Study Guide

2018

Climate Change

This Study Guide is to be used to help Envirothon teams prepare for the 2018 Envirothon Program.

Forests Ontario

Ontario Envirothon 2018

Envirothon — A Natural Resource Encounter for the Next Generation

Support for the 2018 Ontario Envirothon has been provided by the following:

Acknowledgements

This Study Guide was compiled by students at Fleming College, Frost Campus, in Lindsay, Ontario. Acknowledgements to Alexander Brekelmans, Nicole Lindman & Sean Neumann who contributed to the content of this guide. Thanks also to Sarah Kelly, Credit for Product Coordinator at Fleming College.

Acknowledgements also given to those who reviewed the study guide:

Kaitlyn Ittermann, County of Peterborough

Melanie Kawalec, City of Peterborough

Remy Rodden, Yukon Department of Environment

Cassandra Carter, Ministry of Natural Resources and Forestry

Yukon Climate Change Secretariat

Jessica Ferguson

Contents

2018 Learning Objectives: Climate Change

Key Topics

1. Climate Change and its impacts
2. Anthropogenic and natural causes which contribute to climate change
3. Measuring/monitoring of climate change
4. Mitigation and policy surrounding climate change

Learning Objectives

1. Describe climate change and the process through which it occurs
2. Outline factors, anthropogenic and natural, which influence climate and climate change
3. Comprehend the consequences of climate change on aquatic, forest, wildlife and soil ecosystems with a specific reference to biodiversity
4. Understand and use appropriate terminology when discussing climate change including, but not limited to: albedo, anthropogenic, atmosphere, cycles, heat sinks, greenhouse gases and hydrosphere
5. Describe the various sources of scientific data which are used as evidence of climate change (i.e. lake cores, tree rings, ice cores, fossils)
6. Explain how individual carbon footprints are assessed and identify personal actions to reduce footprint size
7. Understand how various levels of government, other organizations and individuals are involved in mitigating climate change in Canada and internationally
8. Discuss the effectiveness of provincial and federal policy and initiatives focused on climate change
9. Become familiar with career and educational pathways touching on the study and management/mitigation of climate change
10. Describe innovative technologies and programs combating climate change

Tools and Recommended Resources

The following tools and recommended resources can better help you and your team prepare for the Envirothon program.

Canadian Government—Climate change—Helping Canadians Adapt to Climate Change
http://www.climatechange.gc.ca/default.asp?lang=En&n=2B2A953E-1

Cool 2.0—Energy, Environment and Sustainable solutions
http://cool.greenlearning.ca/

ESSEA: Global Climate Change: Albedo
http://esseacourses.strategies.org/module.php?module_id=99The Climate Reality Project Canada

The Climate Reality Project Canada
http://www.climatereality.ca/

NASA: Global Climate Change
https://climate.nasa.gov/

Ontario Regional Adaptation Collaborative
http://www.climateontario.ca/RACII.php

Ontario Curriculum Links

- **Grade 9/10 Science**
  - D2.4: investigate a popular hypothesis on a cause-and-effect relationship having to do with climate change (e.g., the combustion of fossil fuels is responsible for rising global temperatures; the concentration of atmospheric CO is responsible for rising global temperatures; global temperatures have been on the increase since the industrial Science 107 revolution; the severity of cyclones, hurricanes, and tornadoes increases as atmospheric temperatures increase), using simulations and/or time-trend data that model climate profiles (e.g., data from Statistics Canada and Environment Canada)
  - D2.9: compare different perspectives and/or biases evident in discussions of climate change in scientific and non-scientific media (e.g. with reference to knowledge, beliefs and values)
  - D3: demonstrate an understanding of natural and human factors, including the greenhouse effect, that influence earth's climate and contribute to climate change
  - D3.3: describe the natural greenhouse effect, explain its importance for life, and distinguish it from the anthropogenic greenhouse effect
  - D3.4: identify natural phenomena (e.g., plate tectonics, uplift and weathering, solar radiance, cosmic ray cycles) and human activities (e.g., forest fires, deforestation, the burning of fossil fuels, industrial emissions) known to affect climate, and describe the role of both in Canada's contribution to climate change
  - D3.5: describe the principal sources and sinks, both natural and/or anthropogenic, of greenhouse gases (e.g., carbon dioxide, methane, nitrous oxide, halocarbons, water vapour)
  - D3.6: describe how different carbon and nitrogen compounds (e.g., carbon dioxide, methane, nitrous oxide) influence the trapping of heat in the atmosphere and hydrosphere
  - D3.8: identify and describe indicators of global climate change (e.g., changes in: glacial and polar ice, sea levels, wind patterns, global carbon budget assessments)
- **Grade 11 Biology**
  - B1.2: analyse the impact that climate change might have on the diversity of living things (e.g., rising temperatures can result in habitat loss or expansion; changing rainfall levels can cause drought or flooding of habitats)
- **Grade 11 Environmental Science**
  - analyse, on the basis of research, social and economic issues related to a particular environmental challenge (e.g., overfishing, deforestation, acid rain, melting of the polar ice cap) and to efforts to address it
  - analyse ways in which societal needs or demands have influenced scientific endeavours related to the environment (e.g., the development of drought- and pest-resistant crops to address the rising global need for food; research into alternative energy sources in response to demands to address the impact on climate change of burning fