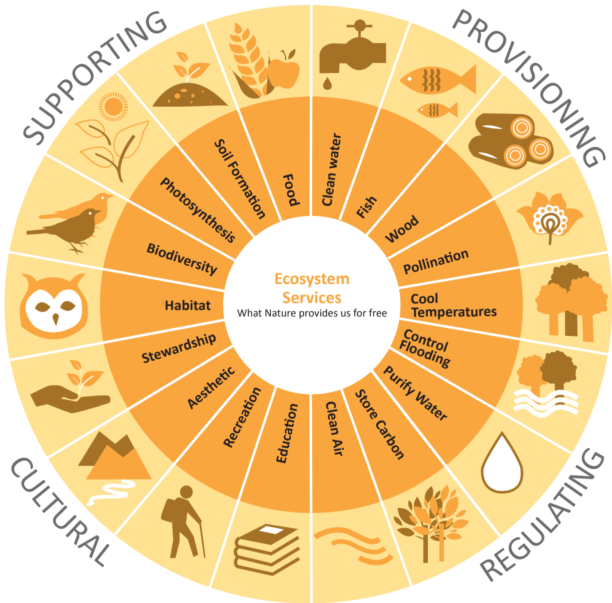
North America is a region with a rich history of effective innovation and implementation with respect to responses that have been responsible for some spectacular successes. The environmental challenges that are now identified as having the highest priority are triggering a new round of innovation. The three response areas identified as having special interest in the region are new forms of governance, harnessing the data revolution, and advancing sustainability at the city level.

In each of these three areas, a brief introduction is provided along with a taxonomy of responses that illustrate iconic and informative examples from the region, and where possible synthesize insights having to do with patterns, trends, and lessons learned.

3.3.1 New forms of governance

North America is demonstrating enthusiasm for adaptive governance approaches and showing promise for supporting transformative breakthroughs that previously seemed elusive. This enthusiasm is driven by experience with the

Figure 3.2.17: Ecosystem services



Source: Adapted from Sukhdev *et al.* 2010

Table 3.2.3: Examples of ecosystem service-related activities in federal agencies, US

Department/agency	Example programmes areas or activities
Department of Agriculture (USDA) Economic Research Service (ERS)	Markets for ecosystem services
Natural Resources Conservation Service (NRCS)	Conservation programmes with landowners on water quantity and quality trading, programmes to quantify environmental effects of conservation practices and programmes
US Forest Service (USFS)	Forest management, project-level planning, public–private partnerships, forest plan revisions
Department of the Interior (DOI) US Fish and Wildlife Service (FWS)	Habitat and species conservation, conservation banking, refuge management
US Geological Survey (USGS)	Valuation of ecosystem services, natural disaster preparation and response, science and decision support
Bureau of Land Management	Habitat protection, renewable energy siting
Bureau of Reclamation	Water projects, cost/benefit analyses
Environmental Protection Agency (EPA) National Center for Environmental Economics	Benefits assessment methods, science-policy analysis
Office of Research and Development	Classification of ecosystem services, data infrastructure, impacts of policy on ecosystem services,
Office of Water	Clean water trading, classification, valuation
Office of Air and Radiation	Clean air offset trading, secondary review of air quality standards
Office of Sustainable Communities	Urban planning, green building, clean water, clean air, environmental justice
Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA)	Coastal/marine conservation, resiliency, natural disaster preparation and response, climate adaptation, fisheries management, natural resource damage assessment, restoration
Bureau of Economic Analysis (BEA)	Economic and environmental information for businesses, environmental accounting
Economics and Statistics Administration	Collaboration with businesses on natural capital valuation
Department of Defense (DoD)	
Service Departments	Installation and resource management
US Army Corps of Engineers (USACE)	Water resources management, wetland mitigation, flood management, ecosystem restoration, project evaluation
Department of Transportation (DOT) Federal Highway Administration	Ecosystem-wide considerations for planning and mitigation
Department of Homeland Security (DHS) Federal Emergency Management Agency	Mitigation of risks of floods and other natural disasters, benefit–cost analysis of disaster mitigation activities
Department of Housing and Urban Development	Urban planning, natural disaster preparation and response

Source: Schaefer *et al.* 2015

application of ideas that go back several decades. Collectively, determination to apply these ideas has contributed to the codification of practical skills and techniques, the emergence of communities of practice, and the forging of links with larger management communities beyond the environmental realm. As a consequence, efforts to apply environmental solutions grounded in adaptive governance are experiencing real success, giving fresh life to the search for mechanisms to achieve sustainability. Elements of the North American approach to adaptive governance have multiple roots, and they have come together in a distinctive manner.

The idea of adaptive management was articulated systematically by Canadian ecologist Buzz Holling and his colleagues as early as 1978 (Holling 1978). Working variously at the University of British Columbia, the Canadian Department of Forestry, and the University of Florida, Holling was instrumental in the emergence of a cadre of scientists and practitioners in North America eager to find practical ways of managing complex, multi-sectoral, multi-scale, environmental and resource problems. Among the defining elements of adaptive management are careful monitoring of system behaviour, inclusion of all relevant actors with a role in either perturbing the system or benefiting from it, an explicit focus on making effective decisions under conditions of uncertainty, attention to management strategies that contribute to learning about system functioning and policy effectiveness, and appreciation of treating iteration as a virtue and policies as experiments.

Another element with strong North American roots is collaborative governance (Vodden 2015). This has to do with processes of engaging multiple stakeholders, typically under government leadership but involving a broad range of actors, with an emphasis on seeking to understand a policy that can then be implemented. Much of the framework for environmental and natural resource legislation in Canada and the US, dating back to the early 1970s, is built around elements of collaborative governance. These elements commonly employ heavy use of assessment and planning. Over time, a large community of practice has emerged to build consensus among disparate groups and interests, execute mandated assessments, and develop plans that are compatible with cooperative interests and regulatory constraints.

Finally, North America is also a nexus for digital development and home to its entrepreneurial counterpart, the modern start-up. The billions of dollars earned by founders of companies such as Amazon, Apple, Ebay, Facebook, Google and Microsoft, led to the emergence of a distinctively new approach to product development engendered by mimicry of the practices that produced those billions. It emphasizes rapid iteration, continuous testing, high tolerance for creating structures and processes if old ones seem sub-optimal, and appreciation for the virtues of disruption. A new generation of professionals has come of age taking the merits of the startup model as a given, and has acquired practical experience its execution. As a result there are growing numbers of people comfortable with this model throughout the region, including many working on environmental issues.

In recent years North America has witnessed what could be called a 'mash-up' of these management currents, triggering waves of examples that demonstrate the vibrancy of policy approaches previously labelled as attractive in theory but extremely difficult to realize.

An approach has emerged that makes the process of starting a company less risky by placing experimentation ahead of elaborate planning, customer feedback over intuition, and iterative design over the costly upfront big design developments; it is known as the "lean" start-up (Blank 2013). Lean is defined as a set of principles and methods used to pinpoint and eliminate inefficiencies in organizational processes. The goal of Lean is to enable organizations to improve the speed and quality of their processes by eliminating wasteful activities such as wait times, overproducing unnecessary reports, defects, confusing instructions and extra process steps. An example of how the lean methodology was successfully applied is Washington State's Samish Bay (Box 3.2.1). The US EPA also provides lean starter kits and an abundance of resources and reference material to help organization lean tools and techniques to develop better, faster and smarter management of environmental issues.

System innovation

System innovation is a concept used to illustrate a horizontal policy approach that mobilizes technology, market mechanisms, regulations and social innovation to solve complex societal problems in an interdependent manner. Moving beyond coherence or policy alignment, a system innovation approach to governance involves non-governmental policy actors and places heavy emphasis on addressing systemic problems in particular sectors or technology areas (OECD 2015).

Moving towards more system innovation-based governance requires sophisticated analytical tools to model systemic problems and an understanding of the casual relations among different elements of a particular system, as well as new models of standards and/or technology platforms, and public-private partnerships (OECD 2015).

Resilience

Resilience, in the simplest terms, can be defined as a system's ability to mitigate and withstand disturbances and bounce back afterwards, while continuing to function. Greater resilience at the regional level means anticipating change and then shaping community responses to promote a more sustainable future, without losing options in the process (Saavedra and Budd 2009). Resilience thinking emerged from the natural sciences with the pioneering work of ecologists C.S. Hollings, Lance Gunderson and others. Natural and social scientists that examine resilience study the lifecycles of complex socio-ecological systems and the factors that make those systems robust or vulnerable (Mazur 2013).

The question of what resilience is and how it is gained or lost has emerged as the focus of significant research in North America and elsewhere. There is an established body of work on the concept within the social sciences and the natural sciences, as well as an emerging field of interdisciplinary studies on the resilience of integrated social–ecological systems (Downes *et al*. 2013).

Consequently, the challenge of steering North America toward greater system innovation and resilience in terms of its regional governance architecture can be highlighted in the following three regional governance approaches. The case studies provide greater details and context in terms of the three regional governance approaches.

Unconventional local-level partnerships

Environmental challenges and climate change present complex problems that affect many different sectors of society in different ways. Similarly, solutions to individual problems may benefit from non-traditional alliances among local government, religious groups, activists and others. Food and Fuel for the Forces (FF4F), for example, is a partnership between farmers, the US military, local government and sustainable food activists.

The military's motivation is preserving farm and forest landscapes while the end result is greenhouse gas emission reductions and increased access to local food. These unconventional partnerships, which have emerged as a response to regional and global pressures, present a plethora of potentially scalable models to be considered by federal governments in North America and globally.

Inclusive governance

The key issue to be discussed and highlighted in the regional inclusive governance approach is how greater inclusive or shared governance can allow a greater voice to politically and economically marginalized communities in dealing with environmental degradation/pollution issues?

Many indigenous and rural communities live in natural landscapes susceptible to degradation. Inclusive governance of waste materials and land stewardship is required for long-

Box 3.3.1: Key features of adaptive governance

Adaptive governance is more than a governance mode: it is a continuous problem-solving process (Munaretto *et al*. 2014). The strength of adaptive governance is that it seeks to establish ways and means that focus on preparing for change and surprises, with strategies that embrace and integrate uncertainty while taking action. At the same time it recognizes there are inherent weaknesses in any plan that will have to be accommodated. A summary of the identifying features of adaptive governance:

- **polycentric institutions:** recognize the multiple, nested and redundant centres of power, and a mix of hierarchies, markets and community self-governance;
- **collaboration:** networks and partnerships, a sharing of power and responsibility, it is self-organizing, and there are mechanisms for conflict resolution;
- **experimentation:** focusing on policy and management as experiments and as learning by doing;
- **flexibility, incrementality, and reversibility:** allows for adjustments when new information becomes available, especially in the presence of high uncertainty;
- **collective deliberation:** collective search for solutions to societal problems;
- **participation:** partnering with scientists, resource users, interested publics and policy makers, as well as the community of practice, bringing a diversity of experience, perspective, preference, interest and values;
- **variety:** seeks development of multiple problem frames and multiple solutions;
- **integration of different kinds of knowledge:** local and traditional knowledge; scientific knowledge; and mechanisms for acquisition, integration, and sharing of knowledge;
- **creating social and corporate memory:** mobilizing and making use of experience with changes in the past;
- **building learning strategies:** improve routines and management practice through acquisition of challenging assumptions, facts, values, and norms; and build trust, appreciation, and consideration;
- **taking actions at bioregional scale:** matching scales of ecosystems and governance;
- **enabling resilience management:** focus on a system's capacity to absorb change, learn from it and self-organize;
- **developing adaptive capacity:** focus on and enable the capacity of society to adapt.

term human health and ecosystem functioning. Canada's First Nation, tribal communities, African-American, Latino, Asian-Pacific Islander, and other marginalized communities should and need to play a new part in shared environmental governance.

Adaptive governance

The key issue to be discussed and highlighted in the regional adaptive governance approach is what new tools, resources and management structures are needed to achieve adaptive governance with foresight and integrated resource planning to account for consequences across environmental themes.

Box 3.3.2: Washington State protects shellfish in Samish Bay by adopting new approaches to governance

Several state and local governments are challenging the norms and adopting new ways of working to tackle their most pressing environmental problems. Lean management is one such continuous improvement methodology that is being used to engage teams of front-line staff to generate rapid responses and solutions. Lean was first applied in the private sector manufacturing industry but has successfully made its transition to other industries. The Lean methodology is known for delivering improvements to speed, quality, and cost effectiveness by eliminating waste from processes.

A successful lean problem-solving application is Washington Skagit County's efforts to restore shellfish in Samish Bay. Working across agencies, levels of government and divisions between private and public interests, they are pioneering cross-jurisdictional alignment and innovative problem solving.

Five years ago, thousands of hectares of shellfish beds in Samish Bay were closed to harvest after dangerous levels of faecal coliform bacterial pollution were detected in the Samish River. Over the next 3 years, a broad coalition of groups working under the banner of the Clean Samish Initiative was able to cut pollution levels significantly. Progress had stalled, however, before state pollution standards were met, and water quality remained unsafe during rainy times of the year.

As part of the Governor's statewide Results Washington initiative, several different state agencies that share responsibility for shellfish restoration began seeking ways to better align their efforts. Using lean tools, they were led to focus on the Samish watershed, and in late 2014 they began a long process of reaching out to local partners and laying the groundwork for bold joint action.

The work culminated in the spring of 2015, when a widely diverse team of front-line stakeholders came together for an intensive workshop centered on finding the root causes of the problems, not just symptoms. Participants represented three local government entities, five different state agencies, shellfish farmers, dairy farmers and the local Samish Indian Nation. Working with the plan the team produced, the Clean Samish Initiative embarked on a 90-day focused effort to identify and reduce sources of faecal coliform bacterial pollution in the Samish River. They used collaborative, lean-based approaches to identify remaining problems and find practical on-the-ground solutions to eliminate pollution sources.

Work is now characterized by improved data analysis, empowered employees with improved morale, reduction in process complexity, enhanced process speed, removal of bureaucratic obstacles and rapid deployment of innovative solutions. Collaboration and innovation only increased after the first 90 days, as "continuous improvement" becomes the team's new way of doing business. Efforts to reopen the shellfish beds, once stalled, are again showing progress and a growing momentum.

Shellfish Coordination Group tackling specific challenges to find effective, on-the-ground solutions
©S. Klein

Critical issues under the adaptive governance theme might include drivers of change, such as demographics and population change; consumption patterns; endangered flora/fauna trafficking; energy use changes; innovation in dealing with tradeoffs, such as between ecosystem protection and economic development, to avoid either/or type choices; as well as a need for foresight; the ability to anticipate diverse possibilities; and an evolving institutional landscape that incorporates new data and that nudges public, private and civil society actors towards greater integrated and collaborative action (Halpern 2015; Thaler and Sunstein 2008).

One emerging adaptive governance issue is the degree of market certainty that the private sector requires in terms of allocating capital investment versus the policy flexibility that adaptive governance measures require in terms of implementation success. British Columbia provincial revenue neutral carbon tax policy represents a good example of striking the balance between market certainty and regulatory flexibility.

3.3.2 New generation of environmental informatics and analytics

Harnessing the data revolution

Big datasets that capture the complex nature of the environment and human behaviour can yield incredible scientific results. New ways of linking datasets to derive meaningful insights and creative techniques for visualizing data are integral in the process of cultivating powerful information for decision-making. North America has demonstrated a long and rich history of acting on environmental challenges through its effective use of data. However, in this big data era of increased connectivity, advanced analytics and improved computing, this region will be required more than ever to demonstrate its data leadership in creating value from analytics.

The rapid transformation of real time information on environmental systems can be a powerful tool for policy development. In the US public-private partnerships have demonstrated how information can be assembled, analyzed and utilized to inform both policy responses and the public. Open data programmes such as open.canada.ca and data.gov are becoming increasingly popular to find data and resources for research. Data collection tools, ranging from satellite imagery and novel sensors to smart meter technologies, are effecting transformation and providing better options to respond to environmental emergencies (data.gov 2015).

Better data drives better decisions

In a time when the effects of climate change are more prevalent than ever, there is an urgent need for decision makers to identify and make use of new methods for tackling issues. The old approaches of monitoring, reporting and using laws, regulations and codes to manage and mitigate environmental problems may no longer hold. In a time of urgency, methods that provide speed, accuracy and flexibility to prevent or minimize environmental risks will have the most influence. The data revolution is well underway and offers unprecedented opportunities for businesses, governments and citizens to harness data for making informed decisions to protect the environment (IEAG 2014).

North America has made significant progress in utilizing data, informatics and analytics by getting data in the hands of decision makers to make system-critical changes; rapid assessment and detection of environmental risks; the management of complex systems and data visualization; and using behavioural economics to drive environmental performance. The iconic examples in the following section illustrate how North America is transforming data into actionable insights.

Timely and impactful decision-making

The new data landscape is permitting the delivery of usable information to decision makers who can make system-critical changes. This pathway is exploiting the power of a strong data infrastructure with near-universal reach, in combination with a vast increase in relevant data and a growing understanding of decision-maker needs. Precision agriculture is one of the most mature examples. Agricultural decision makers at all levels require access to quality information to address complex environmental and economic challenges. There has been exponential growth over the last decades in the amount of data collected on farms in Canada and the US Relevant and real-time data is being captured through yield monitors, smartphone apps, radio frequency identification (RFID) sensors and images from satellites or drones to support better decision-making (Heppner 2015). By taking advantage of data analytics, farmers can apply the right amount of care and resource in the right place at the right time to extract as much value from every seed and minimize the environmental impacts by reducing waste and energy use.

Nitrogen is an effective fertilizer for producing high crop yields, yet it can quickly transform from helpful to harmful as excess is leaked into the water, air and ground. This results in contamination of drinking water, eutrophication of rivers and lakes, emissions of the greenhouse gas – nitrous oxide, and other forms of nitrogen pollution. However, precision agriculture companies are offering software applications that enable farmers to efficiently apply nitrogen to their fields. Farmers can analyze and manage data collected on their fields and derive management zones from geospatial analysis to then accordingly vary the rate of applied fertilizer to those zones (Moran 2013).

The use of precision agriculture could extend well beyond the production of annual crops, it has the potential to revolutionize approaches used to monitor and manage orchards, livestock, and forests. New approaches in precision agriculture to collect real time data from the environment represent an important step towards high quality and sustainable agriculture. This powerful data infrastructure, universally applied, could help efforts to feed a global population of 9.6 billion by 2050 (Lowenberg-DeBoer 2015).

Rapid assessment and detection of environmental risks

Environmental emergencies, such as oil spills, groundwater contamination and the release of toxic waste, require rapid responses that demand the rapid utilization of extensive

Box 3.3.3: Indigenous rights and bituminous sands development

The northeast section of Alberta province is the home to the vast majority of Canada's bituminous sands deposits. This petroleum resource is large in energy content, but the reserves are in low concentrations, shallow in depth, and cover a large geographic area relative to conventional oil reserves. As a result, the resource is extracted using strip mining, and processing it requires large amounts of water, some of which is released into groundwater systems, significantly impacting the environment and climate.

This area of Alberta is home to multiple aboriginal communities including five First Nations and seven Métis Locals. Their relationship with the industrial projects is complex. Jim Boucher, chief of the Fort McKay First Nation located in the region, has said, "we have to be realistic … about what is going on in the oil sands developments here. They are massive, and doing a lot in terms of destruction of the land, we are losing our land. On the other hand there is no more opportunity for our people to be employed or have some benefits except the oil sands." This dichotomy between economic development and environmental/human health is difficult for all scales of governments (Sterritt 2014).

science data and information from several sources to minimize environmental damage.

The new data landscape is permitting much more rapid assessment and detection of environmental risks, driven by falling costs, more powerful and flexible sensors, and an approximation of plug-and-play functionality. The unprecedented pace and magnitude of monitoring and assessment capabilities that were deployed in the aftermath of the 2010 Deepwater Horizon oil spill in the Gulf of Mexico constitute a case in point (Lubchenco *et al*. 2012).

The Deepwater Horizon response relied on big data integration and interoperability efforts to contain the contaminants stop the oil spill and respond to the damage. Both the public and private sector coordinated efforts to integrate engineering data, information and advice within weeks. This accelerated effort mobilized teams of scientists to analyze ocean, weather and plant data and to predict the areas that would be affected in order to rapidly dispatch personnel and equipment for the cleanup. There has been rapid acceleration in the science of deep spill containment and mitigation since responding to this event, although scientists still emphasize the importance of obtaining more baseline data to quickly and clearly understand pre-disaster ecosystems, toxicity levels, human health and the movement of oil. The lessons learned are applicable to future events and to educating government and industry on the best ways of preparing and responding to disasters (Alexander-Bloch 2014; Lubchenco *et al.* 2012).

On the other hand, the limitations with remote leak detection systems cannot be underestimated. Remote sensors may be better at detecting large spills and ruptures, but not necessarily good at detecting smaller spills, according to the data collected by the Pipeline and Hazardous Materials Safety Administration (PHMSA). There is no perfect solution to spotting oil spills suggesting that companies combine the best leak detection technology with experienced operators (O'Connor 2014; Song 2012).

Another example of how technological advances help reduce the time required to react to environmental risks is the detection of harmful algal blooms (HABs). These occur naturally, yet in recent years an intensification of HAB development is appearing across the world. This intensification is caused by such factors as climate change, nutrient-rich agricultural runoff, coastal aquaculture farms

Box 3.3.4: Commission on Environmental Cooperation

Since 1994, Canada and the United States have collaborated with Mexico through a unique intergovernmental organization known as the Commission for Environmental Cooperation (CEC). The CEC was created by the North American Agreement on Environmental Cooperation (NAAEC), which was negotiated and came into force at the same time as the North American Free Trade Agreement (NAFTA) to ensure that continent-wide free trade would be accompanied by effective cooperation and continuous improvement in the environmental protection provided by each country.

The CEC comprises a Council, a Secretariat and a Joint Public Advisory Committee. The Council is the governing body of the Commission and comprises minister-level representatives of each country. The Secretariat provides technical, administrative and operational support to the Council. The Joint Public Advisory Committee (JPAC) - five citizens from each country - advises Council on any matter within the scope of the NAAEC.

The CEC is funded by equal contributions from Environment Canada, the US Environmental Protection Agency, and the Secretaría de Medio Ambiente y Recursos Naturales of Mexico. The CEC's 2015–2020 Strategic Plan is focused on three themes of cooperative activity:

- Climate Change Mitigation and Adaptation
- Green Growth
- Sustainable Communities and Ecosystems

In addition to fostering cooperation between the three national governments, the CEC has some unique authorities and objectives, including:

1. Fostering Public Engagement and Transparency. The CEC attempts to engage the public not only in the business of the CEC itself, but also to provide the public with an opportunity to comment to the three governments on any matter within the scope of the NAAEC Agreement.
2. Investigating Enforcement of Environmental Laws. Articles 14 and 15 of the NAAEC provides citizens an opportunity to petition the Secretariat to investigate a failure of one or more of the three countries to implement and enforce its own environmental laws.
3. Supporting Communities Initiatives. Starting in 2010, the CEC started a grant programme, known as the North American Partnership for Environmental Community Action (NAPECA), to fund efforts by smaller, hands-on organizations that build partnerships at the community level.

and the transport of HABs in ship ballast water. High-resolution satellite imagery, more powerful sensors and improved communication capabilities have contributed significantly to their detection. New instruments to autonomously collect high-frequency HABs and relevant environmental data can improve forecasting capabilities, enable prevention strategies and minimize the requirement for costly survey vessels and human sampling analysis (Seltenrich 2014). Using technology to forecast and track HABs can dramatically reduce their effects on human health, fisheries and economies.

Management of complex systems and data visualisation

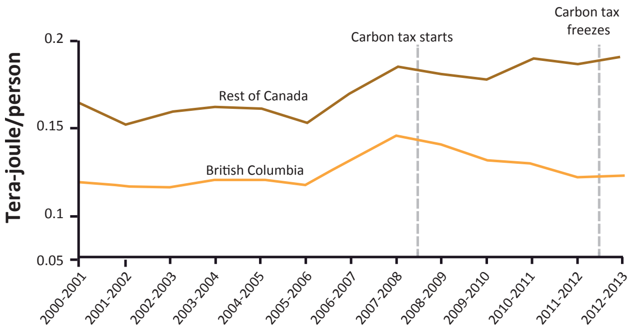
Information is more easily and quickly understood when

Box 3.3.5: British Columbia revenue neutral carbon tax

In 2008, the Canadian province of British Columbia (BC) introduced a revenue neutral carbon tax system, which has resulted in diminishing fossil-fuel use as compared to the rest of the country, without harming the provincial economy (Mankiw 2015). In addition to putting a price on carbon, the BC carbon tax plan is revenue neutral, meaning every dollar generated by the tax is returned to BC residents through reductions in other taxes. The BC Minister of Finance is required by law to annually prepare a three-year plan for recycling carbon tax revenues through other tax reductions (Murray and Rivers 2015; BC Ministry of Finance 2015).

British Columbia applies a number of carbon-related taxes primarily to transportation fuels, natural gas, and fuels used in industrial processes, while it has provided a number of tax rebates including a personal income tax rate cut, a low-income climate action tax credit, a small business rate cut, a general corporate tax rate cut, and industrial and farm property tax cuts. In addition, BC distributed a one-time payment of CAD 100 to all residents in June 2008 (Sumner *et al*. 2009).

Figure 3.3.1: Sales of fuels subject to BC carbon tax



Source: Elgie and McClay (2013)

The introduction of a consumption-based tax on greenhouse gas emissions is likely to be politically difficult, irrespective of its merits in terms of environmental effectiveness and economic efficiency. A key lesson from the BC carbon tax is that popular support and acceptance of a carbon tax may depend on the prevailing fuel prices and economic conditions at the time of the launch. While the introduction of a carbon tax appears to have been politically popular in British Columbia and Canada when it was initially launched, opposition grew as fuel prices increased and economic conditions deteriorated. Whether carbon taxes can garner support in tougher economic times remains to be determined (Duff 2009; Wiebe and Duff 2009).

visual representations are used to communicate complex problems. Environmental challenges require decision makers to visualize, analyze and act on insights from vast amounts of data to understand the past and anticipate the future.

In collaboration with universities, the new Google Earth Engine's platform for scientific analysis and visualization of geospatial datasets is helping federal, state and private partners make more targeted decisions to restore and protect the environment. The University of Montana developed the interactive Sage Grouse Initiative (SGI) mapping tool that combines layers of vital pieces of information to illustrate a more cohesive picture of connected landscapes. For example, it is possible to visualize the areas that are likely to rebound after wildfire and resist invasion of cheatgrass. Since Google Earth Engine is created for the web, it is possible to implement science into planning and decision-making immediately (Heater 2016).

New technology permits more effective visualization, understanding and management of complex systems. Such capabilities are driven by the combination of sensor webs, interoperability standards, open data architecture, open modelling environments, and the emergence of powerful web-based data tools. Such capabilities lie behind path breaking innovation in the assessment of fire risk in North America, and in novel approaches to monitoring watershed systems through networked sensors coupled to real-time distributed hydrologic models.

The Open Water Data Initiative is one such example that has adopted an integrated approach to understanding problems by connecting a comprehensive set of water data into a national water data framework with the capability of leveraging existing infrastructure, tools and systems. This type of integrative framework enables faster research, accurate forecasts, more modelling and a better understanding of the interactions between water, land and climate in a period of major hydrological change. Scientists, meteorologists and emergency response teams can address issues and develop solutions more effectively by exploiting the geospatial platform (Blodgett *et al*. 2015; OWDI 2015).

Disruptive technologies are now enabling better visualization and prediction of wildfire spread in real-time by using new high-resolution satellite instruments, sensors, interactive maps and historical data. Predictive data analytics, data modelling tools and fire simulators are critical in guiding fire responders on how to make proactive decisions (Natural Resources Canada 2015c).

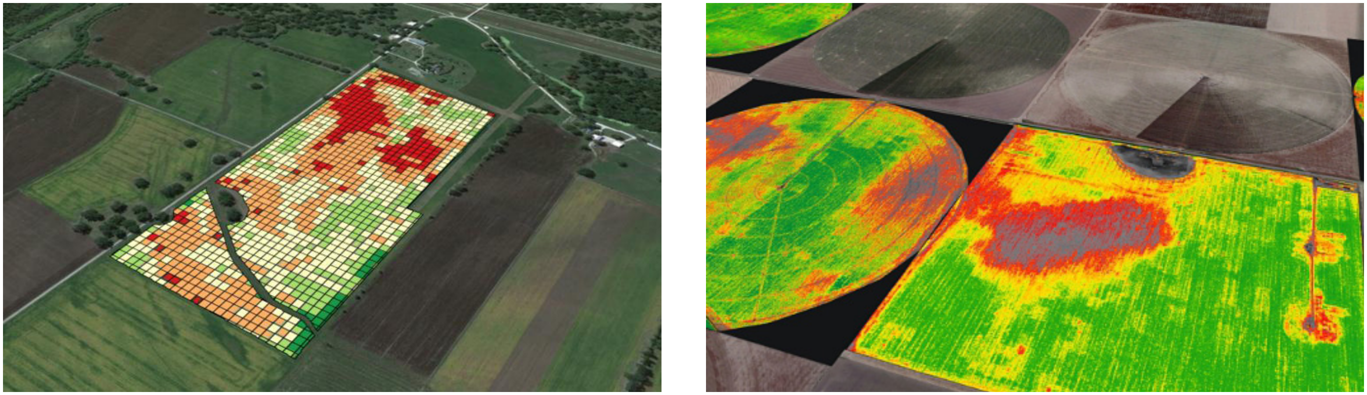
Where there are data gaps, citizen scientists are playing a pivotal role in filling gaps for which governments are unable to collect relevant data. Citizen science, also known as community science, is a growing movement that enlists the public in scientific discovery, monitoring and experimentation across a wide range of disciplines and research (Theobald *et al*. 2015). For example, the Community Collaborative Rain, Hail and Snow Network (CoCoRHaS) uses crowd sourcing of data and organizes nearly 20 000 volunteers to collect daily precipitation measurements across Canada and the US (Doesken and Reges 2010).

Behavioural economics to drive environmental performance

Finally, at the same time as the technology around data and information systems has taken off, the field of behavioural economics has given rise to a new approach to policy making that is highly suited to the effective use of information.

There are several examples of how effective use of behavioural economics resulted in significant changes that positively impacted the environment. The Social and Behavioural Sciences Team (SBST) in the White House discovered that a small prompt had the power to save money and resources. An automated pop-up window with a simple message nudging executive-branch employees to switch to double-sided printing saved 300 million pieces of paper a year (Holdren 2015). The SBST aims to reflect the best understanding of human behavior, such as how people engage, participate and respond to policies and programmes, into improvements in Federal policies and programmes.

Figure 3.3.2: Drone-enabled agricultural intelligence



Technology companies are providing drone-enabled agricultural intelligence where users can record aerial field-level crop data to identify yield-limiting problems. There is tremendous potential for agricultural producers to use technology to increase crop yields with fast, reliable data to support decisions in the field.
Source: ©2016, Agribotix LLC.

The field of behavioural economics is attracting attention from environmental economists to understand the motives and driving forces behind human behaviour in decision-making. Consumer behaviour is complex and challenging to predict reliably – despite research, knowledge and awareness geared towards choices beneficial to the environment, many consumers continue to rely on non-renewable resources, fail to recycle, engage in wasteful acts, under-utilize public transport and engage in actions that harm and neglect the environment. Behavioural economics is an active area of research that uses effective nudges to encourage behaviour change (Frederiks *et al*. 2015).

Behavioural economics is also applied to demand-side management, encouraging consumers to change the way they use electricity. The US Energy Information Administration (EIA) is interested in how behavioural economics can influence energy demand. There is a challenge in meeting high demand, therefore demand-side management's goal is to motivate customers to use less electricity during peak hours or shift their demand to off-peak periods, at night and weekends. Strategies such as rewards, education or financial incentives are used to encourage behavioural change. An example of the commercial application of demand-side management is the company Opower. Behavioural economics has the potential to drive environmental protection and generate solid proposals for environmental policy design (EIA 2014).

Big data, big responsibility

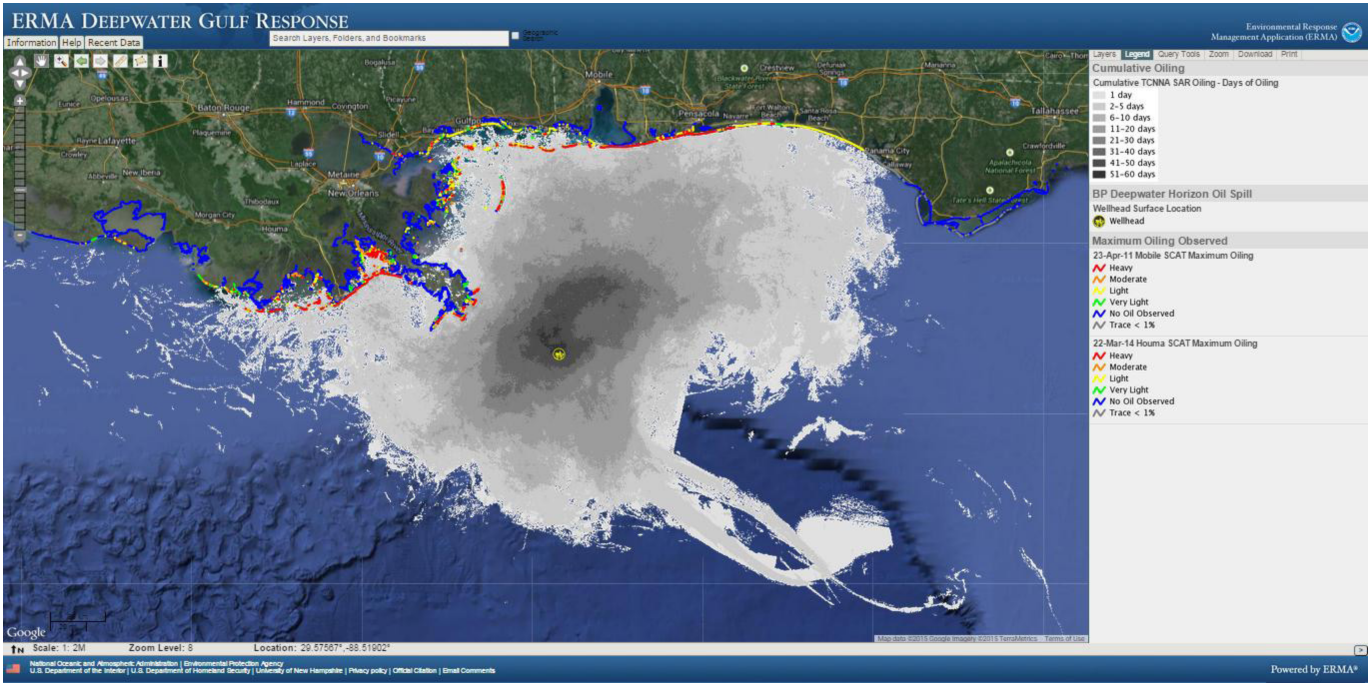
North America is data rich and could play a key role in helping data-poor countries solve development challenges and achieve the Sustainable Development Goals (SDGs). The challenge is to mobilize resources and close the gaps in access and data use between developed and developing countries, between the information-rich and information-poor, and between the public and private sectors. **Figure 3.3.6** shows how advanced economies are ahead on nearly every indicator for access, usage and impact of digital technologies. In the meantime, tools to leapfrog existing technologies exist, such as cellphones to gather data, provide behavioral information and disseminate information. Farmers in developing countries are in a position to obtain weather forecasts through their phones and also to connect with other farmers. Overall, distributing technology and innovation from developed countries to developing countries for the common good will enable data to play a purposeful role in the realization of the SDGs (IEAG 2014).

3.3.3 Advancing sustainability at the city level

Recent experience in North America suggests that cities are well-suited to manage problems because they create social change, are collectively well matched to what is needed, and are accessible. The degree to which cities possess the ability to create change is in many instances more promising than that of national governments. Cities have the potential to directly regulate land use, and can adjust tax policies with greater freedom. Though exceptions are notable, cities are typically less hamstrung by ideological factionalism, making it easier to focus on interest-based and evidence-based problem solving.

North American cities in recent years have seized opportunities to make dramatic improvements on a range of environmental issues. In contrast to the year 2000, when

Figure 3.3.3: ERMA web-based mapping application: Deepwater Gulf Response



The Environmental Response Management Application (ERMA) team created a new, regional version of their web-based mapping application, incorporating data specific to the Gulf of Mexico and the rapidly escalating Deepwater Horizon oil spill within a few days into the disaster. Here, ERMA shows the location of the wellhead, the days of cumulative oiling on the ocean surface, and the level of oiling observed on shorelines.
Source: NOAA 2014

European cities were widely considered to have made more advances in sustainability than North American ones, a 2011 comparison found dramatic success stories in Canada and the US, narrowing if not closing the gap (EIU 2011; Beatley 2012).

In North America there is growing recognition of the fact that many of the most promising advances in environmental response arise from the creative melding of multiple elements of the policy toolkit, and often in ways that have never been used before. As a result, there is heightened interest in sustained efforts to enhance enabling conditions of such policy innovation. For example, investment in methodological research and analytical tools that facilitate natural capital accounting implementation, contributes to the increased resource stewardship, transparency, accountability, and understanding of risk. Likewise, investment in data and information infrastructure, including the legal and policy frameworks that support such infrastructure, facilitates far-reaching activities that seek to leverage the power of data and information for environmental goals.

Cities are increasingly the centres of dynamic innovation regarding environmental policy in North America. Recent years have seen a heightened attention on urban environmental policy, characterized increasingly by bold efforts to tackle some of the most challenging elements of the sustainability agenda.

Cities are proving themselves capable of approaching difficult issues in pragmatic and constructive ways, in contrast to the factionalism and polarization that has come to characterize much of the national-scale environmental policy landscape. This contrast between national polarization and urban pragmatism is consistent with a general finding that urban politics are comparatively nonpartisan (Ferreira and Gyourko 2009). Most US cities conduct elections on a nonpartisan basis; of the 30 largest cities, only 8 conduct partisan-based elections (NLC 2015).

In addition to having a favorable political climate, in general, cities also often have a favorable set of policy instruments that are well-suited to the challenging cluster of sustainability problems because of the difficulties and complexities that bedevil the search for solutions. To a greater extent than national governments, they can coordinate action and investment across multiple sectors; can sustain long-term searches for fair trade-offs and effective policy designs; and can engage in detailed place-based planning.

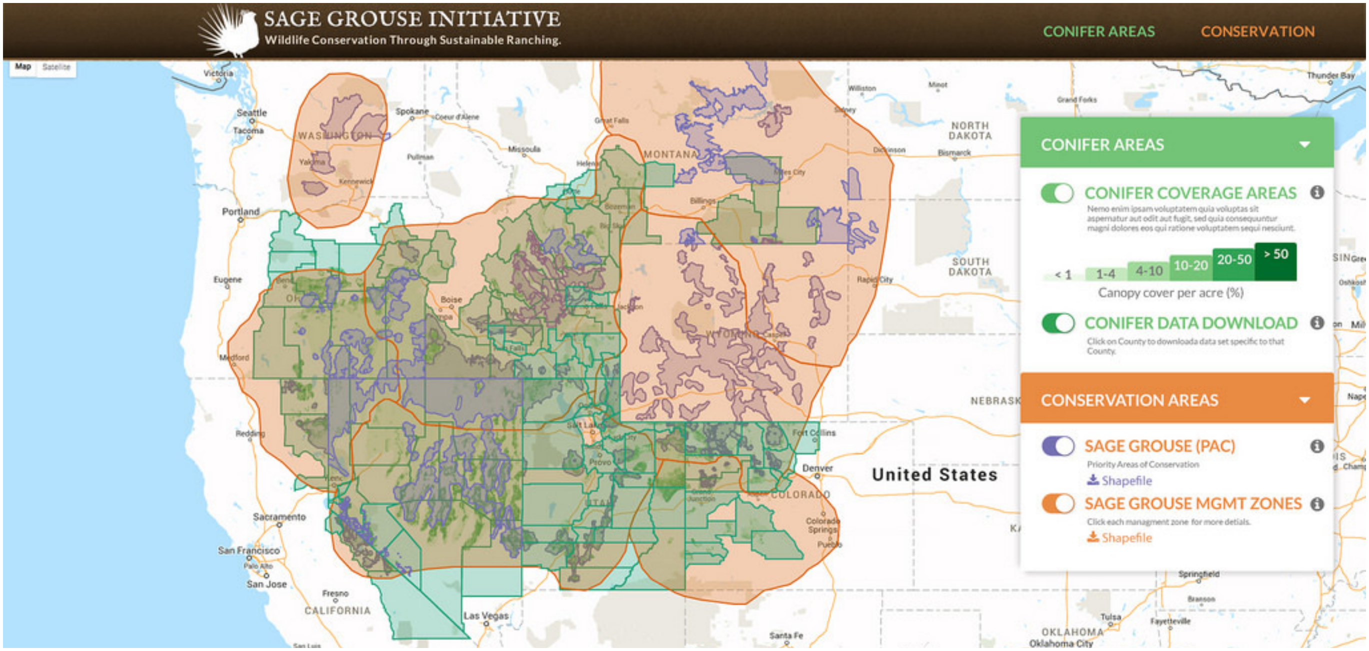
Innovative approaches to urban infrastructure challenges

Cities serve as experimental locations for the practical expression of sustainability-centred policies and progressive adaptation regimes (Whitehead 2013; Betsill 2001). Threats relating to urban ecological security have prompted cities to respond in innovative ways to mitigate future ecological constraints and protect their social and economic interests. This represents a shift away from conventional wisdom that perceives resource constraints as limiting factors in growth, and instead focuses on a systematic framework recognizing the need to appropriately prepare for an anticipated future (Hodson and Marvin 2009). Cities are distinguished by their abilities and capacities to implement desired change.

Modern cities are often challenged with the problem of surface water runoff due to the impermeable surfaces covering vast urban spaces (Spirn 1984). For example, the City of Philadelphia, Pennsylvania, as little as one-tenth of an inch of rain can cause the city's aging combined sewer system to discharge significant volumes of untreated sewage and rainfall into waterways (Bauers 2009). To respond to this urban infrastructure challenge, Philadelphia developed the first and only EPA-approved green infrastructure plan that aims to convert 34 per cent of existing impermeable surfaces within the combined sewer drainage areas to "Greened Acres" by 2036, and saves USD 5.6 billion in the process by avoiding the traditional grey infrastructure route.

Philadelphia's "Green City, Clean Waters" programme is a green stormwater infrastructure project with a "triple bottom line effect," providing for various environmental, social, and economic benefits. It is estimated that that this plan will offset 1.5 billion pounds of carbon annually, equivalent to removing 3 400 cars from roads, in addition to

Figure 3.3.4: Sage Grouse Initiative (SGI) interactive mapping tool



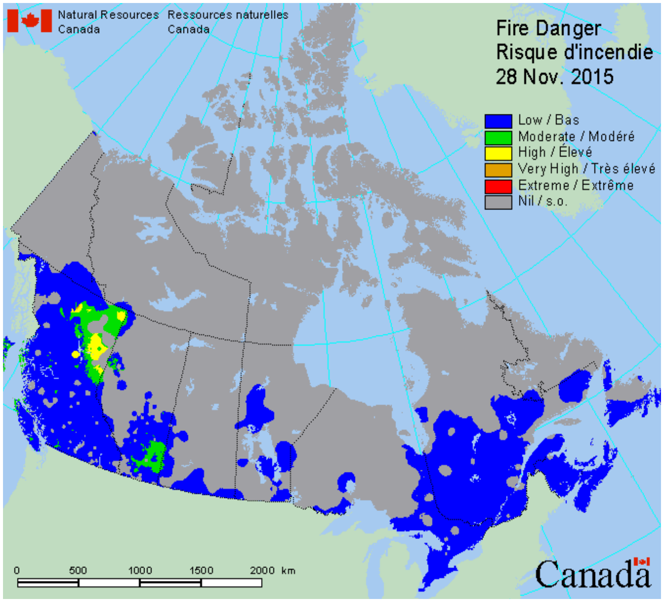
The SGI Interactive Web Application enables conservationists to help plan the best conservation efforts to restore sage grouse habitat.

Box 3.3.6: Climate data initiative launches with strong public and private sector commitments

In 2014, the White House launched the Climate Data Initiative, which is an ambitious new idea geared towards bringing together extensive open government data and design competitions to develop data-driven planning and resilience tools for local communities.

Commitments from private and philanthropic sectors will aid in the effort to provide communities across America with the information and tools they need to plan for current and future climate impacts. The Climate Data Initiative is expanding on the existing success of the Obama Administration's effort to unleash the power of open government data. The government released a significant amount of hard-to-get valuable data in sectors such as energy, health, education, global development and public safety since launching data.gov in 2009, the central website for government data resources. Researchers, innovators and entrepreneurs are all utilizing this open data to create services, businesses, tools and applications (White House 2014).

Figure 3.3.5: Canadian Wildland Fire Information System: Head fire intensity in Canada, 2015



Source: Natural Resources Canada 2015c

USD 8.5 million in water quality and habitat improvements over 40 years. In the process, this project will introduce 250 local green jobs and other range of jobs, including special opportunities for convicts re-entering society. Approximately 20 deaths due to asthma will be avoided, 250 fewer work and school days will be missed, and deaths due to urban heat will be cut by 140 over 20 years. These green infrastructure additions are projected to increase property values by USD 390 million over 45 years, while simultaneously increasing property taxes the city will acquire (PWD 2011).

Green infrastructures have emerged to become an important planning strategy to improve urban space systems in the last few decades (Tzoulas *et al*. 2007). In a broad sense, green infrastructures are conceptualized as a complex system that spans geographical contexts and with multiple components (e.g. trees, soil, and constructed infrastructure) organized into a landscape, which performs multiple functions and offer variegated benefits (Rouse and Bunster-Ossa 2013). The green infrastructure additions in this project will span many spaces, composing: 38 per cent green streets; 2 per cent green schools; 3 per cent green public facilities; 5 per cent green parking; 10 per cent green open space; 16 per cent green industry, business, commerce, and institutions; 6% green alleys, driveways, and walkways; and 20 per cent green homes. Since its adoption in June 2011, the Philadelphia Watershed Department and private developers have introduced more than 1 100 "green stormwater tools" to the city (PWD 2011).

While many US cities have experimented with green infrastructures in managing combined sewer overflows, Philadelphia is the first city to have green infrastructures as its foundation. To complement these efforts, regulations introduced by the Philadelphia Watershed Department (PWD) in 2006 require developers to manage the first inch of rainfall on all new development projects and redevelopment projects of certain sizes (Hansen 2007).

Philadelphia's plan is not the result of a sudden shift in political or public attitudes and rapport but rather the result of a decade-long coordination across agencies, which resulted in a merging of three departments to become the PWD, as well as partnerships with non-profit organizations to change public attitudes (Madden 2010).

Innovative collaboration techniques and coordination mechanisms are facilitated by motivations to reduce vulnerabilities (Hughes 2015). Governance is considered a factor that influences the effectiveness of climate adaptation (Mazmanian *et al*. 2013). While governance has traditionally been understood as response frameworks by government to address public concerns, this enclave has widened to encompass other actors important in the management of public concerns (Bell and Hindmoor 2009). This is evidenced in Philadelphia's successful coordination of its green stormwater infrastructure programme, as well as Newark, New Jersey's recent Riverfront Park programme, which was the recipient of the EPA 2015 Smart Growth Achievement Award.

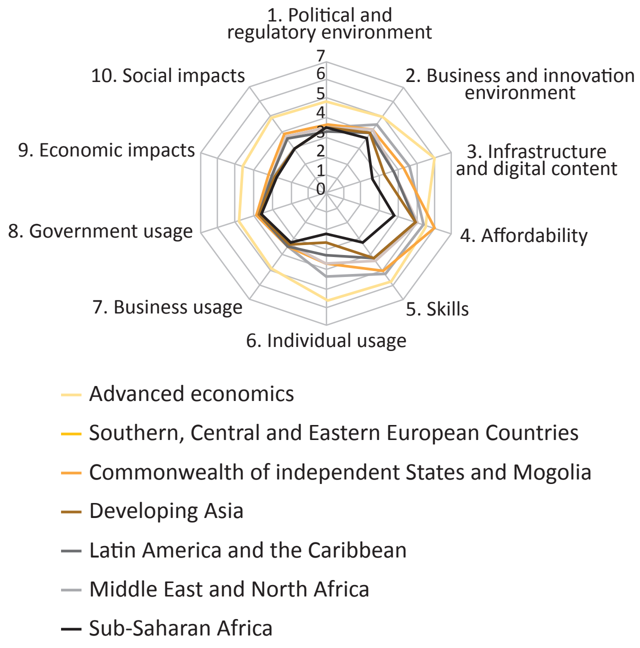
New mechanisms for collaboration formed when the New Jersey Department of Environmental Protection and the US Army Corps of Engineers jointly reviewed the waterfront development permit for the Riverfront Park project, to expedite what is typically an extensive review process. Situated on the site of a former metal smelting plant and located in Newark's Ironbound Neighborhood, an ethnically diverse and blue-collar residential area, the Passaic riverfront was inaccessible by the public for many decades due to commercial use and contamination. Through an innovative participatory process that engaged more than 6 000 residents through boat tours along the riverfront and educational outreach programmes for youth, the city exceeded its "2 cent from 2 per cent" campaign to have citizens influence the design of the park project and ensure that the new development reflects community values and interests, while preserving its identity (US EPA 2015m).

Beyond functioning as a public space, this park simultaneously acts as a passive stormwater handling site by being an undeveloped park area while also featuring small stormwater catchment drains that run parallel to the boardwalk. Furthermore, innovative financing manoeuvring allowed the City of Newark to use green park spaces as environmental caps. "Capping" generally refers to paving of a site or constructing a structure, but using environmental caps allowed the City to stretch their budget and use remediation dollars towards the development of the Riverfront Park (City of Newark 2012). The presence of this park can encourage the restoration of lost habitats and wildlife to help reduce flooding and stormwater pollution (US EPA 2015n).

Meanwhile, in the Halifax Regional Municipality (HRM) of Nova Scotia, traffic congestion generated conversations in 2011 regarding the need for a "congestion charge" for roads leading into the city (CBC 2013). The problem of congestion is not new to Halifax, given that a 2001 Discussion Paper prepared by the Halifax Chamber of Commerce (HCC) stated that the municipality's transportation networks were in "critical condition" and that this negatively affected four different centre of commerce: Burnside Industrial Park, Bayers Lake Park, downtown core of Halifax, and retail communities along the Bedford Highway (HCC 2001). To address this transportation challenge, the HRM introduced an Active Transportation Plan in 2006, which it then updated in 2014. It also developed the Halifax Transportation Demand Management Function Plan in 2010, which was later incorporated into the 2014 Regional Plan, merging together transportation demand management and active transportation.

Transportation demand management works in tandem with active transportation by facilitating programmes, policies, and initiatives that augment transportation efficiency and accomplish specified objectives that often includes prioritizing "active transportation" (e.g., all forms of human-powered transportation modes, most notably walking and bicycling) options (Seber 2014). The Halifax Regional Municipality Regional Plan listed the goals of

Figure 3.3.6: Inequalities in access to and use of ICT Services



Source: IEAG 2014

Box 3.3.7: LEO Network – using technology to share environmental observations

The world is changing rapidly, and local observers can detect subtle changes in weather, landscapes and seascapes, and in plant and animal communities. The Alaska Native Tribal Health Consortium (ANTHC) developed the Local Environmental Observer (LEO) Network in 2009, recognizing the value of local and traditional knowledge and the need for a tool to document and share environmental observations. The purpose was to increase awareness about vulnerabilities and impacts from climate change, and to connect those with traditional and local ecological knowledge with policymakers and technical experts. LEO uses web-accessible Google Maps to display observations of unusual or unique environmental events, which are then shared with LEO members. The maps contain event descriptions, photos, expert consultations and links to information resources. LEO has grown to include hundreds of participants and is helping to increase understanding about the emerging effects of climate change.

LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment, and weather events. These observations are based on local and traditional knowledge, and the experience of network members. With LEO, you can connect with others in your community to help detect, monitor, and find answers about environmental events. You can also engage with topic experts in many different organizations and become part of a broader observer community.

Arctic communities were among the first to experience significant impacts from climate change. In 2009, the Alaska Native Tribal Health Consortium (ANTHC) established the Center for Climate and Health to help describe connections between climate change, environmental impacts, and health effects. In 2012, LEO Network was launched as a tool to help the tribal health system and local observers to share information about climate and other drivers of environmental change.

In 2015, ANTHC and Resource Data Inc. (RDI) developed LEO App to increase access and improve data management and analytical features of the network. In the same year, LEO Network was selected as a model programme under the United States Chairmanship of the Arctic Council, to help raise awareness and improve communication about climate change in the circumpolar region. Today LEO Network is continuing to evolve and to build new partnerships with local observers - across the Arctic and around the world.

"supporting healthy lifestyles, enhancing mobility and public safety, improving environmental quality and reducing auto dependency" as motivators for active transportation (HRM 2014). By engaging citizens online and in-person, Halifax was able to prioritize what active transportation options were most needed, which they discovered to be on-road bicycle networks and improved bikeways.

In North America, cities are already beginning to implement projects relating to the Sustainable Development Goals (SDGs) and addressing climate change at the city level in diverse and entrepreneurial ways that are triggering tangible progress. The climate issue has earned a prime spot on the policy agenda of virtually every major city in the region, and

Box 3.3.8: Cities turn a corner in responding to climate change

Over the past two decades, cities have become critical sites for climate change policy. Shortly after the 1988 Toronto Conference On the Changing Atmosphere helped place climate change on the national and international policy agendas, Toronto became the first city to establish a municipal emissions reduction target (Bulkeley and Betsill 2003; Lambright *et al*. 1996). Since then, hundreds of cities around the world have engaged with climate governance, and as these developments are considered over time, two phases in how cities are engaging with climate change can be clearly seen.

The first is called 'municipal voluntarism' (Bulkeley and Betsill 2013). This primarily involved small and medium-sized cities in North America and Europe who were brought into the world of climate policy by policy entrepreneurs who saw opportunities to use the climate issue for political recognition and focused on leading by example. Transnational municipal networks also developed, such as the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection programme. Through the 1990s, these networks engaged cities in Asia, Australia and Latin America. Activities were largely instances of self-governance in that activities were directed at reducing emissions within municipal operations, rather than within the broader community (Alber and Kern 2008). Institutional capacity issues and the political economy of urban areas often created barriers for municipal governments leading to a gap between the rhetoric and reality of climate action (Krause 2011).

Today a second phase of 'strategic urbanism' has developed, characterized by a broader range of actors engaging in climate governance activities, and a broader view of the urban context for climate change and experimentation with many different types of projects focused on low-carbon development (Bulkeley and Betsill 2013). Here climate change has become integral to the pursuit of wider urban agendas, such as economic development, rather than a separate policy sphere (Hodson and Marvin 2010; While *et al*. 2010). This also reflects a more political engagement with the climate issue than in the previous phase, through initiatives such as the US Mayors Climate Protection Agreement (Gore and Robinson 2009). The C40 Cities network has engaged many of the world's global cities – New York City has played a leadership role – that partner with some of the world's largest multinational firms and financial institutions to develop new technologies and forms of urban climate governance that include low-carbon and resilient infrastructure (Bulkeley 2013).

in many places city leaders have been effective at reducing emissions and enhancing adaptation. This development is the emergence of strategic urbanism, and will only be further catalysed with the implementation of the 2030 Sustainable Development Agenda.

3.4 Conclusion

The aforementioned discussion of North American air, land, biota, water and waste environmental policy response and options indicate that it is a challenging time for policy makers in North America. In terms of the substantial challenges of climate change adaption and energy, Canada and the US have a significant role to play in curbing emissions. Both countries participated in the Paris negotiations aimed at achieving a legally binding and universal agreement on climate and the objective of keeping global warming below 2°C. Implementation will be crucial for these ambitious targets to come to fruition.

There is no doubt that environmental decision-making is a complex process, especially when a systems thinking approach is required to influence responses. However, in this region, officials and experts have expressed strong agreement on the importance of strengthening conventional approaches to environmental policy making with innovations aimed at transforming system behaviour. The efforts to encourage sustainable consumption and production and the implementation of natural capital accounting enable practitioners to consider all of the ecosystem goods and services required for human and ecological wellbeing.

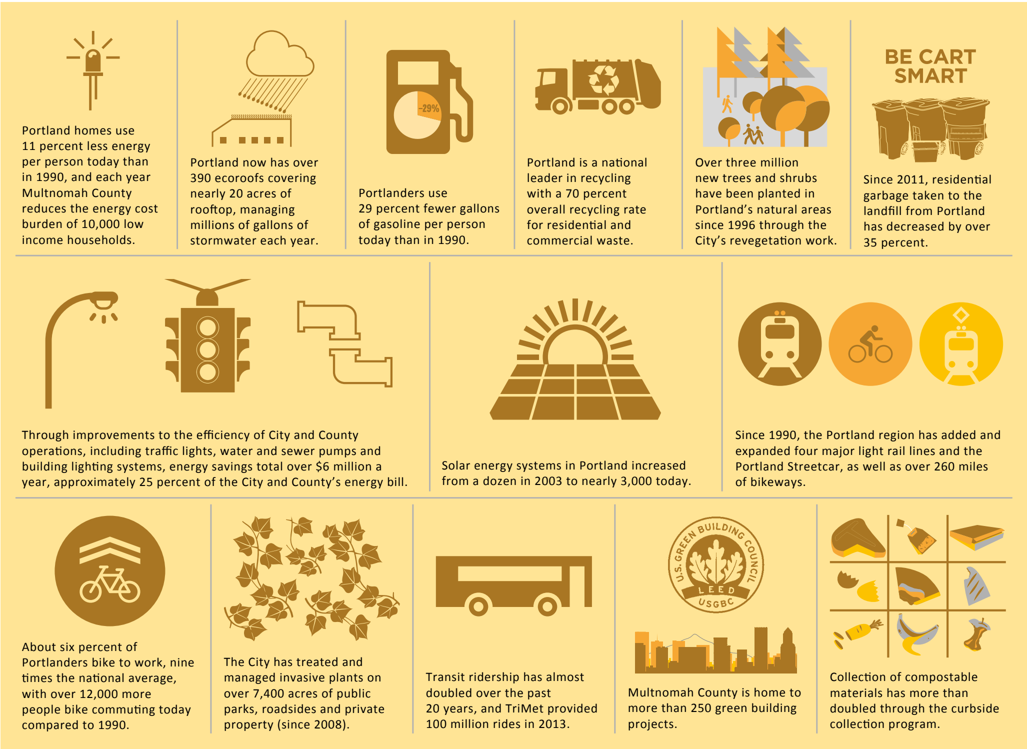
The solutions we have been treating as cross-cutting themes, which include agile and innovative forms of governance, enhanced data analysis and visualization capability, and experimentation with socio-ecologic solutions in cities indicate the powerful potential that exists to drive tremendous transformation in how this region faces the environmental challenges on the horizon.

Box 3.3.9: Portland's leadership in reducing carbon emissions

Since 1990, total local carbon emissions have declined by 14 per cent while 75 000 jobs have been added to the economy and the population grew by 31 per cent – progress towards a goal of reducing local carbon emissions by 80 per cent below 1990 levels by 2050, with an interim goal of a 40 per cent reduction by 2030.

City of Portland and Multnomah County planning strategies note that the intertwined challenges of climate change, social inequity, economic volatility, degraded natural systems and the rising cost of living demand an integrated response that goes far beyond cutting carbon. An 80 per cent reduction of local carbon emissions by 2050 requires reimagining the community and transitioning away from fossil fuels while strengthening the local economy and shifting fundamental patterns of urban development, transportation, buildings, and consumption.

Figure 3.3.7: Portland and Multnomah County Climate Action Plan accomplishments



Source: City of Portland Bureau of Planning and Sustainability 2015

Box 3.3.10: City Governments Cooperating for Sustainability

The International Council for Local Environmental Initiatives (ICLEI) was founded in 1990 by 200 local governments from 43 countries who convened for the first World Congress of Local Governments for a Sustainable Future at the UN headquarters in New York City. Operations started in 1991 at a World Secretariat in Toronto, Canada and a European Secretariat in Freiburg, Germany.

ICLEI's first global programmes were Local Agenda 21s, programmes promoting participatory governance and local sustainable development planning, and Cities for Climate Protection™ (CCP), the world's first and largest programme supporting cities in climate action planning using a five milestone process including greenhouse gas emissions inventories to systematically reduce emissions. The Council's programmes and campaigns looked beyond mere environmental aspects and embraced wider sustainability issues. The ICLEI Council acknowledged this and formally broadened the mandate of the association in 2003, renaming the association ICLEI–Local Governments for Sustainability.

By 2050, it is projected that two-thirds of all humans will live in cities. Evidence of the seriousness of the new urban initiative in advancing sustainability is seen in the emergence in 2008 of the Urban Sustainability Directors Network (USDN), which began as an informal exchange of information among a handful of city sustainability directors, but grew. It held its first formal meeting in 2009, by which time it had 70 members and today 136 municipal sustainability directors from Canada and the US are members. The network emphasizes peer-to-peer learning and the diffusion of innovation. It has published a guide to greening cities and distributes a regular report that helps members keep abreast of new ideas, innovation and practical lessons (USDN 2015).

See links for Chapter 3

See references for Chapter 3

CHAPTER 4

Outlooks: Megatrends, emerging issues, technologies, and sustainable development

4.1 Setting the scene

The nature and scale of the current challenges and opportunities facing North America will require the region to build on its history of innovation, environmental regulation, and integrated data systems, while leveraging the region's comparative prosperity, abundant natural resources, and educated population. The long history of peaceful and constructive cooperation between Canada and the US also provides an opportunity for shared efforts toward common environmental goals and their implementation.

Although the region has made good progress with respect to many environmental issues including water quality, air quality, and waste management, there remain serious challenges that have in some instances made it difficult for the regulatory structure of the region to keep up. Activities in North America not only affect the region's environment and

Key messages

The outlook for North America is a mixture of emerging possibilities and problems: While environmental conditions with regard to air, land, water and biota are broadly positive, there are areas where trends are negative and conditions warrant concern. Some environmental problems are not yet responding to the policies, and in some instances are getting steadily worse. These cases are generally characterised by complex, often unanticipated interactions across systems.

- North American responses to these circumstances reflect the diversity, ingenuity and innovation of the region. Policymakers in North America are combining the best of the traditional environmental policy toolkit with innovative approaches, and there is evidence that this blending is bearing fruit.
- There is already a growing dissemination of innovation using mobile and other applications to improve access to information, adjust production and consumption systems, improve efficiency, reduce waste and environmental impacts, and to inform governance processes.
- The North American population will continue to grow, and although the overall population is aging, the demographic structure is relatively stable and mature. Urbanization of the population continues with its implications for consumption patterns, utilization of natural resources, environmental impacts and demands for improved urban infrastructure.
- Green energy is on the rise in North America, and is becoming economically competitive, even without the benefit of specific environmental interventions.
- Innovations in governance to promote sustainability in North American are being developed across "smart" cities, sustainable agricultural systems and environmental management in using big data, citizen science and integrated and adaptive decision-making systems to respond swiftly and flexibly in the context of a rapidly changing region.

◄ Credit: Shutterstock/GiSpate

communities, but also play a role in global environmental degradation. The connectivity between North American consumers and global trade offers the region an opportunity to contribute to a transformation toward the type of consumption and production and resource management that a sustainable common future requires. The role is a shared one, among governments, educational institutions, civil society organisations, business and industry, and consumers.

While there has been some encouraging progress toward sustainability in North America, the scale of what still needs to be done will require mobilisation of all elements of North American society. Some of these challenges include adapting to consequences of climate change, mitigation of greenhouse gas (GHG) emissions, and consuming sustainably. A sustainable future requires foresight and effective governance approaches to address future challenges and build on opportunities. This requires the discernment of trends, economic, social and technological changes, identification of elements of inter-related systems, and the leveraging of innovative change.

Section 4.1 describes current trends and projections for the economy, population and demography, the environment, and the energy sector, to identify potential future challenges, risks and opportunities. In the context of these projected trends, we look at opportunities and challenges to move toward a sustainable future from emerging and potentially disruptive new technologies (4.2) and from already expanding, but still relatively new technologies in critical cross-cutting areas such as cities, agriculture, water, energy and transportation (4.3). Section 4.4 looks at governance systems and tools critical in advancing sustainable development in North America such as a role in promoting and achieving Sustainable Development Goals and policy processes, adaptive governance, improvements in data use and mobile technology and citizens' science.

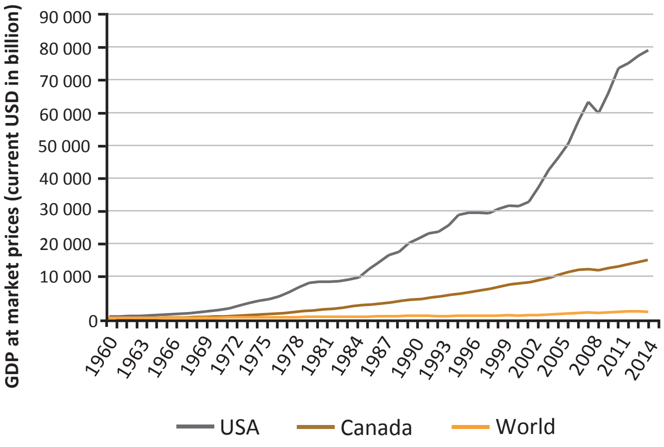
4.1.1 Economic trends

North America is a wealthy region of the world and a major trade partner for many countries. In terms of overall size, in 2014 the GDP of the US was almost USD 17.5 Trillion, the largest in the world (Canada was about USD 1.8). China is the second largest economy of the world, with a GDP of about USD 10.4 Trillion (World Bank 2016). Predicting future GDP growth, recessions, or recoveries is fraught with uncertainty, but North America seems likely to remain the world's largest economy for quite some time. The following figure shows North America's GDP relative to the world. The GDP of the region is high compared to the global level, however, by the late 1980s as formerly communist countries were beginning to modify their economies and emerging economies achieved considerable GDP growth, North America's relative share of worldwide GDP began to decline.

At the same time, GDP per capita has been steadily increasing in the region since the 1960s. GDP per capita is fairly similar between the two countries; it ranges between USD 50 000 to USD 55 000. This level is approximately 5 times higher than the same indicator at the global level (**Figure 4.1.1**).

Looking into the future for economic change is challenging, and most of the forecasts only project a few years ahead. Based on often qualitative studies using experts' views, it is anticipated that the global economic power shift away from the established advanced economies in North America, as well as countries in Western Europe and Japan will continue over the next 30 years (World Bank 2016). China has already overtaken the US in 2014 to become the largest economy in purchasing power parity (PPP2) terms. Increasing China's role in other economic indicators such as exchange rate (MER) will likely continue over the next decades. However, North America and Europe will remain very significant players in the global economy for decades to come. This includes keeping the GDP per capita relatively high compared to average income in the leading emerging economies. It is also projected that both the US and Canada will be still seen as providing lower risk investment opportunities due to their political and institutional stability and rule of law.

Figure 4.1.1: North America's GDP relative to the world



Source: World Bank 2016

The ability of the two countries to be leaders in global innovation because of their long-term institutional and political stability has been recognised for decades. For example, Silicon Valley is the world's leading centre of technology innovation. Similarly, Canada has its own centres, particularly Waterloo (De Vynck 2015). Technology innovation that drives so many of the world's economies and other changes across societies will continue to be one of the major drivers of change in North America and will continue to disseminate around the world.

Even with this overall wealth in North America, it is not equally distributed. Disparities in income and opportunity exist. Shifting patterns of income distribution in North America reflect a trend, similar to countries in other regions, toward increased disparity between the very rich and the very poor. This disparity often also exists inter-generationally, between the young and the old (Beine *et al*. 2009). Thus even the social goals and targets of the recently adopted global Sustainable Development Goals (SDGs) are of relevance to various regions in North America and to significant segments of the North American population.

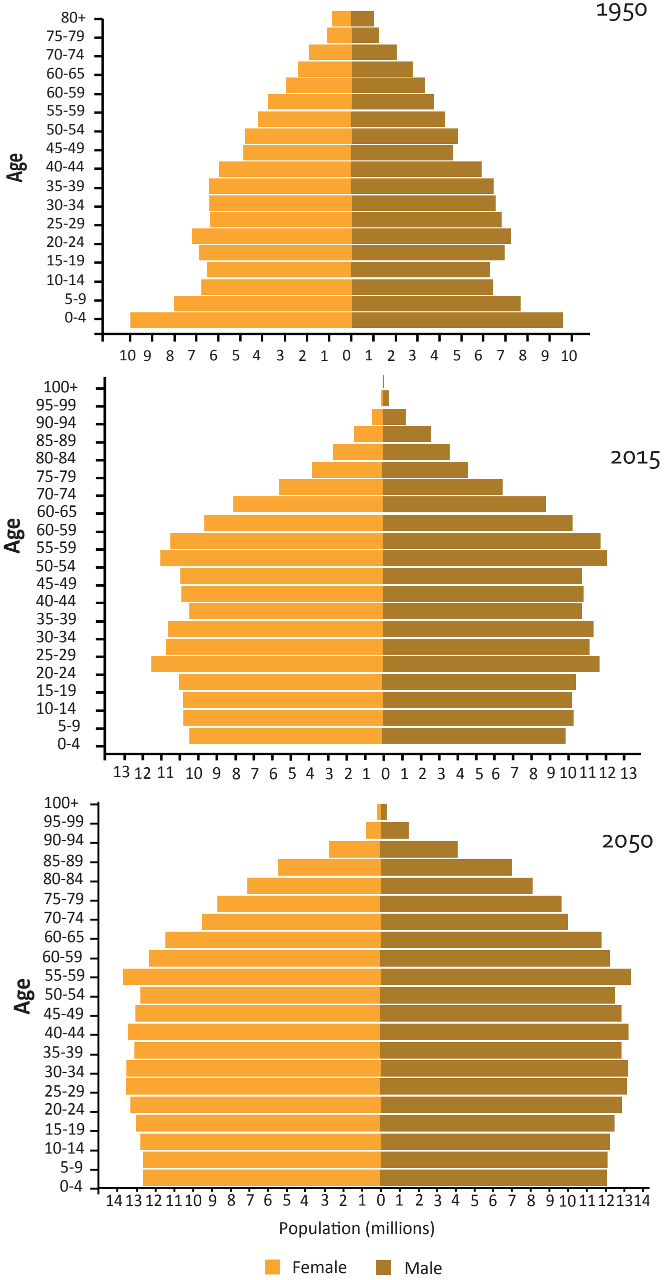
4.1.2 Population and demographic trends

The current population in North America is 355 mill of which 320 million people live in the US and 35 million in Canada (Colby and Ortman 2015; Statistics Canada 2015). The total US population is projected to increase by 98.1 million between 2014 and 2060, an average of 2.1 million more people per year. In 2014, the domestically born population was projected to be 276 million, and this segment of the population is projected to grow by 62 million by 2060 (Colby and Ortman 2015). At the same time, the foreign-born population is projected to increase from 42 million to 78 million (Colby and Ortman 2015). According to a medium-growth scenario, the Canadian population will grow steadily to 52.6 million in 2061 from 35.5 million in the 2014 (Statistics Canada 2011). Based on this trend, the population growth rate during the next fifty years is expected to below that of the last three decades (1980–2010).

While there has been steady population growth in Canada and the US, neither country has grown at rates comparable to some others. In the next 50 years, the growth rates in the two countries are also expected to be below the rates of the past three decades. There has also been a considerable increase in the number of people aged over 65 in the region, which has recently become higher than the number aged less than 15 (**Figure 4.1.2**).

The population continues to be spread unevenly across the continent with the increasing urbanisation and centralisation of populations in the large cities often located in coastal areas of the 21st century. This region contains some of the most urbanised landscapes in the world. In Canada and the US, more than 80 per cent of the population is urban (McPhearson *et al*. 2013) –according to the UN, 82 per cent of Canadians and 81 per cent of the US population lived in cities in 2014 (UN DESA 2014). For 2050, the UN projects further increases in urbanisation, with up to 87 per cent of the population in the US and 88 per cent in Canada living in cities (UN DESA 2014). Furthermore, the concentration of people in North America tends to be in a few larger cities.

Figure 4.1.2: Canada and the US (combined), ageing population, 1950, 2015 and 2050



Source: Colby and Ortman 2015; UN DESA 2015; Statistics Canada 2011

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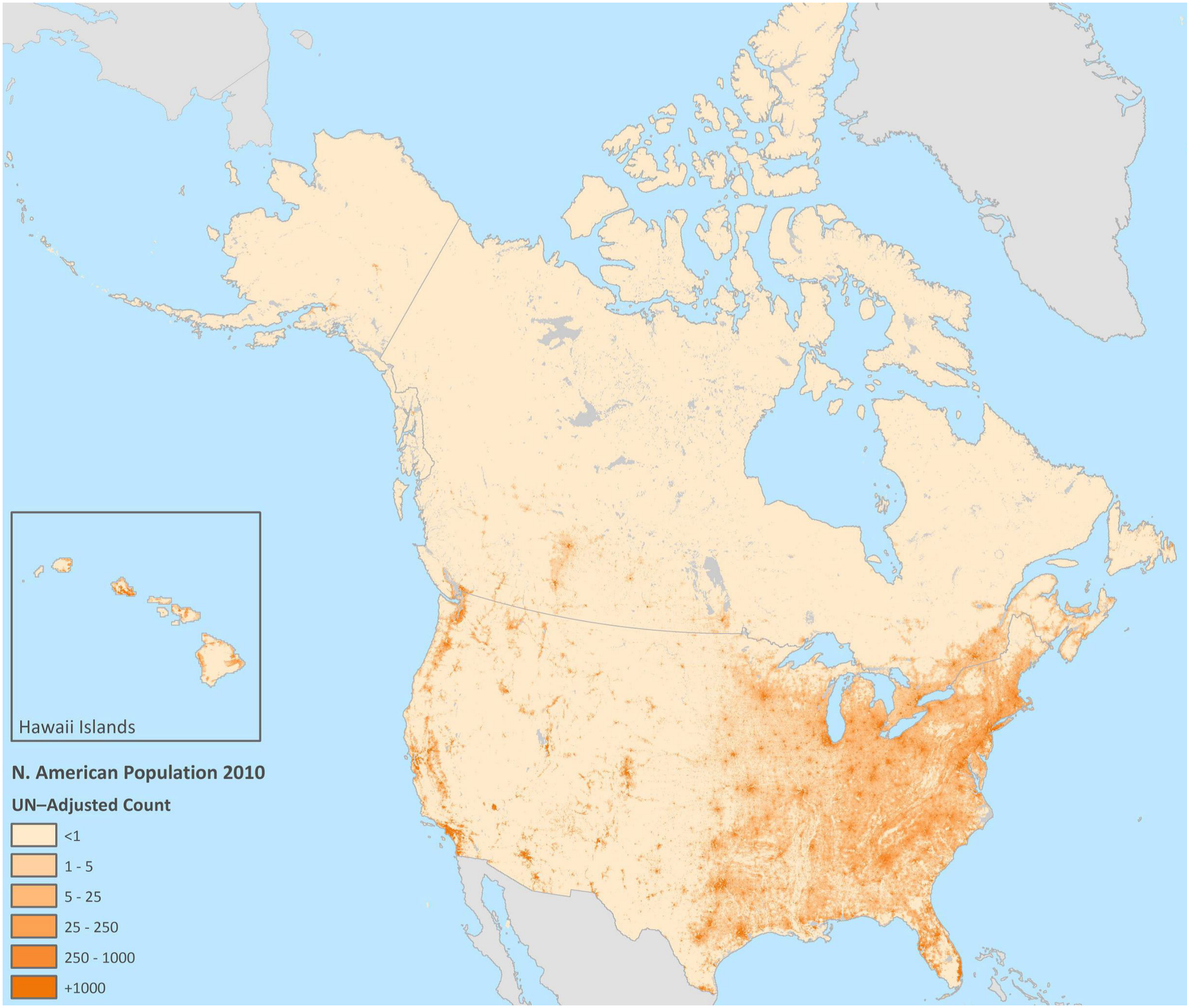
4.1.3 Climate change and energy

No region is immune from the consequences of climate change. In North America, serious and potentially long-term droughts are matched in other places by catastrophic rainfall and local flooding. Rising sea levels also threaten coastlines in North America, with special concern for the cities that lie at or below current sea levels. The recent effects of Hurricane Katrina on New Orleans and Hurricane Sandy on New York and New Jersey demonstrate the destructive potential of hurricanes and a general social incapacity to manage their effects. Arctic regions also face many challenges in the 21st century, among which climate is a crucial component through its impacts on food resources, on infrastructure and housing, and on traditional livelihoods.

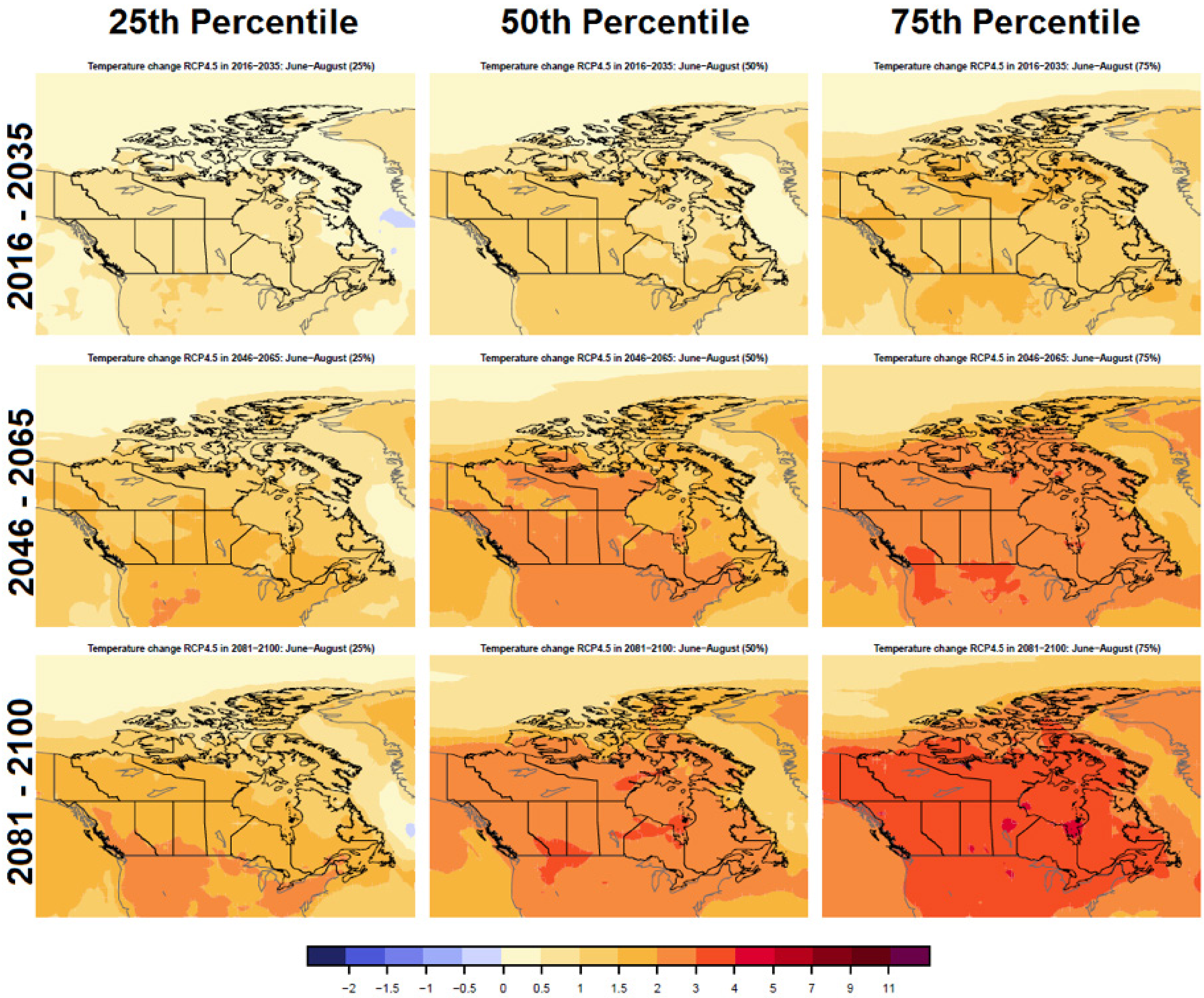
In 2014, the Intergovernmental Panel on Climate Change (IPCC) reported with high confidence that major climate change has already occurred in North America, such as the occurrence of extreme events, including droughts and floods (IPCC 2014). It projected that climate-related stresses and vulnerabilities *"particularly related to severe heat, heavy precipitation, and declining snowpack will increase in frequency and/or severity in the next decades (very high confidence)"*. Furthermore, in North America global warming will lead to oscillations between more frequent extreme heat events and daily precipitation extremes over most of the region. Finally, of key importance to already fragile Arctic/

Figure 4.1.3: North American population density, 2015



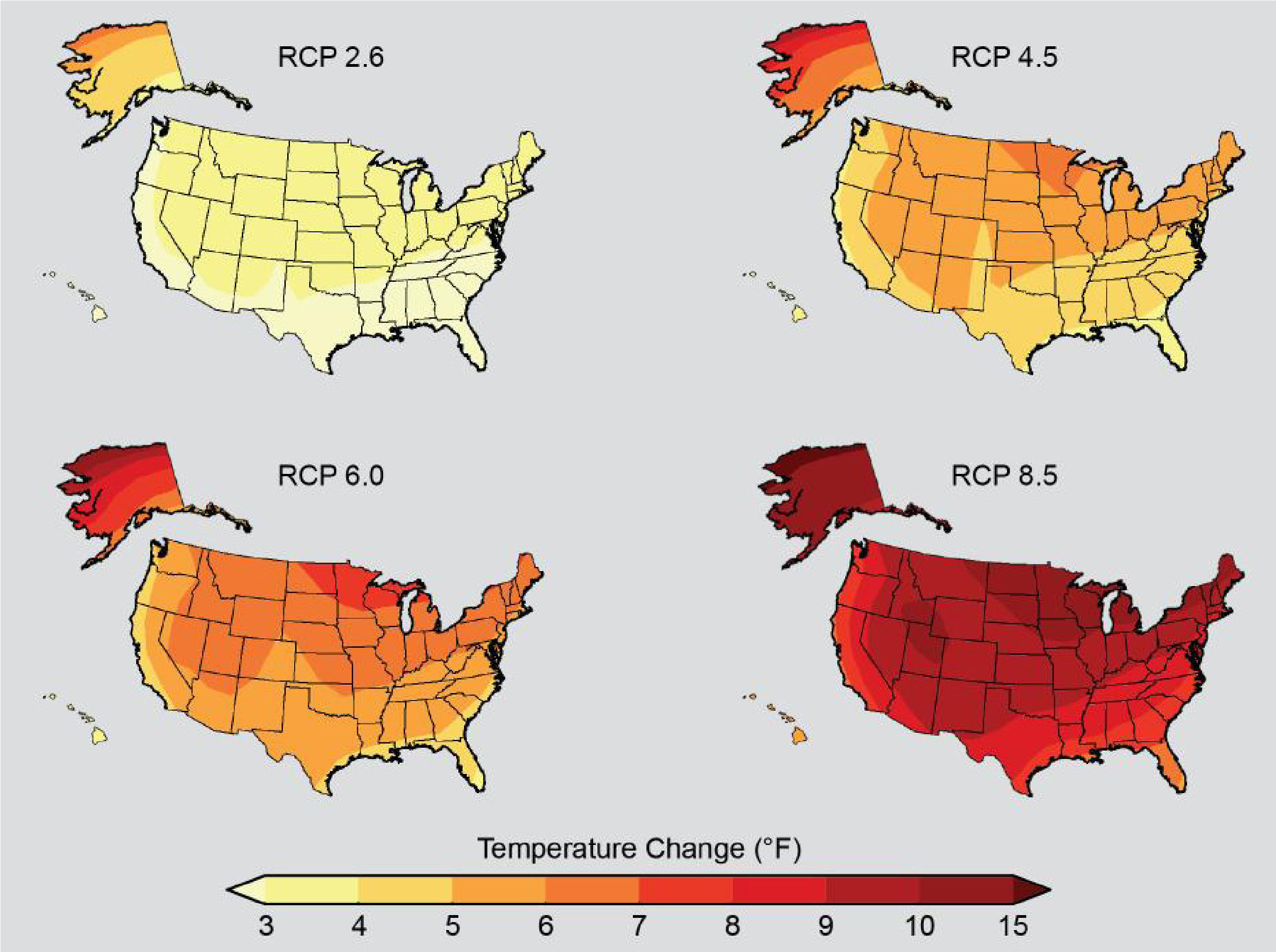
Source: CIESIN 2015

Figure 4.1.4: Climate change projection for North America



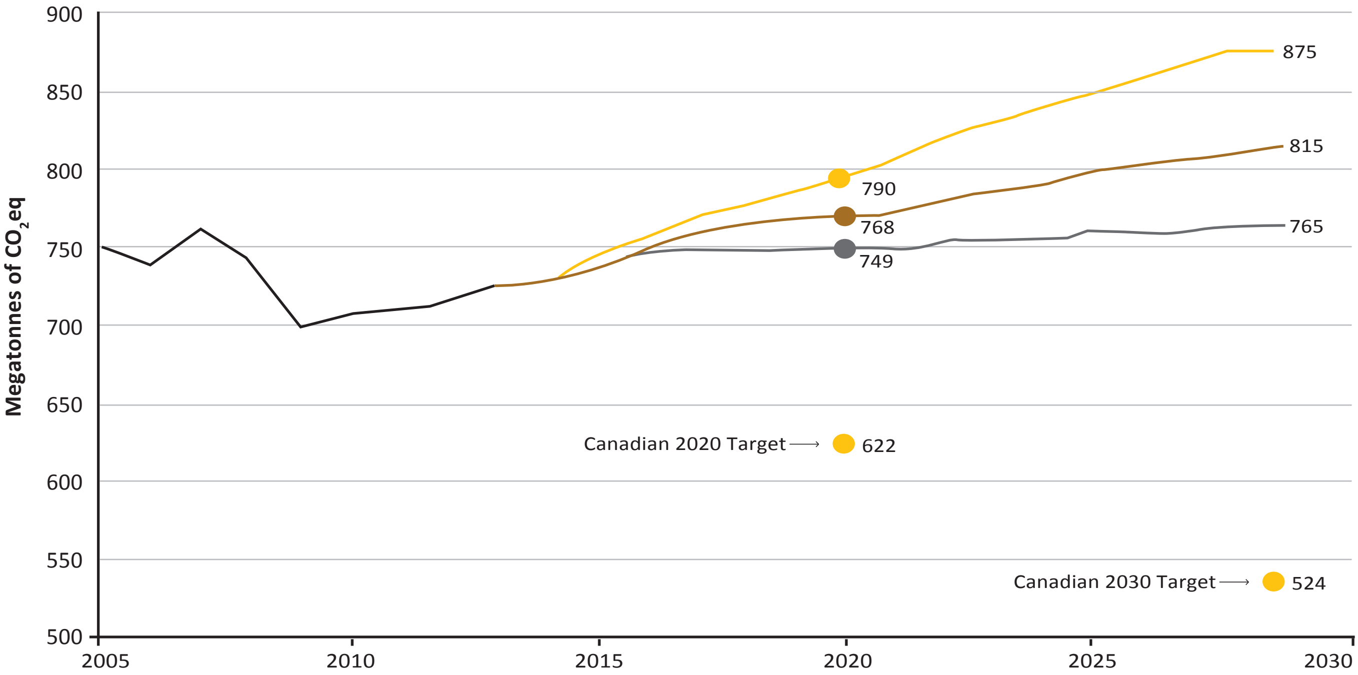
Projected changes in summer surface air temperature (ºC) across Canada for the middle and end of the 21st century based on CMIP5 simulations, and more recent RCP scenarios. Change is computed relative to the 1986-2005 baseline period. The colour scale indicates temperature change in ºC with positive change (warming) indicated by yellow through red colours and cooling by blue colours.
Source: Environment and Climate Change Canada 2016a

Figure 4.1.5: Projected temperature change by 2071-2099



The most recent model projections (CMIP5) for temperature change in the US take into account a wider range of options with regard to human behaviour, including a lower scenario than has been considered before (RCP 2.6). This scenario assumes rapid reductions in emissions – more than 70 per cent cuts from current levels by 2050 and further large decreases by 2100 – and the corresponding smaller amount of warming. On the higher end, the scenarios include one that assumes continued increases in emissions (RCP 8.5) and the corresponding greater amount of warming. Also shown are temperature changes for the intermediate scenarios RCP 4.5 (which is most similar to B1) and RCP 6.0. Projections show change in average temperature in the later part of this century (2071-2099) relative to the late part of last century (1970-1999).
Source: Walsh *et al*. 2014

Figure 4.1.6: Canada's emission projections in 2020 and 2030 (Mt CO_2 eq)



The historical GHG line shows the emissions starting at 749 Mt in 2005, falling to 699 Mt in 2009 and then rising to 726 Mt in 2013. Starting from 2013, there are three trend lines which represent three unique scenarios for projected GHG emissions based on three alternative assumptions about economic growth and energy prices. The line above the middle line with same starting point in 2013 represents the higher-than-average annual GDP growth, high oil and gas prices scenario. Its values in 2020 and 2030 are 749 and 765 respectively. The middle line starting in 2013 is the reference scenario. Its values in 2020 and 2030 are 768 Mt and 815 Mt respectively. The line below the middle line which has the same starting point in 2013 represents slower GDP growth, low oil and gas prices scenario. Its values in 2020 and 2030 are 790 and 875 respectively. Canada's GHG reduction targets are also noted on the graph. The 2020 target is 622 Mt CO_2 eq and 2030 target is 524 Mt CO_2 eq.
Source: Environment and Climate Change Canada 2016b

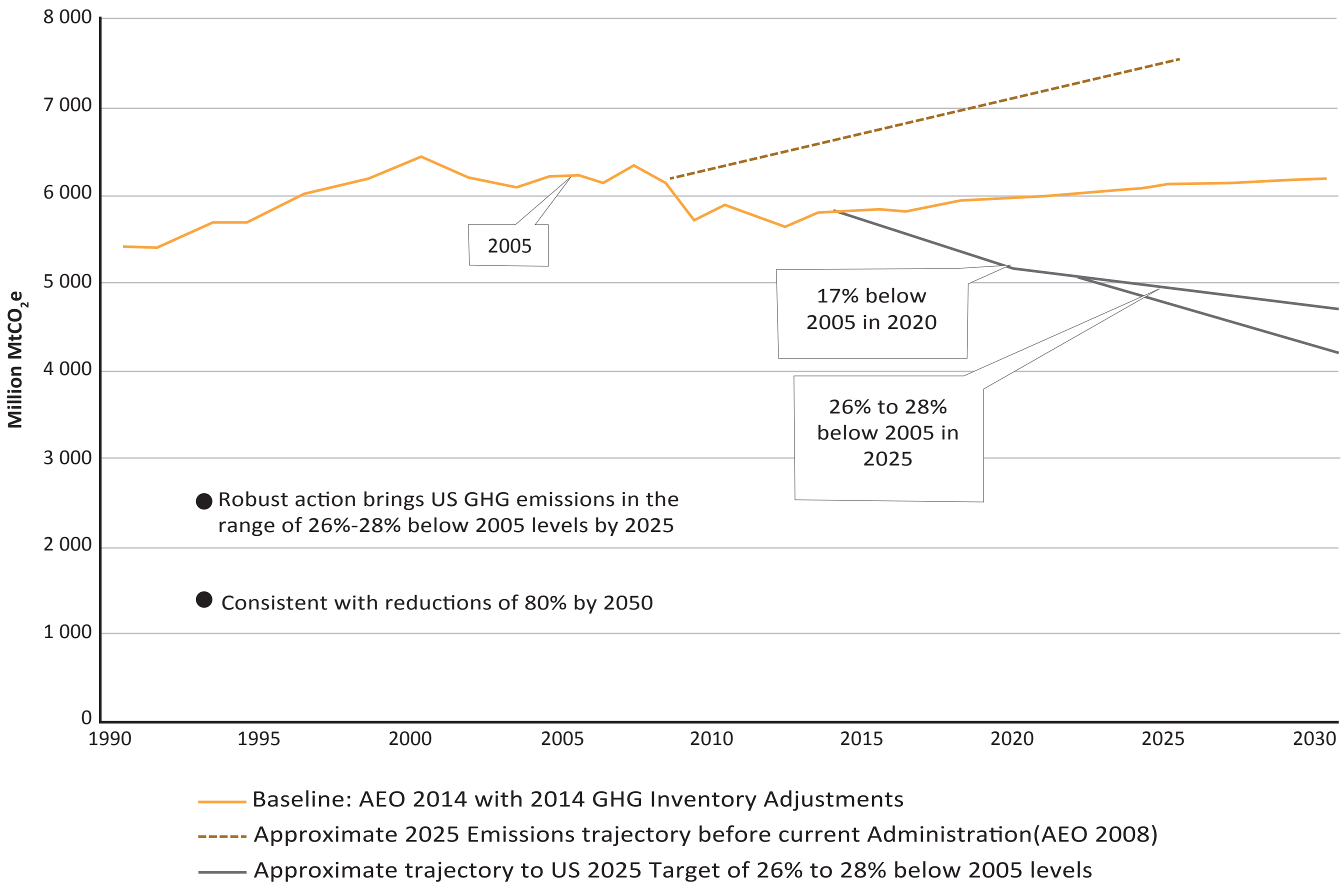
Northern communities and ecosystems, the panel projected that North America will experience more frequent low-snow years, shifts toward earlier snowmelt runoff and increased run-off over much of the western US and Canada (Romero–Lankao 2014).

Today's electric utility systems and transportation in North America are the highest contributors to GHG emissions. Electric utility systems rely on a number of very large energy generation facilities and an extensive power distribution network. While mitigation and reduction of greenhouse gas emissions is essential to slow climate change, there are also potential solutions. Based on the International Energy Agency (IEA) assessment, greenhouse gas emissions in industrial and other sectors will continue to grow. The IEA estimates, however, that emissions from industrial energy generation (which does not include electric utilities) could be halved if the best available technologies were implemented over the next three decades (**Box 4.1.1**). Further reductions could be achieved by developing smarter transportation modes and by expanding green energy options for residential use.

Both the US and Canada were strong supporters of the global agreement reached in Paris in December 2015 and are actively designing ambitious policies to achieve the commitments made there.

On March 31, 2015, the US formally submitted its Intended Nationally Determined Contribution (INDC) to reduce GHGs stating the intention "to achieve an economy-wide target of reducing its GHG by 26-28 per cent below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28 per cent". On May 15, 2015, Canada submitted its INDC stating "Canada intends to achieve an economy-wide target to reduce its GHG emissions by 30 per cent below 2005 levels by 2030" (Canada 2015). US President Obama and Canadian

Figure 4.1.7: Historic and projected US GHG emissions under Obama Administration targets

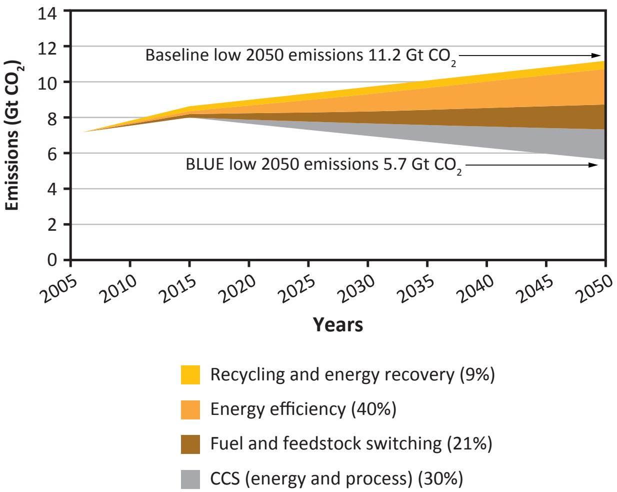


Source: UNDS 2016

Box 4.1.1: Potential emission reduction in energy production, OECD countries with focus on North America

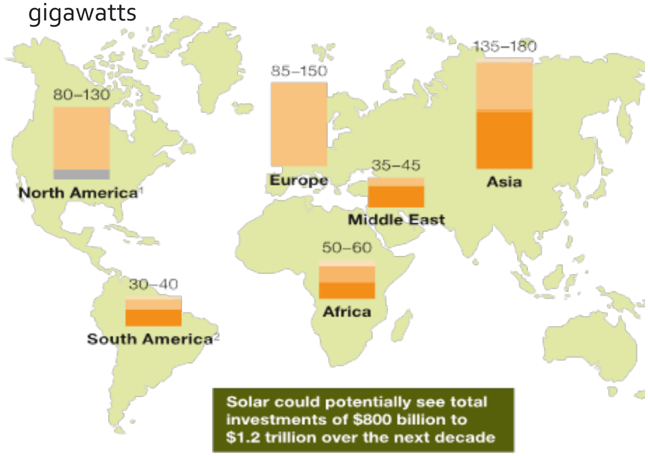
The International Energy Agency (IEA) has developed a series of forecasts of industry emissions. Industry accounts for 40 per cent of emissions from energy production and has developed a series of scenarios to assess the emission reduction potential of industry through implementing of best available technology (BAT) and development and deployment of new technologies over the studied time frame 2006 - 2050.

Figure 4.1.8: Technologies for reducing CO_2 emissions



Source: IEA 2009

Figure 4.1.9: Growth in solar photovoltaic energy potential, cumulative capacity additions 2012-2020, gigawatts



Source: McKinsey & Company 2012

Prime Minister Trudeau released a joint statement on March 10, 2016 declaring their commitment to join and sign the Paris Agreement and highlighting a shared vision of a prosperous and sustainable North American economy, opportunities afforded by advancing clean growth, coordinated domestic climate action, deepening cooperation on clean energy, and a new partnership to embrace the opportunities and to confront the challenges in the changing Arctic (Government of Canada 2016).

Continued efforts on the part of Canada and the US to implement the historic Paris Agreement, which both countries signed on April 22, 2016, and increase their ambition over time will be instrumental. In addition to implementing their respective INDCs, attention also needs to be paid to increasing efforts on adaptation and resilience planning.

4.1.4 Land and water

North America has extensive water resources and a robust water infrastructure system to deliver safe drinking water to most communities and to manage water for irrigation, hydroelectric power, and industrial, recreational, and fish and wildlife uses. The current state and trends of water resources in North America is described in Section 2.4.

In recent years, drought has become a more common occurrence in the arid part of the region, west of the 100th meridian (See Section 2.4.2). Combined with an unsustainable reliance on groundwater aquifers and changes in climate, there is a pending water crisis in many areas of the western US that will affect agricultural and urban communities. Drought may have long-lasting implications for the human settlements and ecosystems in an already vulnerable area of North America (NASA 2015).

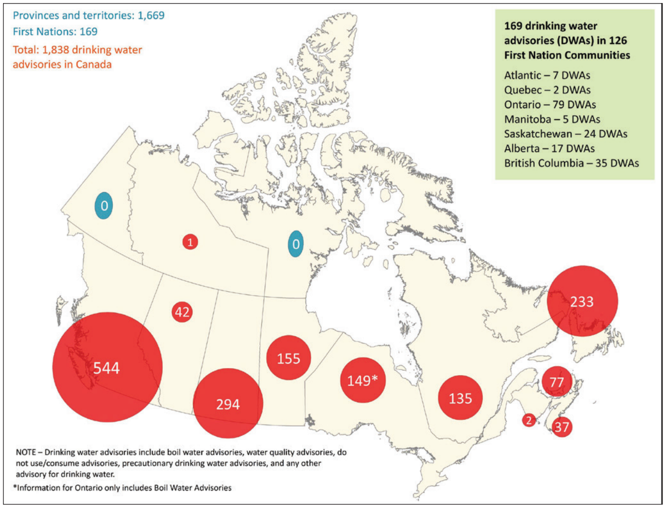
Most US states are already projected to experience regional (e.g., within specific states) water shortages in the next decade (US Government Accountability Office 2014). Similarly, parts of Canada are reaching limits to available clean water. In 2015 there were at least 1 838 drinking water advisories, 1 669 in communities across Canada and 169 in 126 First Nations communities often as an outcome of degraded infrastructure (The Council of Canadians 2015). Watershed competition between urban centres, agricultural districts and industrial facilities further compounds the ecological problems of water-stressed natural habitat and interrupted hydrologic cycles. The impacts related to climate change and other challenges will require the region to adapt to new trends in hydrology. This will require changes in current protection and management of flood zones, improved water efficiency in the agricultural, municipal and industrial sectors, and effective management of water storage to buffer the effects of climate variability (Graf *et al*. 2010).

Given the above challenges, especially with increasing threats from climate change, one of the key requirements is better management of water shortages and droughts. The US is currently experiencing very serious droughts (Section 1.2.5) and perhaps more ominously, NASA projects that extremely serious mega-droughts – droughts lasting for more than three decades – will continue into the 21st century (NASA 2015) – in NASA's study, the current likelihood of a mega-drought is 12 per cent. There is a serious likelihood of a drought reminiscent of the Dust Bowl of the 1930s that could last up to 35 years.

Drought also has other consequences besides affecting water available for human consumption, wildlife habitat, and agriculture. In 2015, US forest fires have been so frequent and intense that there may be a reduced likelihood of some of these lands ever returning to forested conditions (Schwartz 2015). These conclusions are based on several cases where mature female trees were completely burned, thus removing potential future seedlings, with ground that is so charred that re-vegetation will take a very long time.

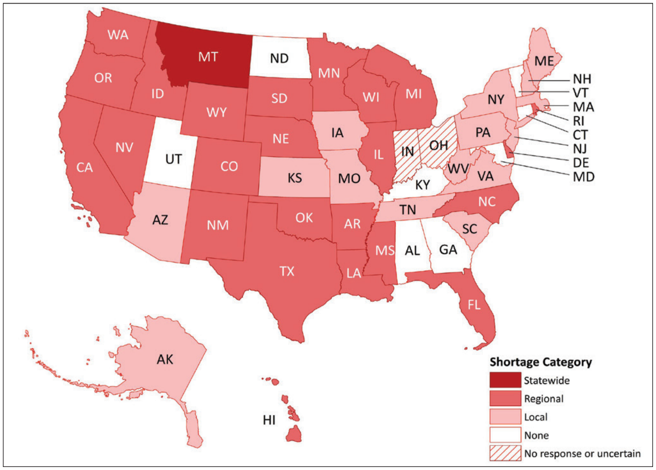
In Canada, wildfires have significant effects on forest ecosystems. Approximately 53 000 fires burn 2 million hectares each year in Canada, based on a 10-year average (**Table 4.1.1**). While only 2–3 per cent of these wildfires grow to more than 200 hectares, they account for almost 97 per

Figure 4.1.10a: Canada water shortages and advisories 2015



Source: The Council of Canadians 2015

Figure 4.1.10b: US states, water shortages likely over the next decade, 2013.



Government Accountability Office conducted a survey of 50 state water managers and reviewed reports and documents from entities, such as federal agencies and environmental organizations, and interviewed federal officials and experts, including environmental and industry officials, to understand freshwater issues across the US.
Source: US GAO 2014a

cent of the annual area burned (*CIFFC n.d*). Given Canada's size, the use of remote sensing data is a cost-effective way to achieve a comprehensive overview of forest fire activity in near-real time. This creates a need for advanced monitoring techniques, such as satellites and ground truthing, and effective systems of information coordination to ensure timely responses, accurate prediction and effective coordination between provinces and regions.

As with water use, future land use and land-cover changes will depend on population growth, considerable expansion of urban areas, and de-population of rural ones. Land-use change in North America was relatively moderate in recent years; for example, between 2005-2010 only 1.2 per cent of land cover change occurred (**Table 4.1.2**; CEC 2010). In the US, land-use scenarios assume that suburban and exurban areas will expand by 15–20 per cent between 2000 and 2050, cropland and forest areas are projected to decline most compared with 1997, by 6 per cent and 7 per cent, respectively, by 2050 (Brown *et al*. 2014). In Canada, increased land conversion around urban areas is projected to lead to the decline and disappearance of small forests and natural areas close to urban areas. Also, urbanisation is usually associated with increased point and non-point source pollutant discharges, such as wastewater treatment plant effluent, septic leakages, and pesticides and fertilizers of agriculture. Without mitigation, these pollutant discharges will damage biodiversity and habitat (El-Khoury *et al*. 2014).

Given the projected changes in water resources, land-use change and specific challenges such as droughts and forest fires, it is critical to focus on integrated water-land management to reduce cumulative impacts and the unintended consequences of narrowly-focused policies for either conservation or development.

4.1.5 Chemicals and human health

Across the North American landscape, point-source contamination and persistent chemical and pharmaceutical pollutants are creating increased concerns about human and environmental health. While there are chemical management, regulation and oversight programmes in

Table 4.1.1: Canada and the US, summary of forest fires

	Canada				US total
	2015 (to date)	10-yr average (to date)	% of normal	Prescribed	
Number	6 669	5 301	126	58	43 931
Area (ha)	3 953 043	2 089 888	189	8 311	3 398 504

Source: Canadian Interagency Forest Fire Centre (CIFFC)

Table 4.1.2: Area of change in square kilometres and % between the land cover map of 2005 and 2010

Area	km^2	%
North America	259 285	1.22
Canada	204 049	2.06
United States	52 294	0.55
Mexico	2 942	0.15

Source: CEC 2010

place in both Canada and the US, these are not always able to keep pace with the environmental complexity that results from the widespread use of chemicals, especially in combinations. This situation will not quickly or easily change, as the development of ever newer compounds and use of chemicals continues to increase. As shown in **Figure 4.1.11**, chemical production is likely to increase by 25 per cent in the US and 27 per cent in Canada between 2012 and 2020.

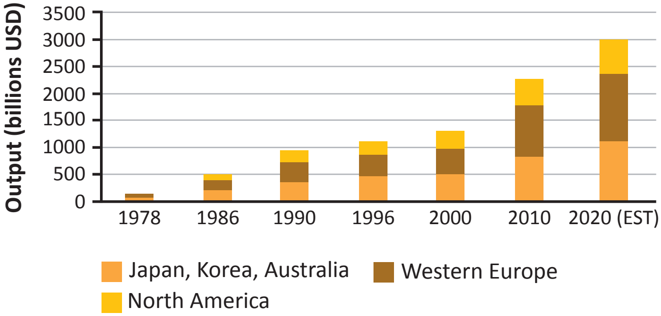
The Toxic Substances Control Act (TSCA) requires the US Environmental Protection Agency to compile, keep current and publish a list of chemical substances that are manufactured or processed, including imports, in the US. There are currently about 85 000 substances listed on the TSCA inventory (US EPA 2015a), and as new substances are developed they are added, at approximately 400 per year. Because of the development and growth of nanotechnology, the US EPA has reviewed about 160 nano-scale substances for possible inclusion on the inventory since 2005 (US EPA 2015b). Environment Canada and Health Canada manage the Chemicals Management Plan (CMP) set up in 2006. The CMP assesses environmental and human health risks posed by existing and new chemical substances, and develops and implements measures to prevent or manage those risks, having completed a triage of some 23,000 chemicals that had been in commercial use during the previous two decades. Canada is one of the few countries that will meet the 2020 global goal of sound management of chemicals and waste.

Both countries also maintain online pollutant release and transfer registries. In the US, this is known as the Toxic Release Inventory (US EPA 2015b) and in Canada, the National Pollutant Release Inventory (Environment Canada 2015). These allow analysis of many aspects of polluting emissions across North America. Additionally, green chemistry approaches to design of products and processes that eliminate or reduce the production or use of hazardous products can be the way to address these potential risks (US EPA 2016a).

Contaminants of emerging concern

Contamination of freshwater systems by new, unmonitored or unregulated contaminants is a problem for both the countries of North America (see Section 2.6.1). Such contaminants of emerging concern have the potential to cause adverse ecological or human health effects (Halden 2015; Rosi-Marshall *et al.* 2013). These include contaminants that may be truly new ones that are unrecognised or not regularly monitored, or ones that are unregulated (Hull *et al.* 2015). Estimates suggest that such contaminants number approximately 40 000 and are rising daily (Halden 2015). They include a wide variety of synthetic chemicals and engineered particles, ranging from pharmaceutical drugs, personal care products, nanomaterials and microplastics (Bellenger and Cabana 2014) to artificial sweeteners (Spoelstra *et al.* 2013) and illicit drugs (Rosi-Marshall *et al.* 2015).

Figure 4.1.11: Growth in chemical production



Source: UNEP 2013

While not a new contaminant, the experience of Flint, Michigan, of high levels of lead in the drinking water supply (see Section 2.4) has focused new attention on water infrastructure and ensuring safe levels of lead in drinking water. This is an issue of concern that emerged during 2015. Addressing contaminants of emerging concern (CECs) into the future will require additional effort towards existing responses including improved monitoring techniques to detect CECs at low concentrations, research to better understand the effects of CECs on human health and the environment, and development of new technologies that may be capable of removing CECs from wastewater.

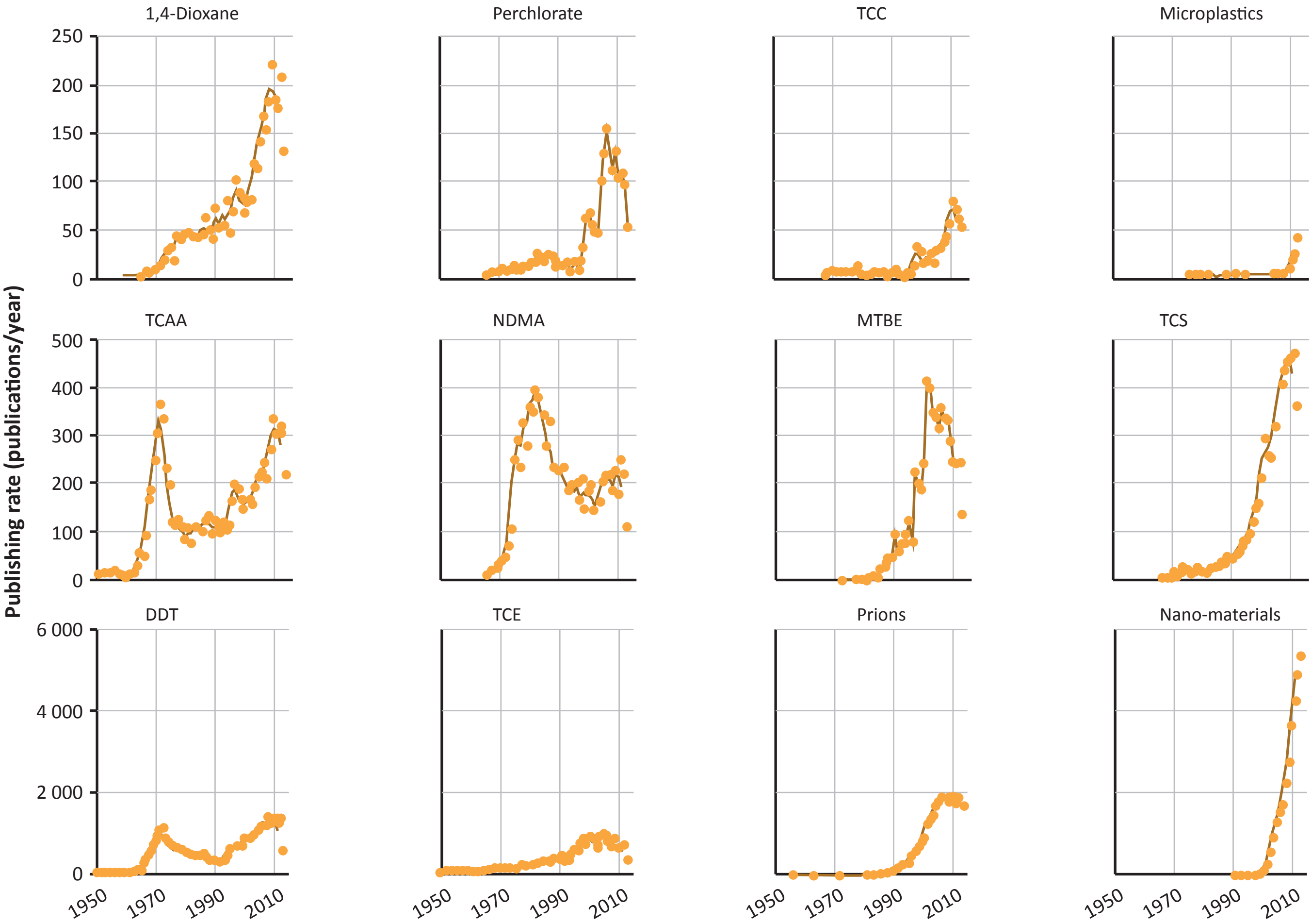
Assessing the occurrence of CECs at low concentrations has become possible with the extremely sensitive analytical methods currently available, which allow for the detection of thousands of contaminants at trace levels (Pal *et al*. 2014). Approaches to set limits for particular contaminants have been proposed, but are still untested, and will be continually revised as understanding grows. These uncertainties complicate communication with the public and hinder acceptance of drinking water originating from wastewater (Pal *et al*. 2014). In some cases, the use of chemicals with high water pollution potential and eco-toxicological risk may have to be restricted, an example being the wide-spread use of antibiotics in animal husbandry (Kemper 2008).

There remains significant uncertainty about the effects of many CECs on human health and the environment. Most of these contaminants are not routinely monitored or regulated through wastewater treatment processes, and in many cases basic presence or concentration data are sparse and somewhat sporadic. Moreover, although evidence from case studies and experiments on potential impacts of a variety of such contaminants is starting to emerge, the detection of compounds does not necessarily signify an impact on aquatic biota or human health. Understanding the fate and transport as well as the environmental and human health impacts of new, unmonitored or unregulated contaminants is an active area of research in North America (**Figure 4.1.12**), with funds from multiple federal agencies – such as the US Environmental Protection Agency, USGS and National Science Foundation in the US and, in Canada, the Natural Sciences and Engineering Research Council, Environment Canada and Fisheries and Oceans Canada – supporting various aspects of this research at institutions across the region.

Although the subject of an increasing body of scientific and popular literature, contaminants of emerging concern remain a challenge to regulate due in part to their diversity and quantity, the complexity in monitoring, the lack of standard products against which to compare them and uncertainty regarding their impacts on ecosystems and human health. Some monitoring issues might be addressed through the identification of indicator contaminants (Metcalfe 2013).

Despite the uncertainty surrounding the ecological and human health impacts of CECs, several sub-national jurisdictions in North America, including seven in the US, have recently regulated or banned microbeads, one type of CEC (Rochman *et al*. 2015). As well, the US passed a federal law in 2015 that will ban the production of person care products with microbeads starting in 2017. In Canada, the province of Ontario has made efforts to control microbeads in personal care products (Ontario 2015) while the federal government declared microbeads toxic in 2015 and is in the process of developing regulations that would phase out the use of microbeads in personal care products (Environment Canada 2015).

Figure 4.1.12: Publishing activity for selected contaminants of emerging concern, 1950–2013



Shown is the sum of publications per year by contaminant and publication trend lines computed from three-year averages of annual publication activity. This means that interest in research is going up.
Source: Halden 2014

4.2 Emerging and potentially disruptive technologies

New innovations are constantly being developed and spreading across diverse sectors of the economy. This section focuses on a few innovative technologies that could make the long-term future as different as ours is from 50 years ago. As these technologies develop and disseminate, they can have both positive and negative effects on environmental quality and on efforts to create a sustainable future. Because of the impacts of these new innovations they are also called "disruptive" as they have the ability to radically transform social, economic, environmental, and governance systems. Such impacts on these systems include changes in demand for labour due to increased productivity by technology, increase data and analytical capacity for targeted services, numerous industrial and medical uses of nanotechnology such as nanotitanium dioxide, and nanosilver, synthetic biology with changes in the economics and flow of raw materials in agriculture, forestry, energy and mining and finally artificial intelligence advancing our abilities of complex problem-solving relying on large amounts of often real-time data. In the next section we explore these emerging potentially disruptive technologies and their impacts, both positive and negative on environment and sustainability. These impacts also create challenges for policy-making and government in terms of responding to fast-paced change with innovative policies that are able to take a systemic perspective and at the same time remain flexible and adaptable.

4.2.1 Three-dimensional (3-D) printing

First developed in the 1980s, three-dimensional (3-D) printing technology, was most focused on prototyping, but introduced several new concepts for manufacturing and supply-chains. First, manufacturing can be localised; instead of mass-producing products at a limited number of sites, some products are now being produced in smaller numbers and at the point of use, thereby reducing transportation needs and costs. Similarly, 3-D printing technology enables the production of necessary items not suitable or required to be mass-produced. Another important aspect of this type of manufacturing is that it is additive: instead of starting with large volumes of materials and creating wastes, production materials are only used during the process itself to build or create the product. As yet, however, the materials used in 3-D printing have not been developed with environmental issues – health risks, recycling or disposal – in mind (Olson 2013). There are also many uncertainties in terms of the environmental consequences of these technologies (Rejeski and Huang 2015). As 3-D printers are becoming readily available, appropriate policies to manage necessary changes in manufacturing patterns and material use should also be in place.

4.2.2 Synthetic biology

Synthetic biology also holds both promise and concern as a general field of emerging or novel technologies in relation to living organisms. In fact, Science Magazine's *2015 Breakthrough of the Year* was for the genome editing method known as CRISPR (Travis 2015). This technique was used for the first deliberate editing of DNA in human embryos. There are already plans to develop pigs resistant to several viruses and wheat that can fend off a widespread fungus, longer-lasting tomatoes, allergen-free peanuts, and biofuel-friendly poplars and other new crops in response to climate change such as salt-tolerance, drought-tolerance, and pest-resistance (Travis 2015). Developing and manipulating natural processes to produce new biological parts or systems, or even to replace conventional manufacturing, for example in the production of biofuels (Woodrow Wilson 2015) could be a powerful tool. Although still at a very early and perhaps even speculative stage, synthetic biology is *"a technological revolution that will transform several markets, including energy, agriculture, healthcare, chemicals and bioremediation"* (Woodrow Wilson 2015). Whether there should be boundaries on synthetic biology – what they might be, who decides, and how they are to be enforced – remains a significant and largely unaddressed question for policy makers.

4.2.3 Geoengineering or climate intervention

These technologies and actions are meant to counter the possibly very extreme climate changes that could have catastrophic effects. There are two broad approaches to geoengineering, the first being albedo modification or reflectance of solar radiation away from the earth and back towards space. These potential modifications have poorly understood risks, particularly at the global scales needed for effective climate modification. Volcanic eruptions are the closest natural analogue. The second approach is through carbon dioxide removal or sequestration from the atmosphere. **Figure 4.2.1** illustrates these processes/technologies.

It is difficult to anticipate all of the potential uses and consequences of these novel biotechnologies. But in adapting to climate change, several possibilities include enhanced conversion of CO_2 by plants and algae in a way that makes BECCS more effective and efficient, along with improved crop resistance to climate impacts. The Global CO_2 Initiative was created to realize the ambitious goal of capturing 10 per cent of global CO_2 emissions and transforming it into valuable products (CO_2 Sciences Inc. 2016). Pursuant to this privately-led effort, announced at Davos on January 21, 2016 are planned to be funded at USD 100M/year for 10 years.

4.2.4 Nanotechnology

The 1996 Nobel Prize for Chemistry was awarded for the discovery of fullerenes. Although this research had been going on well before the award of the prize, this public notice confirmed the importance of nanotechnology. Since then, governments around the world have provided significant funding for nanotechnology research; the US National Nanotechnology Initiative (US NNI 2015a) has had a cumulative research budget of more than US$20 billion since 2001. Nanotechnology is not just a field for research, but application can be found throughout the economy.

Current estimates of revenues from nano-enabled products in the energy and environment areas are more than USD 19 billion in 2013 and more than USD 28 billion in 2014 (Flynn *et al.* 2014). Nanotechnology and nanomaterials

Box 4.2.1: Nanotechnology and the environment

Development of nanomaterial products and technologies is projected to grow exponentially over the next decade. As yet, however, there is only a limited understanding of how this will impact aquatic ecosystems; a whole-lake nano-silver addition experiment was conducted at the Experimental Lakes Area in Ontario from 2013–2014. This experiment makes a unique contribution to the effort by the OECD working party on manufactured nanomaterials to evaluate their risks to the environment (WPMN 2007). The whole-lake experiment aims to characterize the techniques, procedures and policies that must be developed to assess changes in ecosystem function associated with the release of nanoparticles to the environment. Adequate research to identify potential health risks for humans from the ingestion of nanomaterials is also yet to be done. This is another example of how other drivers and pressures besides those relating to ecological health are pushing the development and use of novel technologies. This could include unintended consequences in regions where, for example, water stress is an increasingly serious concern (Trent University 2015).

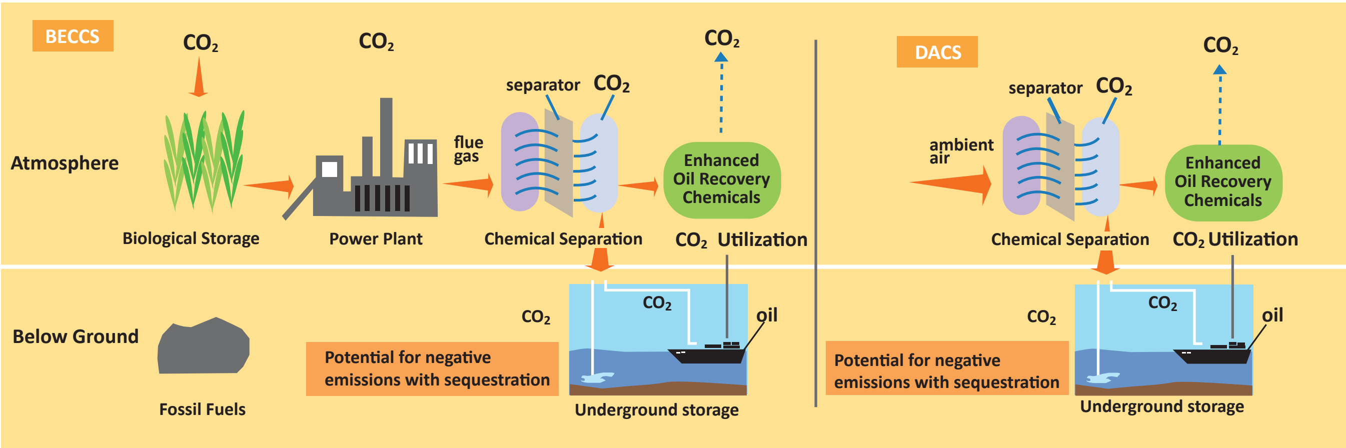
are being applied to green technologies such as solar electricity production (European Commission Science for Environment Policy 2015; US NNI 2015b). At the same time, the expansion of nanotechnologies has raised questions of potential environmental health risks (Weisner *et al.* 2006). There could be unintended exposures to nanomaterials or from nano-based products. According to the Project on Emerging Nanotechnologies database, there are more than 1600 consumer products that contain nanomaterials (Woodrow Wilson 2015). Although this database does not definitively demonstrate human exposure to these various nanomaterials, it certainly shows that there are potential opportunities for such exposure.

Eisen *et al.* (2011) identified health concerns about exposure to engineered nanoparticles and recommend future research that includes hazard surveillance and prospective cohort studies of cardiovascular and respiratory diseases. There are also potential issues of risks to ecosystems and other organisms. As industrial products and wastes tend to end up in waterways, there are clearly potential concerns for ecological toxicity in aquatic systems, and there are some data to demonstrate the potential for ecological risk (Moore 2006). The US EPA states, however, currently "*there is insufficient information about how nanomaterials affect ecosystem health*" (US EPA 2015e).

4.2.5 Artificial intelligence

Artificial intelligence (AI) has already gone through significant developments during the last decade. Currently, however, AI is still very task specific to solve problems such as face and voice recognition, to solve complex algorithms (for example in patient diagnostics), to assess large data sets in stock trading and to optimize decisions involving value-chains and production. With respect to the latter, AI allows

Figure 4.2.1: Bioenergy with carbon capture and storage (left) and direct air capture and storage



In Bioenergy with Carbon capture and Sequestrations (BECCS, left), crops take up carbon dioxide from the atmosphere as they grow. The crops can be burned in power plants to produce electricity, and the carbon dioxide generated is captured and sequestered underground. In Direct Air Capture and Sequestration (DACS, right), carbon dioxide can be removed from the atmosphere as air passes through air filtering structures and is sequestered underground. Orange arrows represent fluxes of carbon; dashed arrows indicate residual carbon dioxide emissions.
Source: US NAS 2015

more efficient use of resources during production processes and improved consumer awareness, leading to better informed choices. Many software applications are already being incorporated into personal electronics to scan, share information, and provide a user with targeted choices.

From the environmental management point of view, AI offers opportunities for more timely and robust environmental management decision support tools. This includes assessing real-time data from numerous monitoring stations, processing large data sets and providing timely information for policy-makers and users. For example AI can be combined with ecological models to predict changes in species distribution and migration due to climate change, or changes in invasive species distribution. Similarly, information from satellites and sensors connected with additional information from local sensors (such as sensors carried by drones) can be used to optimize agricultural processes, including automated tractors and sprayers, and allow tracking food from production to consumption. While the listed examples are still focused to solve specific problems, it is expected that the next step is for researchers and computer scientists to advance AI so that computers can learn general knowledge that can be used to enable them to work in new situations, or respond better to the user's contexts and mood and also to automate many tasks, greatly improving personal efficiency and productivity (Policy Horizons 2012).

4.2.6 Transport systems

Although autonomous and semi-autonomous cars are still under development, it is also important from an environmental perspective to understand that there could be significant changes to existing transport systems. This not only includes individual personal transportation but also public transportation, as well as providing services in hospitals, warehouses and factories. Advancement of such "driverless" cars strongly depends on the advancement of AI to compute and interpret large amounts of information to facilitate smooth and more efficient service delivery. This could mean a considerable opportunity for North American people and businesses.

For example older people who might have been forced to give up cars may continue to be able to "drive". This could result in an aging North American demographic continuing with automobile use and all of its environmental consequences. On the other hand, driverless-car technology may also promote the lower environmental consequences and the more efficient use of current roadways and, for example, reduce the need for parking: one gets out of a car and it goes directly to find the next passenger (The Economist 2015a). The smartphone-based apps that can quickly "call" for a car (in the future, no doubt a driverless car) are also likely to lead to long-term changes in patterns of car ownership and use.

Growth in telework and other changes that reduce use of central offices, and continuing growth in online shopping are all leading to changes in transport needs. Another potential major change in transport systems is drone delivery of packages. Major barriers today are probably more regulatory than technological, and within ten years this form of delivery may be quite common (The Economist 2015b). Any major changes in transport systems of course will have implications for conventional pollutants and greenhouse gas emissions, as well as for sustainable lifestyles.

These emerging technologies provide many opportunities and challenges for users and policy-makers to improve quality of life, environmental management and overall sustainability of the region. Many of these challenges as well as opportunities are explored in a series of scenarios **Box 4.2.2**. Large-scale availability of these emerging technologies means that they become the part of our every-day lives in less than a decade. This growth of coupled technologies, big data and AI to manage more and more of our technologies (transport, appliances, mobile devices, etc.) and lives is generally referred to as the "Internet of Things" (Wired 2016). This "Internet of Things" creates opportunities and challenges for policy-makers to anticipate and respond in a timely manner to the potential consequences to the environment, as well as to the social challenges posed, such as privacy issues, changes in employment types and structures, changes in educational needs, and others.

Early result of ongoing research at the US Department of Transportation, suggest that automated vehicles have the potential to bring about transformative safety, mobility, energy, and environmental benefits to the US's surface transportation system.

4.3 Key opportunities for innovation for critical cross-cutting issues in North America

Beyond the new and emerging technologies that have not been mainstreamed to date and which carry with them both opportunities and challenges, there are a number of innovations and opportunities that are already being adopted in a number of places and sectors. These, for example, include "smart cities" where there is improved access to services; sustainable transport systems; climate smart and sustainable agriculture; water conservation and planning; and green energy. The early applications of these innovations already indicate that they have potential to make significant regional global impacts if implemented on large scale. Thus the role of governments is to create enabling policies and measures to support the spread of these innovations, and the role of citizens and businesses is to actively engage in taking new opportunities on board.

4.3.1 Smart cities and urban infrastructure

With more than 80 per cent of its population living in urban centres, mostly large cities, what happens in and around those North American cities can drive the region toward a sustainable future. Cities are increasingly the centre of dynamic innovation in North America. Recent years have seen a heightened attention on urban environmental policy, characterised increasingly by efforts to tackle some of the most challenging elements of the sustainability agenda. For example, US Mayors put forward a Climate Protection Agreement, at the 2005 Conference of Mayors. The objective was to "meet or exceed Kyoto Protocol targets for reducing global warming (US Mayors 2008). The mayors also played a key role in the successful result at the 21st Conference of the Parties to the UNFCCC in Paris.

A comprehensive assessment of major infrastructure in the US, developed by the American Society of Civil Engineers, indicated an overall grade for the country is D+ with estimates as high as USD 3.6 trillion in order to significantly raise the status and quality of this major infrastructure (ASCE 2013). The situation is similar in Canada, where it was reported that about 30 per cent of municipal infrastructure is between fair and very poor quality (Félio 2012). This calls for strong emphasis on redevelopment that focuses on novel, longer-term and more sustainable solutions that are ready for climate change, rather than conventional solutions that merely repeat past mistakes.

Over the past two decades, cities have become critical sites for implementing climate change policy. Shortly after the 1988 Toronto Conference *On the Changing Atmosphere* helped place climate change on the national and international policy agendas, Toronto became the first city to establish a municipal emissions reduction target (Bulkeley and Betsill 2003; Lambright *et al.* 1996). Focused on leading by example, Transnational municipal networks such as the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection Programme, the Climate Alliance and Energy Cities, helped link these cities through the sharing of best practices and by advancing a model of climate governance heavily focused on model of measuring emissions, setting targets, and developing and implementing climate action plans (Hoffmann 2011; Kern and Bulkeley 2009; Betsill and Bulkeley 2004). There are many opportunities for cities in North America to collaborate with cities in other places, such as Europe, through networks such as 100 Resilient Cities, World Cities Network, Sustainable Cities Network.

In North America, smart cities also plan to increase their resilience. The concept of 'smart cities' reflects a concern with efficiency matched to community well-being. This enables the efficient use of resources to repair and maintain infrastructure, and using the latest innovations and technologies to provide the necessary community services. The need to pool ideas, share best practices and apply intelligent design to urban planning lies behind the Rockefeller Foundation's '100 Resilient Cities' initiative. North American cities chosen so far through a competition to be part of this initiative include: Berkeley, Boston, Boulder, Chicago, Dallas, El Paso, Jacksonville, Los Angeles, Montreal, New Orleans, New York, Norfolk, Oakland, Pittsburgh, San Francisco, San Juan, St. Louis and Tulsa. The initiative Peg provides an on-line platform for collating, interpreting and sharing information that allows citizens to learn what is changing in their city.

Portland, Oregon, is a case in point. In 1993, Portland, Oregon, was the first city in the US to create a local action plan for cutting carbon. Since then, the City of Portland and Multnomah County have collaborated to produce updated climate plans that help guide the design and implementation of city and county efforts to reduce carbon emissions (**Figure 4.3.1**).

Through such local efforts and global efforts like the C40 Cities Climate Leadership Group (Gordon 2013), urban greenhouse gas emissions may be on a downward trajectory at least in some parts of the world. But looking ahead, the long-term trend of reducing emissions across all of the world's major urban areas is unknown. The recent Paris Agreement has added momentum. Also, through state-level efforts, such as Cal-Adapt, tools and data are being developed to assist localities. Innovation and leadership at the city level is likely to continue as a trend in North America when it comes to addressing environmental concerns and making progress on many fronts.

4.3.2 Sustainable transportation

The transportation of people and goods underpins North American society. Transportation is a major source of both greenhouse gases and conventional air pollution. A more efficient, integrated transportation system that does

Box 4.2.2: Scenarios – Digital economy and networks society in Canada

The following set of scenarios provides a snapshot of plausible futures in which different emerging technologies are part of production and consumption systems in Canada. The scenarios illustrate the potential impact of these emerging technologies on the economy and on people's quality of life.

The Scramble 2025 (The Expected Future): In 2025, 50 per cent of the global population has the means and now participates in the digital economy. With the exception of a few large multinational firms, most firms are scrambling to keep up with the pace of change. The business-led, government supported digital skills training centres have been unable to keep up with demand. Many consumers buy customised digital goods and services but most are produced outside of the country.

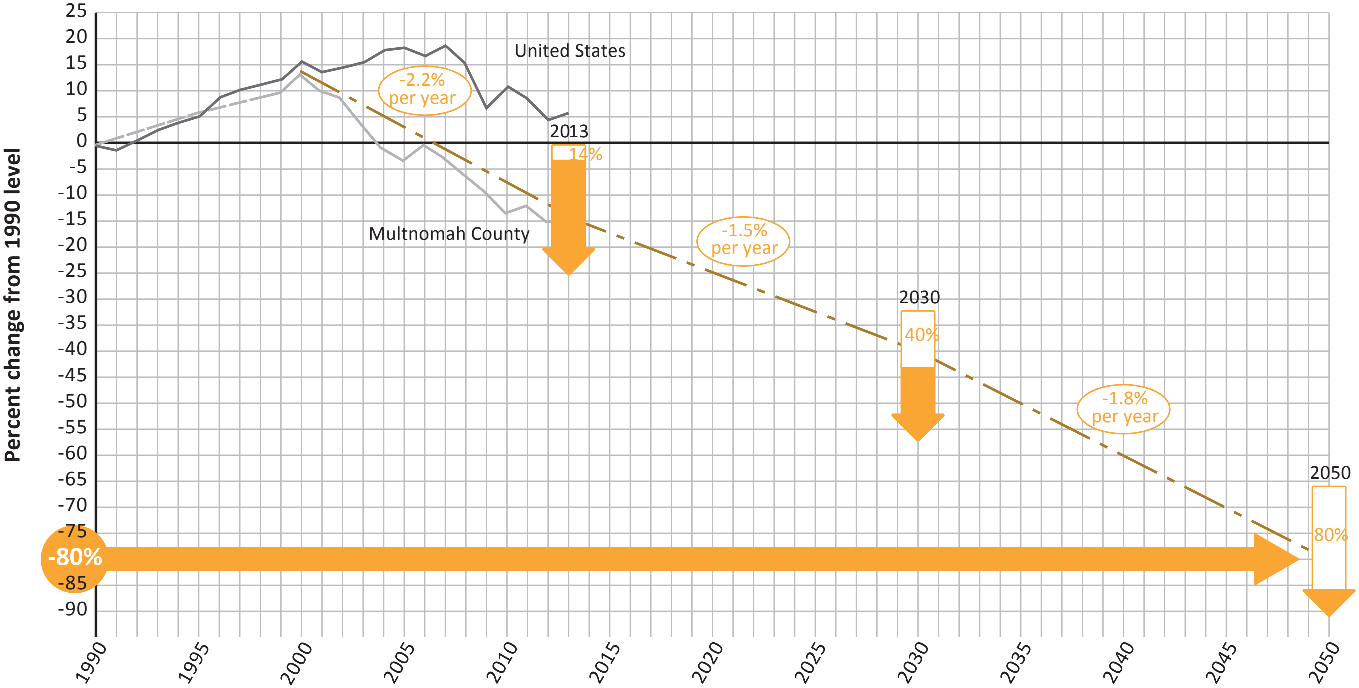
Global Consolidation 2025 (Incremental Decline): A number of large global firms are innovating and consolidating. They are using all available digital technologies to produce low cost but highly customised goods and services for the global middle class. As these technologies increase productivity with fewer workers, unemployment grows, particularly among workers who do not have the necessary skills and knowledge of the new technologies to be part of the emerging trend. For instance, new education modes have revolutionized education using artificial intelligence and data fusion to develop and certify "micro-skills" training in ten minute video segments funded entirely by advertising.

The Digital Economy Arrives 2025 (Incremental Progress): High technology innovation drives a new era of global prosperity and rapid change. Global supply chains become shorter and more digital. Innovations in 3D printing allow nimble investors to quickly customise a growing range of products. Fewer materials are moving around the planet. AI is incorporated in a growing number of smart products, which are sold as services: your running shoes and toilet connect through the internet to monitor your health which lowers your insurance. Data aggregated from many sources help identify emerging issues and offer a system-level analysis. Many government services are delivered automatically by smart software through citizens' smartphones, surfaces and glasses.

Leap-frogging to the Co–Creation Economy 2025 (Transformation): Rapid technological change produced high and persistent unemployment in many countries. By 2025, the infrastructure for a new kind of economy emerges enabling complex chains of people to organise the production and exchange of goods and services without using scarce money. The digital, traditional and emerging co-creation economies all continue to exist and feed global supply chains in different ways. Government is becoming far more agile and networked. Experiments with digital democracy build a rapid but evolving consensus from very diverse voices.

Source: Policy Horizons 2012

Figure 4.3.1: Reducing local carbon emissions in Portland and Multnomah County, 80% below 1990 levels by 2050



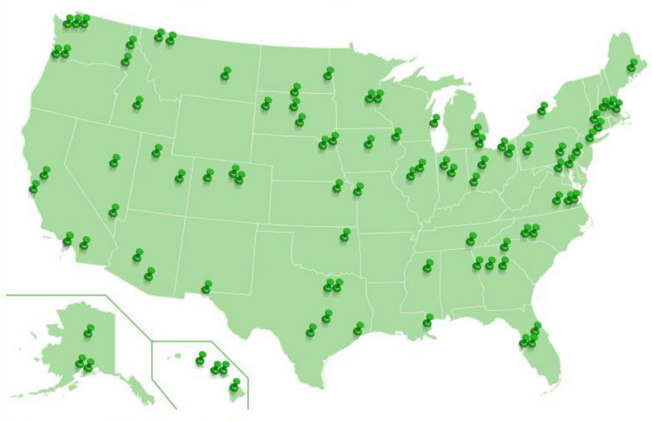
Source: City of Portland Bureau of Planning and Sustainability 2015

not pollute, promotes human well-being, contributes to sustainable development and to healthy communities is a prime example of a cross-cutting issue that addresses a number of the SDGs and targets. An example can be found in Manitoba's Centre Vision for 2035, with its focus on access and opportunities. Rather than transportation per se, it will include the economically disadvantaged and physical challenged. Under the programme there will be more public transportation and the integration of transportation with the layout and design of urban areas will be promoted.

To encourage sustainable transport, the US is carrying out various projects around the country (**Figure 4.3.2**). For example, in Los Angeles, emissions have been greatly reduced through development of public transport, bikeways and being the first major city to switch to compressed natural gas for its bus system (US DOT 2015a). Additionally in the US, the growth in annual vehicle miles traveled (VMT) has significantly slowed over the past 30 years and is expected to slow even more according to forecasts by the US Federal Highway Administration (2015).

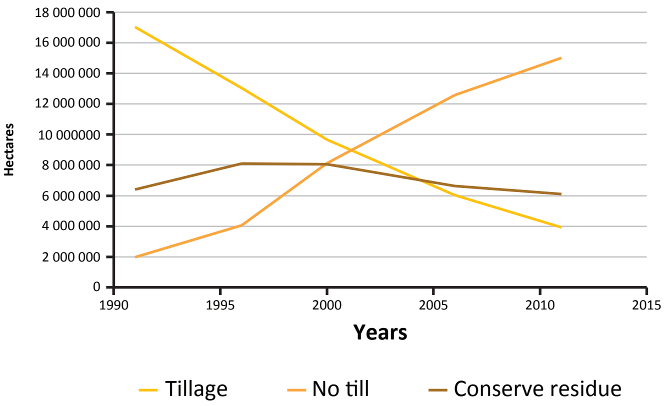
Finally, significant changes in the transportation especially in the cities are already emerging because of the use of smart-phones and mobile technology and due to increasing interest in electric vehicles. These lead to more efficient modes of transportation as well as reduction of emissions including greenhouse gases. For example, car pooling and ride-sharing services provide opportunities for users to access a car close to their location for the specific trip. These services operate

Figure 4.3.2: Sustainable transport projects across the US, 2015



A selection of federally funded transportation projects delivering modern, sustainable and environmentally responsible approaches to mobilise passengers and commercial cargo, while reducing the carbon footprint and improving efficiency
Source: US DOT 2015b

Figure 4.3.3: Tillage system trends in the Canadian prairies



Source: Statistics Canada 2015

both on a membership or single-use basis and allow users to tailor transportation to their needs in congested cities with limited and costly parking where owning a car is not feasible/ relevant anymore.

A more rapid than expected growth of the market for electric vehicles, signals the beginning of another shift in the North American transport sector. As battery costs are expected to continue to fall, this trend of increased adoption and promotion of electric vehicles is likely to continue. Along with existing plug-in hybrids and EVs from a range of automobile companies, these vehicles will slowly penetrate the automobile market and help to further reduce the environmental impacts of cars.

4.3.3 Climate-smart and sustainable agriculture

Management of natural resources such as land and water has critical impacts on our abilities to meet the needs of future generations and to respond to challenges such as climate change. Climate change in particular, coupled with other drivers such urbanisation and land degradation, threatens agricultural production. Climate-smart agriculture is an umbrella term used to describe the features of production that increase resilience of the agricultural systems, while reducing greenhouse gases. There are a number of ways to implement climate-smart agricultural practices including reducing tillage, managing land to reduce run-off, conserving water, and applying fertilisers and other substances in a more precise, targeted manner.

Reduced tillage and/or no till has a long tradition in Canada, and for example most of the farms on Canadian prairies have had reduced till or used no till since the 1980s. The benefits of such land management include reduced erosion, improved soil organic matter, and environmental benefits including improved soil and water quality, biodiversity and reduced greenhouse gas emissions (AAFC 2007). Similarly in the US, data published by the US Department of Agriculture (2010) show that approximately 35.5 per cent of US cropland planted to soybean, corn, cotton, rice, wheat, oats, sorghum and barley in 2009, 35.6 million hectares, had not been ploughed.

With the new and more effective monitoring, data collection and processing technologies, there is consistent progress in what is termed precision agriculture. Particular contributions of the geographical positioning systems (GPS) make it possible to precisely account for place-based characteristics such as topography, yield and nutrients and, based on that data, selectively apply fertilisers and use the most relevant land management techniques. In this way, inputs, run-off and soil erosion can all be reduced while yields are maintained (El Nahry *et al*. 2011). These advancements are being further enhanced by automated tractors and sprayers that can apply water, seeds, pesticides and nutrients in more targeted and timely ways. This precision could further be enhanced through slow-release pesticides. Finally, such automated agriculture could make indoor agriculture more viable in regions where the impact of climate change is degrading arable land, food supply and reliability.

Another critical trend that will likely play a bigger role in the future is the increasing interest in food quality and related improved tracking of food-related information for consumers. This process already started with labelling systems developed in the US. These US Organic labelling referring to any product that contains a minimum of 95 per cent organic ingredients (excluding salt and water) and Canadian Organic Standards revised in 2015 (Government of Canada 2015), as well as specific labelling schemes designed by the major groceries. The US Department of Agriculture (USDA) announced a significant increase in the number of certified organic operations, continuing the trend of double digit growth in the organic sector in 2016. According to new data, there are now 21 781 certified organic operations in the United States and 31 160 around the world (USDA 2016).

In the future we will likely be able to have more information about the quality of our food and trace food production as well as the path of food-borne diseases to a much higher degree. The recent USFDA report showed that an increasing number of people are following the food labels and making more educated dietary decisions (USFDA 2010). These changes are happening at the same time that both countries released updated regulations addressing their food safety

Figure 4.3.4: Logos for organic labelling in Canada and the US

Sources: USDA 2016; AAFC 2015

and labelling to better account for the dietary implications, food sourcing and cultural preferences of the consumers. Advanced technology including using smart-phones is already helping consumers to get better information on available foods by providing details on how and where the food is produced, and nutrition content and impacts of the used production systems on environment and society. Such mobile applications on food quality and availability include:

- The Seafood Watch developed by the Monterey Aquarium provides recommendations for seafood and sushi, and it helps to locate or share businesses that serve sustainable seafood. It also provides in-depth assessments on the sustainability challenges of the seafood industry.
- Applications that provide information on locally-grown products near the user location and help to locate farmers markets and provide to seasonal foods with minimal environmental impacts.
- Online food guides that based on the bar code of the product provide recommendations about the product health implications and environmental responsibility.
- Applications that provide specific advice for people with food allergies on what are a good food choices based on the product's bar code.

Another trend is to improve local food security and quality by promoting land conservation in cities for the expansion of urban and peri-urban agriculture. One example is in British Columbia, where the Ministry of Agriculture and Lands' recent publication *British Columbia Agriculture Plan: Growing a Healthy Future for B.C. Families* emphasizes the importance of locally grown food as an important contribution to food security through local production, environmental stewardship/climate change mitigation and linkages across the urban/agriculture divide (Mullinix *et al.* 2009).

We can expect that in the future these already established trends will continue yielding environmental benefits and better-informed consumers able to make healthier food choices.

4.3.4 Water management and conservation

In the North American context it is critical to explore possibilities for improving water efficiency and reducing overall water use – key areas for reducing water consumption are listed in **Box 4.3.1.** Addressing challenges of water use in production and consumption processes covers many sectors including agriculture, energy production, households and other industrial processes. It includes efficiency and campaigns to change consumer behaviour. Besides educational and awareness-raising campaigns, water metering is an effective tool to encourage behavioural change. For example, in 2011, 58 per cent of Canadian households were equipped with water meters compared to 52 per cent in 1991. When comparing water use, the data shows that average daily water use in Canada dropped by 27 per cent from 342 litres per person in 1991 compared to 251 litres per person in 2011 (Environment Canada 2014).

There are technological advancements in water management that will help us deal with climate change and put us on the path to sustainability. Among these are potentially significant opportunities in wastewater treatment to transition from an energy consuming sector to an energy producing sector. The energy contained in wastewater and biosolids exceeds the energy needed for treatment by 10-fold (WERF 2011). However, harnessing that energy to become net-zero energy or even net energy gains is quite complex. Additionally, energy can be the second-highest cost in the operation of water infrastructure facilities. Approximately 60 per cent of the energy used in wastewater treatment is for aeration, and one other common use of energy is simply for pumping water around the plant (WERF 2011).

Some promising energy production opportunities include anaerobic digestion of biosolids to produce biogas or incineration for thermal conversion to produce steam for power generation. The wastewater sector may very well become a green renewable energy source (Stillwell *et al.* 2010).

Another trend in water management is green infrastructure which is an approach to water management that protects, restores, or mimics the natural water cycle. Green infrastructure is effective, economical, and enhances community safety and quality of life (American Rivers 2016). The USEPA (2016b) defines green infrastructure as "a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits". Conventional grey stormwater infrastructure, including piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment. Green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits.

Green infrastructure incorporates both the natural environment and engineered systems to provide clean water, conserve ecosystem values and functions, and provide a wide array of benefits to people and wildlife. Green infrastructure solutions can be applied on different scales, from the house or building level, to the broader landscape level. On the local level, green infrastructure practices include rain gardens, permeable pavements, green roofs, infiltration planters, trees and tree boxes, and rainwater harvesting systems. At the largest scale, the preservation and restoration of natural landscapes (such as forests, floodplains and wetlands) which naturally filter water and provide other benefits are critical components of green infrastructure (Benedict and McMahon 2012).

Box 4.3.1: US EPA's 10 critical actions to conserve water

1. Conserving and recovering energy: many older water systems lack the energy efficiency improvements that can save money and make them more sustainable systems.
2. Recovering nutrients: nutrient pollution from industrial and agricultural operations has impacted the ecological health of surface water and ground water we depend on.
3. Improving and greening of the water infrastructure: with an aging water infrastructure, the US could benefit from retrofitting, improving, or replacing older systems.
4. Conserving and eventually reusing water: with growing populations and increased water demands, cities and states are encouraging conservation as a way to make the finite water we have stretched further.
5. Reducing costs and improving techniques for water monitoring: making smart choices about water management depends on collecting accurate and timely data. New monitoring and sensing technologies represent an opportunity for responsible stewardship of US water systems.
6. Improving performance of small drinking water systems: more than 94 per cent of the US public water supply systems serve fewer than 10 000 people. Many of the smallest systems, serving fewer than 500 people, struggle to meet drinking water standards.
7. Reducing water impacts from energy production: energy generation, resource extraction and growing feedstock all rely on significant amounts of water. As demand increases on the US energy supply, it will impact water systems.
8. Improving resiliency of water infrastructure to the impacts of climate change: in a changing climate, the distribution of water in the environment will challenge water infrastructure to meet the needs of those who depend on it.
9. Improving access to safe drinking water and sanitation: around the world, hundreds of millions of people still lack access to clean drinking water and sanitation.
10. Improving water quality of our oceans, estuaries, and watersheds: less than half of lakes, rivers, streams, and coastlines achieve a level of quality to safely allow for their intended uses.

Source: US EPA 2014

Improved water use efficiency and green infrastructure are just two examples of efforts to address water quality and quantity issues which will remain crucial in the North American region.

4.3.5 Green energy

The current and potential future growth of renewable energy, storage technologies, transmission expansion and improved energy efficiency is paving the way to development of a sustainable energy system. North America has abundant renewable energy resources that as yet have not been

Table 4.3.1: Energy Content of Wastewater

Constituent	Value	Unit
Average heat in wastewater	41 900	MJ/10°C ·10^3 m^3
Chemical oxygen demand (COD) in wastewater	250 – 800 (430)	mg/L
Chemical energy in wastewater, COD basis	12 – 15	MJ/kg COD
Chemical energy in primary sludge, dry	15 – 15.9	MJ/kg TSS
Chemical energy in secondary biosolids, dry	12.4 – 13.5	MJ/kg TSS

Source: WERF 2011

significantly utilised (**Table 4.3.2**.). Forecasts of the future utilisation of these sustainable resources vary, however, in general significant growth is anticipated (WNAS 2015; US EIA 2016).

Bloomberg New Energy Finance's annual long-term global forecast (BNEF 2015) predicts a general steady, global growth in solar power that is based strictly on economics and not policy. Within the US, at least through 2020, the growth in natural gas and the displacement of coal is expected to continue due to low wholesale prices. From 2020 onwards, the outlook forecasts significant growth in small-scale solar, with 21 gigawatt capacity added per year. This forecast is likely to be further reinforced by policy. The Clean Power Plan (US EPA 2015c) will tend to support the changes that reduce greenhouse gas emissions; however the plan has been, at least temporarily vacated by the US Supreme Court.

Also supporting this growth in solar power is the development of advanced battery technologies for power storage. This technology is needed to support decentralised and off-grid electricity production. Tesla Motors, for example, has announced the development of a residential-scale battery for storage of electricity generated by solar photo-voltaic (PV) panels that essentially generates and delivers power at point of use (Tesla 2015). Much of this growth is occurring in the utility scale markets as a result of frequency regulation market (see Section 3).

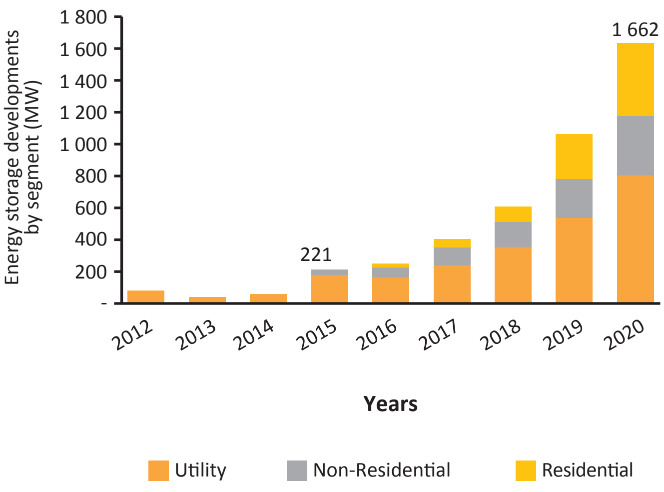
According to the US Energy Storage Monitor (2015) is on track for the most megawatts of storage deployment yet. Projections to 2020 for utility, residential and non-residential can be seen in **Figure 4.3.5** (US ESA 2015). These advances in battery storage technology coupled with falling prices for consumer solar electricity may truly change the dynamic of off-grid electrical production.

Landfill waste produces methane and other gases as they decompose, which can be used to produce electricity. According to the Environmental Protection Agency (EPA), as of July 2014, there are 636 operational projects in 48 states generating nearly 2,000 megawatts of electricity per year (National Waste and Recycling Association 2014). **Figure 4.3.6** shows the relative proportion of landfill gas use as a proportion of total energy use in the US as of 2014 (EIA 2015; National Waste and Recycling Association 2014).

Progress on energy efficiency is also accelerating across multiple sectors in North America including through the increasing use of electric vehicles. Energy efficiency trends are a result of new technologies, improved regulatory requirements, public private partnerships and changes in consumer behaviour.

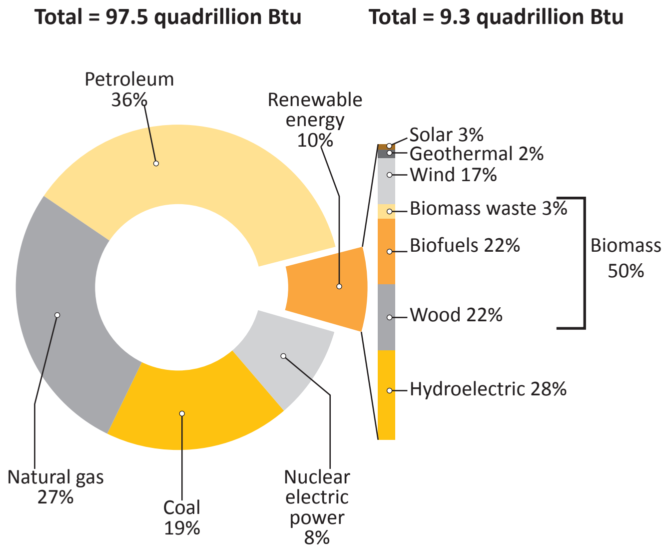
Despite these changes in alternative energy generation and energy efficiency, there remain significant issues with the consequences of energy development in North America. In particular, there are serious concerns with the consequences of hydraulic fracturing (fracking) to extract oil and gas from shale deposits, although this source of energy will continue to play a role in North America (**Figure 4.3.7**; Gielen *et al.* 2015, US EPA 2014).

Figure 4.3.5: Annual US Energy Storage Deployments (MW), 2012-2020



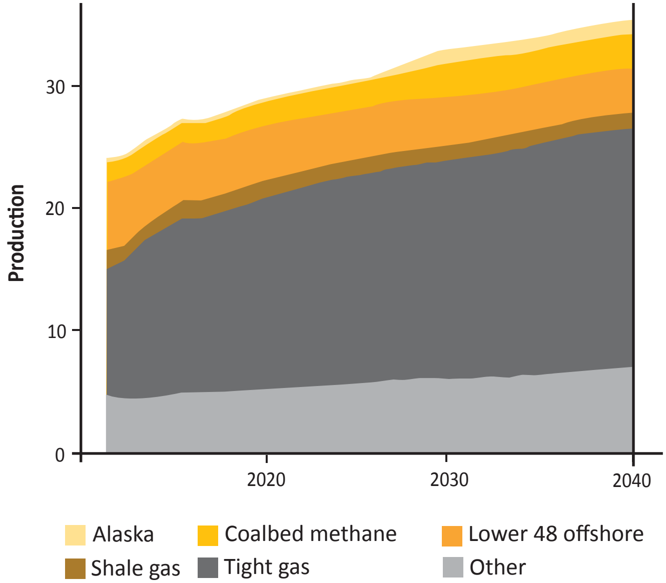
Source: US ESA 2015

Figure 4.3.6: US energy consumption by energy source, 2014



Source: Adapted from EIA 2015

Figure 4.3.7: US, natural gas production, historical developments and projection, 1990–2030



Source: US EPA 2014

4.4 Addressing challenges through the Sustainable Development Goals

4.4.1 Introduction

The 2030 Sustainable Development Agenda, comprised of 17 Sustainable Development Goals (SDGs) was adopted in September 2015 by the United Nations General Assembly. This agenda is both universal and integrated and seeks to balance the three dimensions of sustainable development: the economic, social and environmental (UNGA 2015). The 2030 Sustainable Development Agenda has been embraced by both Canada and the US (Government of Canada 2016; White House 2015). Of these 17 goals, 16 SDGs focus on specific issues, such as ending poverty and hunger, equitable quality education, achieving gender equality, ensuring sustainable management of natural resources and promoting sustained, inclusive and sustainable economic growth (**Figure 4.4.1**). Goal 17 aims to strengthen the means of implementation and

Table 4.3.2: US, renewable energy resource potential

	2012 Capacity	2012 Generation	Technical Potential (NREL)		REmap 2030		REmap 2030 Technical Potential	
	GW	TWh/year	GW	TWh/year	GW	TWh/year	% of GW	% of TWh
Solar PV (rooftop)	5.4	8.0	665	819	45	75	7%	9%
Solar PV (utility, urban)	1.9	3.6	1 218	2232	89	159	7%	7%
CSP	1	1	38 066	116 146	2.4	8	0.01%	0.01%
Wind (onshore)	60	140	10 995	32 784	314	994	3%	3%
Wind (offshore)	0	0	4 224	16 976	42	160	1%	1%
Biopower (solid) (production)	12	50	51	400	74	401	145%	100%
Biopower (gaseous) (production)			11	89	4	89	38%	100%
Geothermal (hydrothermal)	3	15	38	301	24	184	63%	61%
Geothermal (EGS)			3 976	31 345				
Hydropower	78	276	153		114	431	75%	

Source: Gielen *et al.* 2015

revitalise the global partnership for sustainable development were submitted developed (**Figure 4.4.1**). Government and organisations at multiple levels are exploring the potential means of implementation, monitoring and reporting for the 2030 Sustainable Development Agenda, as well as the potential implications of the set of SDGs for the national and sub-national accountability and reporting processes in Canada and the US.

4.4.2 Applying SDGs in North America

While all the SDGs emphasize sustainability, there are specific SDGs to address climate change, human health, hunger and agriculture, water, terrestrial ecosystems and forests, biodiversity, cities, oceans, sustainable consumption and production, and energy.

The 17 goals are highly integrated and cannot be implemented in isolation. For example, the second goal that focuses on hunger and sustainable food production also aims to promote an agricultural system resilient to climate change. The 11th goal, regarding cities and human settlements, also emphasizes the importance of reducing the adverse per capita environmental impact of cities. Goal number 12, on sustainable production and consumption, requires sustainable management and efficient use of natural resources. Increased action on reductions in greenhouse gas emissions, and increased attention to the challenge of sustainable consumption and production, are among many examples illustrating the priority that the region is placing on meeting global responsibilities. The desire for better integration is also reflected in the proliferation of multi-sectoral policy initiatives that seek to identify and implement actions. These linkages indicate that implementation needs to be based on an integrated strategy that brings together all aspects of sustainable development. While at first glance some of the SDGs seem to apply primarily to situations in the developing world, most still

Figure 4.4.1: The Sustainable Development Goals

On 25 September 2015, a new global agenda to end poverty by 2030 and pursue a sustainable future was unanimously adopted by the 193 members of the United Nations. The historic adoption of the new Sustainable Development Agenda, with 17 global sustainable development goals (SDGs) at its core, marks the beginning of new 15-year journey of national action and international cooperation. The SDGs commit every country to take an array of actions that will not only address the root causes of poverty, but also increase economic growth and prosperity and meet people's health, education and social needs, while protecting the environment.
Source: UNDG 2015

resonate with the North American situation, as well as directing ways in which developed countries can provide assistance to developing ones.

Currently, both Canada and the US are in the midst of coordination efforts to identify how to implement the SDGs nationally and to assist other countries to achieve the SDGs. In Canada, a new Federal Sustainable Development Strategy for 2016 – 2019 has been developed and is currently undergoing public consultation (Government of Canada 2016). This strategy focuses primarily on environmental issues, but for these it links Canadian priorities to relevant SDGs. Clearer guidelines on national implementation can be expected in the end of 2016 and in early 2017. An example of the US commitment to the SDGs is the work of USDA and US EPA on Food Waste with a pledge to reduce food waste by 50 per cent by 2030 (target 12.3).

So far, academia, unions and non-governmental agencies have been promoting the need—in both countries—to integrate SDGs into national and sub-national planning. There are a number of existing and ongoing policies and programmes in Canada and the US dealing with relevant issues for the 2030 Agenda that can be used as vehicles to implement SDGs in the future.

Box 4.4.1: Relevance of SDG 12 on sustainable consumption and production for North America

Among many priorities relevant for SDGs in the region, sustainable consumption and production (SCP) is critically important to the transition pathway to a sustainable low carbon economy. Critical relevance of goal 12 on SCP for North America, include:

Waste reduction: efforts to reduce waste, such as food waste, may require more efficient use of resources or ensure that products are reused or recycled instead of ending up in landfills. Less waste means more efficient use of resources and less impact such as reduction in GHGs from agriculture and transportation.

Resource efficiency: efforts toward resource efficiency may mean the redesign of existing systems to consume more renewable resources and fewer non-renewable ones, preserving and conserving ecosystems and natural resources, renewable and non-renewable.

Consumer behaviour: efforts toward changing consumer behaviour that focus on education about ecological footprints and the difference between needs and wants, caution that, for a sustainable future, individual need (in any region) cannot be infinitely elastic on a planet with increasing population and finite resources.

In each instance, SCP points to a nexus of human activity and environmental systems. While now more is known than ever before about the nature of that nexus, we are reminded by a changing climate that the effects of such interaction are reciprocal. Environmental conditions constrain as well as enable human activity. Working toward the SDGs and toward SCP, both in a North American context and in contributions toward sustainable development elsewhere, requires a better understanding of the human-environmental systems most at risk or under pressure in a world in which the climate is changing. Whether it is the provision of fresh water for all, the eradication of poverty, the improvement of air quality, or the enhancement of soil fertility, how people interact with local ecosystems as we produce and consume affects how they are able to live together toward a sustainable future.

Source: US EPA 2014

The SDGs provide an opportunity to help frame the development agenda within the region and help guide implementation for the next 15 years as we move toward a global sustainable future. In the following section we review key tools and approaches to governance and policy-making that aim to advance sustainability in the two countries and contribute to achieving SDGs. Many of these opportunities discussed here are already being implemented. However, they will likely need to become more widespread to make an impact at the regional scale over the coming 15 years.

4.5 Managing the transition – the role of governance, planning and monitoring

Given the nature of sustainability, the relevant data and its interpretation need to include traditional sources and methods, but also to go beyond them to measure what is required. Qualitative as well as quantitative assessment is therefore required, especially when consideration is given to alternative data sources. Some of the resources and approaches available for this comprehensive monitoring and evaluation are noted here briefly. The following sections summarize opportunities and challenges to manage the transition towards a sustainable future by focusing on policy development and planning, the data revolution and monitoring efforts. This section combines already-tested approaches with new approaches that if adopted widely could significantly accelerate the needed transition.

4.5.1 Measuring growth for a sustainable future

Governments in every developed nation are focused on monitoring and reporting on economic conditions with regular quarterly and annual economic data and gross domestic product (GDP) trends. Compared with this, governmental efforts to report on the environment are weak. This is also partly due to monitoring challenges, as well as the difficulty to monetise many environmental contributions the same way as key sectors of economy. The imbalance in the effort devoted to measuring the economy and the environment is just one reason for concern. Equally troubling is the narrow focus of economic measures themselves, which centre mainly on a small suite of highly influential macroeconomic indicators. Of these, GDP is the best known. While of clear importance in managing the economy, GDP and its counterparts all suffer from a bias toward short-term economic conditions. Much less attention is paid to understanding the foundations that ensure the long-term viability of the economy: that is, our wealth. Alternative metrics are being developed to include environment and social aspects of development.

The most frequently used term in discussions regarding alternative metrics is 'beyond GDP', to rather focus on wellbeing of people and the planet. This includes efforts to identify and measure parameters that relate to the quality of life for both individuals and local communities. A concern for quality of life, moreover, must be part of the conversation about sustainability; a higher quality of life may be advocated in response to the reduction in material wealth that sustainable levels of consumption require.

Ecosystems-based accounting

Just as well-being is not part of GDP-based accounting, neither is the environment. Ecosystems provide an array of valuable services to people, but typically are not well accounted for in national regulatory decision-making processes. Canadian valuation efforts include work to develop the Environmental Valuation Reference Inventory (EVRI) database managed by Environment Canada to bring relevant information on costing ecosystem services based on available studies and publications (EC 2011b).

In 2011, the US President's Council of Advisors on Science and Technology (PCAST) produced a report, Sustaining Environmental Capital: Protecting Society and the Economy. In it, the authors cite Kumar's (2010) estimates of the values of different ecosystems and their services (**Table 4.5.1**)

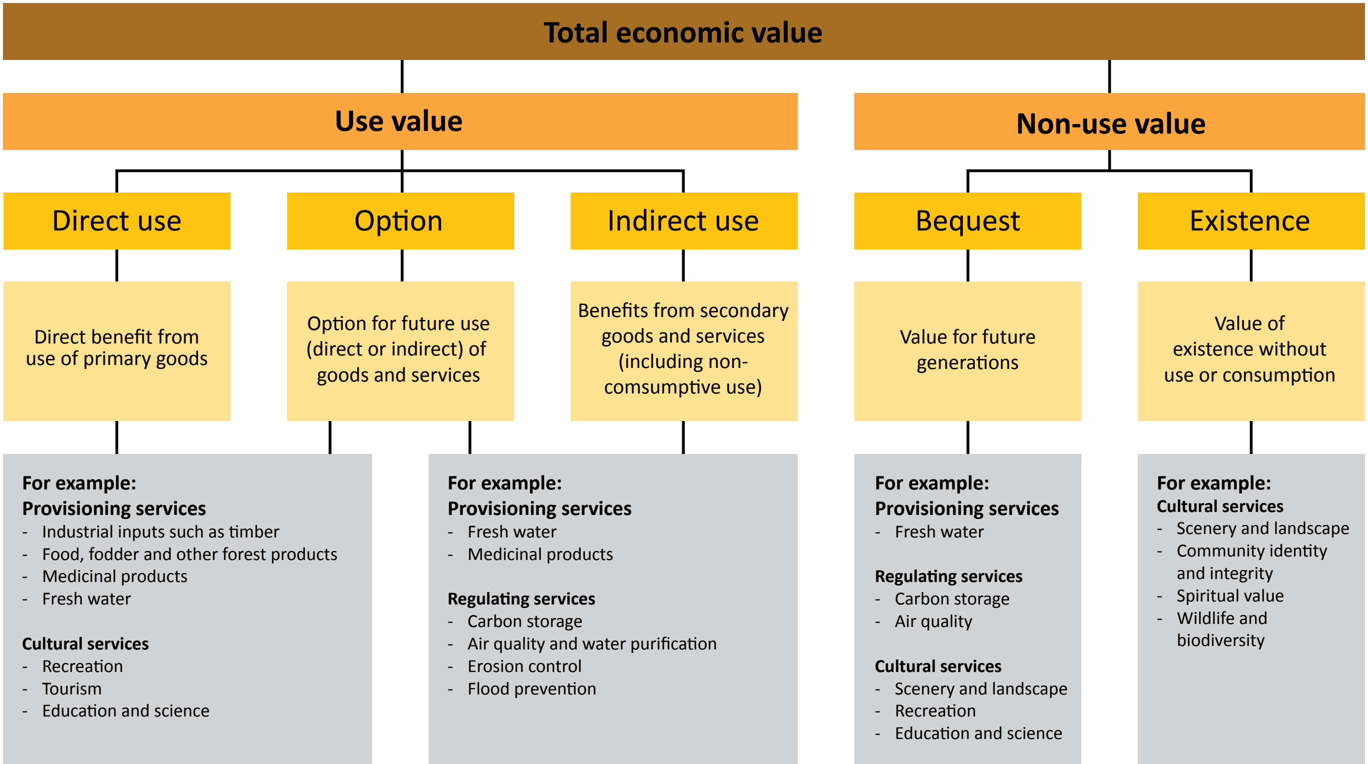
Genuine Progress Indicators

Another approach that provides a more inclusive metric to better account for wellbeing and environmental impacts of development utilises a set of indicators, the so called "Genuine Progress Indicators." Use of these indicators is based on the notion that it is important to environmental policy that these services are properly accounted for in regulatory decision making (Daly and Cobb 1989).

The 2012 Canadian Index of Wellbeing defines well-being as "the presence of the highest possible quality of life in its full breadth of expression focused on but not necessarily exclusive to: good living standards, robust health, a sustainable environment, vital communities, an educated populace, balanced time use, high levels of democratic participation, and access to and participation in leisure and culture." This approach, using these general categories, has been applied to Ontario, and one sees that during this time period, GDP rose much more significantly than did well-being (Canadian Index of Wellbeing 2012).

Similarly, in the US a number of State governments have also concluded that traditional economic measures do not

Figure 4.5.1: Example of an ecosystem valuation framework



Source: Kumar 2010

accurately depict the health and welfare of their communities, and are not, on their own, the best way to make budgetary and policy decisions. Thus, several US States have begun to use the Genuine Progress Indicator (GPI) to complement their Gross State Products. The policy application of the GPI is to gauge whether economic growth effectively improves well-being (Genuine Progress Indicator). For example, Maryland has seen its economic component increase dramatically, while social and environmental indicators have remained flat or declined (Daly and Posner 2011; McElwee 2014).

Inclusive wealth approach

This approach was developed by UNEP as part of the broader coordination with other efforts within the beyond-GDP domain such as the OECD, French government efforts and World Bank initiatives. The framework sets out to measure and track four categories of assets: produced capital, natural capital, human capital, and social capital. Taken together, these make up inclusive wealth. The focus of this approach is to develop a comprehensive accounting system to look in detail not only on produced capital that is often captured in the GDP, but also look at enabling factors such as human and natural capital. This approach allows identifying unsustainable trends such as increased produced capital and declining natural capital or low human capital and increasing produced capital indicating that economic growth occurs by also depleting natural resources and/or by low-skilled jobs with low added value. The UNEP inclusive wealth framework, was applied at the global level and resulted in two global inclusive wealth reports in 2012 and 2014 (UNU-IHDP and UNEP 2012; UNU-IHDP and UNEP 2014). The latest report included experimental estimates for 140 countries, including Canada and the US.

Inclusive wealth is a more effective metric than GDP, even though some of its elements lend themselves more to qualitative rather than quantitative assessment. It is an extension of the idea of "natural capital" to include the social and cultural capital that just as clearly must be conserved and preserved if we are to create a sustainable future.

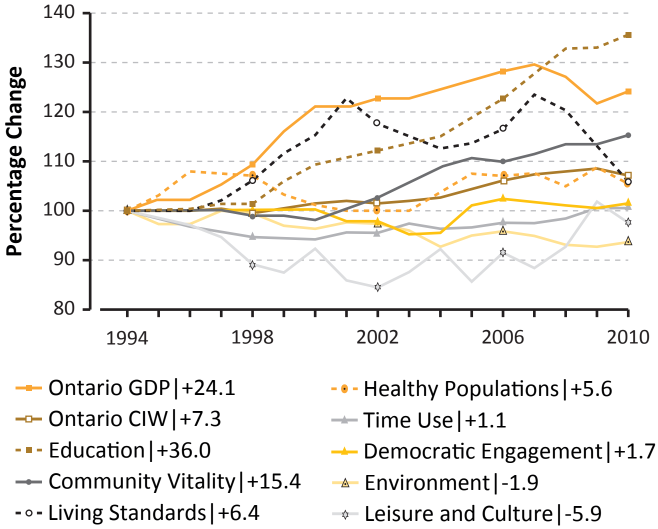
4.5.2 Governance and planning approaches to address uncertainty and complexity

The complexity of issues across North America, combined with the uncertain dynamics of climate change, necessitates that an adaptive approach be used for both planning and policy design to effectively manage the transition to sustainability. In analysing future scenarios for environment and development, the GEO 5 report came to a similar conclusion from a global perspective and put forth the notion of an adaptive and integrated cross sectoral approach to governance as a way forward (UNEP 2012).

Adaptive planning

The focus of approaches on adaptive planning is to ensure that developed plans and policies are flexible enough to address challenges as they occur and at the same time to allow exploration of opportunities. The core components of this approach are to work with future scenarios to determine what is possible and to engage stakeholders' to identify additional trends and opportunities and get feedback on what are acceptable risks and responses. This can be distilled to five key components, including: (1) Multi-actor deliberation and agenda building; (2) Futures analysis and long-term collective goal setting; (3) Enabling self-organisation and networking; (4) Variation, experimentation and innovation; and (5) Reflexivity and adaptation.

Figure 4.5.2: Trends in the Canadian Index of Wellbeing for Ontario from 1994 - 2010



Source: Canadian Index of Wellbeing 2012

For example, US Government Accountability Office (GAO), responding to congressional concerns about the federal government's fiscal exposure to national flood and crop insurance programmes, undertook a comprehensive review of the insurance programmes including an expert review of over 20 studies and private and public sector data and interviews with agency officials and insurance providers (US GAO 2014b). The GAO report highlighted specific concerns and put forth recommendations to the Federal Emergency Management Agency and the Risk Management Agency outlining potential policy improvements. In Canada, the Manitoba Agriculture Risk Review Task Force was created in 2015 to evaluate existing programmes and policies aimed at helping producers recover from climate-related challenges, and to explore improvements to risk management programming.

Integrated forward-looking approaches to planning

Decision-makers face a number of challenges across social,

Table 4.5.1: Estimates of values of different ecosystems

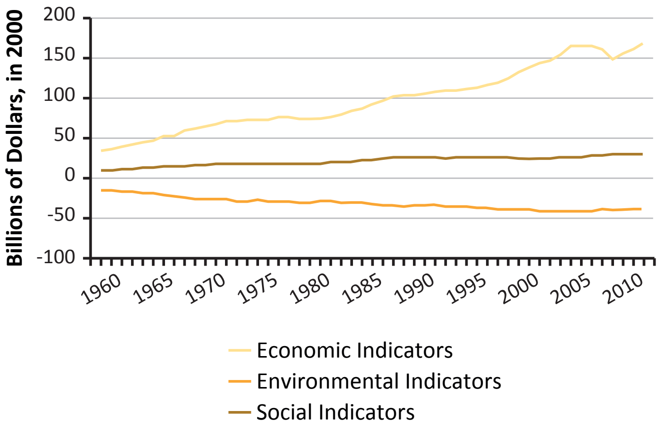
	Minimum USD/ha/yr				Maximum USD/ha/yr			
	Provisioning	Cultural	Regulating	Habitat	Provisioning	Cultural	Regulating	Habitat
Coral reefs	6	0	8	0	28 892	1 084 809	33 640	56 137
Open oceans	8	0	5	0	22	0	62	0
Coastal systems	1	0	170	77	7 549	41416	30 451	164
Coastal wetlands	44	10	1 914	27	8 289	2904	135 361	68 795
Inland wetlands	2	648	321	10	9 709	8399	23 018	3 471
Rivers and lakes	1 169	305	305	0	5 776	2733	4 978	0
Tropical forests	26	2	57	6	9 384	1426	7 138	5 277
Temperate forests	25	1	3	0	1736	96	456	2 575
Woodlands	7	0	9	0	862	0	1 088	0
Grasslands	237	0	60	0	715	11	2 067	298

Source: Kumar 2010

economic and environmental domains. Most of these challenges are dynamic and intertwined pointing to a need to design policies that are able to account for uncertainty and address the complexity and unintended consequences of policy decisions and actions (Bazilien *et al*. 2012)—all in a multi-stakeholder context. For governments and policy-makers, this requires proactively and effectively identifying points for intervention within the complex structures and systems and ensuring interventions are able to adjust to changes in the system (World Economic Forum 2012).

A critical part to address such complex future challenges and to advance sustainability in the region is to improve integrated and strategic approaches on planning. The core component of such approaches is to enable effective integration between different sectors, different agencies and different types of policy instruments such as regulations, incentives, voluntary schemes and awareness raising efforts. Such an integrated approach is not only relevant for government planning, but also business planning that increasingly needs to account for their whole-value chain. Additionally, the complex nature of the systems that are at play necessitates that solutions be conceived and implemented through collaboration at multiple levels of governance. In particular, when implementing cross-sectoral, multi-dimensional strategies the importance of vertical coordination and collaboration across different levels of governance is crucial for addressing

Figure 4.5.3: Genuine Progress Indicator



Sources: Adapted from Daly and Posner 2011; McElwee 2014

Table 4.5.2: Types of capitals in inclusive wealth and their availability in Canada and US

Capital	Definition	Canada	US
Produced capital	Includes roads, railways, ports, buildings, machinery and a wide variety of other built assets.	18% of the total capital	21% of the total capital
Natural capital	Includes timber, minerals, oil and gas. It also includes ecosystems of all kinds; wetlands that help create clean drinking water, and forests.	31 % of the total capital	7% of the total capital
Human capital	Formal education is an important source of human capital but on-the-job learning and what we learn from our families and peers is equally important.	51% of the total capital	72% of the total capital
Social capital	The social and cultural institutions that make up social capital dictate the use, distribution, and value of the other capital assets and therefore play an important role in creating wealth.	No estimates	

Source: UNU-IHDP and UNEP 2014

sustainability and promoting integration. Scenario planning tools provide opportunities to bring together these planning needs.

Planning tools, such as scenario planning, provide a more direct means to couple integrated and forward-looking analysis into one process. In the United States, the Federal Highway Administration (US FHWA) uses scenario planning as an analytical tool for transportation professionals to gain a better understanding of potential challenges and then adjust strategies, policies and internal planning procedures. Similarly, Policy Horizons of the Government of Canada focuses on developing foresight and scenarios over medium time horizons for current pressing issues such as emerging technologies, educational change, and regional development and disparities at the global level. The scenario planning approach, generally, provides a structured framework for analysing various forces that contribute significantly to future development and for creating shared visions.

4.5.3 Data revolution - data access and participation

To measure progress toward sustainability, including progress under the SDGs, and to be able to adjust the course of actions, good-quality and timely information is necessary. Recently, we saw an increase of both data availability, such as through the open-data movement as well as greater participation of citizens and other agencies to engage in data collection and data analyses. There has also been an increase in the use of data to inform strategies and actions. Thus, the current approach to data collection and monitoring combines both advancement in monitoring systems, and greater engagement with citizen science.

Advancement in mobile technology

Recent advancement in mobile technology, the use of smart phones and various applications can be already seen as powerful tool to encourage sustainable behaviour (See discussions in Sections 2.4, 2.9 and 3.3). These tools help for example by proving relevant and all-the-time accessible information for consumer for example of the environmental impacts and origins of the products, by optimizing transportation systems by allowing users to engage in car and ride sharing and by connecting people with skills to assist others and those in need.

It is to be expected that in the future the connection between service providers and users, citizens sharing common interests and governments at all levels will advance. It is important to consider these new technologies as tools for promoting sustainable behaviours directly with citizens as well as tools for citizens to increase the accountability of governments and businesses in their efforts to achieve sustainability and the SDGs.

Citizen science

Working with citizens to improve data collection, monitoring and data analyses can be a useful tool in addressing environmental challenges (Cigliano *et al*. 2015; Aceves-Bueno *et al*. 2015). Especially in areas such as water and air pollution and biodiversity, there are considerable efforts to engage citizens and to support limited capacities in monitoring and reporting agencies. A key advance in citizens' engagement in monitoring can be attributed to progress in mobile technology and applications allowing uploading of real-time data, measurement and pictures. For example, the US EPA has online pollution monitoring apps allowing citizens to directly measure neighbourhood air quality levels (US EPA 2012). The power of these tools is still under development as the technology advances and new applications for data collection and monitoring are being developed. Furthermore, citizen science cannot only be used to provide data for monitoring, but rather to conduct targeted data collection to inform law and regulations enforcement. A good example of such role of citizens' engagement and the use of citizen science in enforcement is the coastal migratory whale monitoring system along the coastline of British Columbia, in which some 1 500 trained volunteers submit sightings of migratory whales to the Vancouver Aquarium. Another example is the US-based Bucket Brigade, which empowers people to collect data to test air quality for harmful exposure of toxic particles and chemicals such as volatile organic compounds (VOCs) (Vaughan 2014).

Finally, opportunities in citizen science are prompting government agencies to rethink and introduce new policies linking new sources of data with management and compliance. This includes looking at new technologies to measure pollution emissions as well as looking at how the decision-makers can make better use of new technologies and link these technology opportunities with new compliance tools in enforcement.

Advanced monitoring systems

Satellites allow for an ever-expanding set of certain types of data, but require a significant commitment in order to process and interpret the information in a timely manner. The volume of data, moreover, and the resources required to process it, may push other kinds of data collection to one side and thus skew the depiction of global problems at the ground level. Only an on-going and increasing commitment to both data collection and interpretation will enable science policy decisions to be made on the basis of the most pertinent and recent scientific observations. With competing demands for financial resources, however, such support may not materialise.

The question therefore becomes one of priorities and whether data about climate change, needed to inform policy decisions, will take precedence over other priorities. In part, this gap between the funding needed to process more scientific data and what is provided may be addressed through creative approaches to its interpretation. The other types of information that indigenous local knowledge systems provide would also complement other data by filling in gaps or by providing insight into other, less easily measured dimensions of natural systems. It is not a question of amassing all the data there is – it is about getting all the data possible, and then using it to provide a dynamic framework for policy making.

While the focus of this outlook is environmental, because of the social and cultural dimensions of sustainability, the human element cannot be excluded. Civil society groups and organisations not only effectively deliver local programmes, but they are more likely to be aware of changing local conditions. An emphasis on citizen science, through which innovative tools enable citizens to contribute local scientific data, for example by mobile phones, not only reduces the cost of acquiring the information, but also engages a larger group of people in understanding what is going on in their

Table 4.5.3: General steps of scenario planning and modes of application in the policy process

Phases	Stress Testing (adaptation)	Scenario Analysis (forecasting)	Visioning (Backcasting)
Foresight	Identify the plan or strategy and clarify the focus question and indicators of success	Clarify the focus question and indicators of success	Clarify the focus question and indicators of success
	Identify key drivers of change and critical uncertainties	Identify key drivers of change and critical uncertainties	Identify key drivers of change and critical uncertainties
	Develop array of plausible scenarios	Develop array of plausible scenarios	Develop desired vision of the future
Insight	Assess vulnerabilities and opportunities	Address the focus question in the context of the plausible scenarios	Identify a plan of action that can achieve the desired future
	Identify adaptive actions	Identify recommendations	Perform stress test (column 1) of the plan of action
Action	Implement adaptive actions	Outreach and communication	Implement plan of action
	Monitoring, adaptation and continuous improvement	Monitoring and scenario updating	Monitoring, adaptation and continuous improvement

Source: Swanson *et al.* 2014

local communities and ecosystems. In addition to providing a new source of data, it makes it easier to persuade people of the consequences of their observations and thus make them more supportive of the resulting policy decisions, thereby enabling the kind of local social and cultural transformation that a sustainable future requires.

4.6 Conclusion

The environmental outlook for North America is unfolding in a context of improved environmental conditions. Because of the rich bounty of natural resources and decades of efforts to remove the most glaring pressures, the state of the region's air, water, land and biota is quite good. The region has a low environmental burden of disease, one of the richest biodiversity levels in the developed world, and large expanses of majestic natural beauty.

North American responses to environmental challenges reflect the diversity, energy and ingenuity of the region. In some cases, the traditional policy instruments that helped drive the progress of recent decades have begun to focus on these new challenges. In other cases, less traditional approaches such as public-private partnerships, multi-stakeholder coalitions and citizen engagement campaigns are rising to the challenge. The heritage of relying on rigorously collected data, integrated into robust decision-making processes, has been adapted to new forms of data and new situations to address these challenges.

North America has the means and opportunity to provide global leadership in efforts to achieve a sustainable future. A clear way that this can be done is by exhibiting leadership in implementing the 2030 Sustainable Development Agenda and the SDGs, both at home and abroad. North Americans can find ways to address the social and cultural implications of transitioning the North American economy to one that is based on resource efficiency and sustainable into the future. Efforts need to focus not only on solving North America's environmental problems, but also on providing the tools, models, skills and information that developing countries require to deal with their own.

Box 4.5.1: Examples of long-term well-established citizens-based monitoring systems in North America

- The Ontario Reptile and Amphibian Atlas is a citizen-science project that tracks distributions and spatial trends of reptiles and amphibians across the province over time.
- Citizen Scientists is a volunteer driven, not-for-profit group that focuses on ecological monitoring, environmental training and education.
- NatureWatch is a community that engages all Canadians in collecting scientific information on nature to understand the changing environment.
- Puget Sound Partnership is a programme to coordinate and implement a shared, science-based system of measurement and monitoring that allows assessment of collective actions.
- Celebrate Urban Birds is a project developed and launched by The Cornell Lab of Ornithology to engage diverse urban audience in citizen science and scientific investigation.
- The National Weather Service (NWS) Cooperative Observer Programme is the US's weather and climate observing network where nearly 9,000 volunteers participate in observations on farms, in urban and suburban areas, National Parks, seashores, and mountaintops.
- Landscape Watch Hampshire is an innovative new community project to characterise the county's landscape in 2005 and 2013 by analysing aerial photos held by Hampshire County Council and thereby identify the changes that have taken place over a period of eight years.
- Monarch Watch is a non-profit education, conservation, and research programme based at the University of Kansas that focuses on the monarch butterfly, its habitat, and its fall migration.
- Bug Guide is a US-Canada initiative to collect information and photographs of insects to monitor species location and phenology and create a regional knowledge community;
- E Butterfly is a real-time, online checklist and photo repository to report, organise and access information about butterflies in North America.

See links for Chapter 4

See references for Chapter 4

Acronyms and abbreviations

10YFP	10-year Framework of Programmes (on Sustainable Consumption and Production)
AAFC	Agriculture and Agri-Food Canada
AC	Arctic Council
ACAP	Arctic Contaminants Action Programme
ACEEE	American Council for an Energy Efficient Economy
AEO	Annual Energy Outlook
AI	Artificial intelligence
AMAP	Arctic Monitoring and Assessment Programme
AMOC	The Atlantic meridional overturning circulation
ANTHC	Alaska Native Tribal Health Consortium
AR4	Fourth Assessment Report
ATFS	American Tree Farm System
AVHRR	Advanced very high resolution radiometer
AWWA	American Water Works Association
BAT	Best available technology
BEA	Bureau of Economic Analysis
BECCS	Bioenergy with Carbon capture and Sequestrations
BISON	Biodiversity Information Serving Our Nation
BMP	Beneficial management practices
BNEF	Bloomberg New Energy Finance
CA	Calcium
CAAQS	Canadian Ambient Air Quality Standards
CAFE	Corporate Average Fuel Economy
CEC	California Energy Commission
CanWEA	Canadian Wind Energy Association
CAP-EPR	Canada-wide Action Plan for Extended Producer Responsibility
CBD	Convention on Biological Diversity
CBFA	Canadian Boreal Forest Agreement
CBP	Chesapeake Bay Program
CCA	Canadian Council of Academies
CCAC	Climate and Clean Air Coalition
CCEMC	Climate Change Emissions Management Corporation
CCFM	Canadian Council of Forest Ministers
CCME	Canadian Council of Ministers for the Environment
CCP	Cities for Climate Protection

CCRS	Canada Center for Remote Sensing
CCTF	Canadian Climate Change Task Force
CDWR	California Department of Water Resources
CEAA	Canadian Environmental Assessment Act
CEC	Commission for Environmental Cooperation (under NAFTA)
CEC	Contaminants of Emerging Concern
CEEA	Canadian Environmental Assessment Act
CEPA	Canadian Environmental Protection Act
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CESD	Commissioner of the Environment and Sustainable Development
CIA	Central Intelligence Agency
CIESIN	Center for International Earth Science Information Network
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLEO	Circumpolar Local Environmental Observer
CLRTAP	Convention on Long-range Trans boundary Air Pollution
CO	Colorado
CO_2	Carbon dioxide
CoCoRHaS	Community Collaborative Rain, Hail and Snow Network
COD	Chemical oxygen demand
CONANP	National Commission of Protected Natural Areas
COP21	21st Conference of the Parties (under the UN Framework Convention on Climate Change)
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRISPR	Clustered regularly-interspaced short palindromic repeats
CSAPR	Cross-State Air Pollution Rule
CWFC	Canadian Wood Fibre Centre
CWS	Canada-wide standards
DACS	Direct Air Capture and Sequestration
DAL	Dependable agricultural land
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DEFRA	Department for Environment, Food and Rural Affairs
DFO	Fisheries and Oceans Canada
DOC	Department of Commerce
DoD	Department of Defence
DOT	Department of Transportation
EC	Environment Canada
EJ	Environmental Justice
EPA	Environmental Protection Agency (United States)
ECCC	Environment and Climate Change Canada

EfW	Energy-from-waste
ELA	Experimental Lakes Area
ELOHA	Ecological Limits of Hydrological Alteration
ENSO	El Niño Southern Oscillation
EPRI	Electric Power Research Institute
EQIP	Environmental Quality Incentives Program
ERMA	Environmental Response Management Application
ERS	Economic Research Service (United States)
EU	European Union
EVRI	Environmental Valuation Reference Inventory
FCOP	Forest Carbon Offset Protocol
FCSAP	Federal Contaminated Sites Action Plan
FEMA	Federal Emergency Management Agency
FF4F	Food and Fuel for the Forces
FGDC/NVCS	Federal Geographic Data Committee/Vegetation Classification Standard
FIP	Forest Innovation Program
FL	Florida
FWS	The United States Fish and Wildlife Service
GA	Georgia
GAO	US Government Accountability Office
GBIF	Global Biodiversity Information Facility
GDP	Gross domestic product
GEO	Global Environment Outlook
GHGs	Greenhouse gas emissions
GIS	Geographic information system
GLFC	Great Lakes Fishery Commission
GLWQA	Great Lakes Water Quality Agreement
GPI	Genuine Progress Indicator
GPS	Geographical positioning systems
GRACE	The Gravity Recovery and Climate Experiment
GW	Gigawatts
HABs	Harmful algal blooms
HAER	Human Activity and the Environment Report
HCC	Halifax Chamber of Commerce
HRM	Halifax Regional Municipality
ICCATF	Interagency Climate Change Adaptation Task Force
ICLEI	International Council for Local Environmental Initiatives
IEA	International Energy Agency

IGBP	International Geosphere Biosphere Program
IISD	International Institute for Sustainable Development
IJC	International Joint commission
IMO	International Maritime Organisation
INDCs	Intended Nationally Determined Contributions
IPCAP	Indigenous Peoples Contaminants Action Programme
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISARM	Internationally Shared Aquifer Resources Management Initiative
ITC	Investment Tax Credit
IUCN	International Union for Conservation of Nature
IWRM	Integrated water resources management
JPAC	Joint Public Advisory Committee
LCA	Life-Cycle Assessment
LEO	Local Environmental Observer
LIDAR	Light Detection And Ranging
MA	Millennium Ecosystem Assessment
MATS	Mercury and Air Toxics Standards
MBBR	Monarch Butterfly Biosphere Reserve
MCL	Maximum Contaminant Level
MD	Maryland
MFCN	Marine Fish Conservation Network
MGD	Million gallons per day
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of understanding
MPAs	Marine protected areas
MPWG	Montréal Process Working Group
MRLC	Multi-Resolution Land Characteristics
MSW	Municipal Solid Waste
N	Nitrate
NAAEC	North American Agreement on Environmental Cooperation
NAAQS	The National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAFC	The North American Forest Commission
NNI	National Nanotechnology Initiative (United States)
NAFTA	North American Free Trade Agreement
NALCMS	North American Land Change Monitoring System
NAPECA	North American Partnership for Environmental Community Action
NAQWA	National Water-Quality Assessment Program (under USGS)

NAS	National Academy of Science
NASA	The National Aeronautics and Space Administration
NAWW	North America Water Watch
NCA	Natural capital accounting
NDCs	Nationally Determined Contributions
NDVI	Normalized Difference Vegetation Index
NEGIS	Northeast Greenland ice stream
NFWPCAP	National Fish, Wildlife and Plants Climate Adaptation Partnership
NHTSA	National Highway Traffic Safety Administration
NLCD	The National Land Cover Database
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOP	National Ocean Policy
NPL	National Priorities List
NRCan	Natural Resources Canada
NRCSM	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRI	National Resources Inventory
NSIDC	National Snow and Ice Data Center
NWS	The National Weather Service
OECD	Organisation for Economic Co-operation and Development
OMECC	Ontario Municipal Employees Coordinating Committee
OMI	Ozone Monitoring Instrument
OR	Oregon
OWDI	Open Water Data Initiative
PAH	Polyaromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
PCAST	President's Council of Advisors on Science and Technology
PCBs	Polychlorinated biphenyls
PM2.5 -	Particulate matter with a diameter of 2.5 micrometres (0.0025 millimetre)
PNAS	Proceedings of the National Academy of Science (of the United States of America)
POPs	Persistent organic pollutants
PTC	Production Tax Credit
PV	Photo-voltaic
PWD	Philadelphia Watershed Department
RCRA	Resource Conservation and Recovery Act
RDI	Resource Data Inc.
RGGI	Regional Greenhouse Gas Initiative

SBST	Social and Behavioural Sciences Team
SCP	Sustainable consumption and production
SDGs	Sustainable Development Goals
SEEA	System of Environmental and Economic Accounts
SEEA-EEA	System of Environmental and Economic Accounts - Experimental Ecosystem Accounting
SEIA	Solar Energy Industries Association
SGI	Sage Grouse Initiative
SNA	System of National Accounts
SPPI	Sustainable Public Procurement Initiative
SSO	Source-separated organic
STAR	Science to Achieve Result (EPA Natural Gas STAR programme)
Stats Can	Statistics Canada
TEAP	Technology and Economic Assessment Panel (the Montreal Protocol)
TEK	Traditional ecological knowledge
TM	Thematic Mapper
TSCA	Toxic Substances Control Act (United States)
UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFAO	Food and Agriculture Organization of the United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNSC	UN Statistical Commission
UNU-IHDP	United Nations University - International Human Dimensions Programme
US	United States
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
US NNI	US National Nanotechnology Initiative
USACE	US Army Corps of Engineers
US BR	United States Bureau of Reclamation
US DA	The United States Department of Agriculture
US DN	Urban Sustainability Directors Network
US EIA	US Energy Information Administration
US FDA	The Food and Drug Administration
USGS	US Geological Survey
USGS-NAWQA	United States Geological Survey National Water Quality Assessment
VMT	Vehicle miles traveled

VOC	Volatile organic compound
WA	Washington
WCS	Wildlife Conservation Society
WHO	World Health Organization
WTE	Waste-to-energy
WUI	Wild land-Urban Interface
WWF	World Wildlife Fund
ZNE	Zero net emissions

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Chapter 1

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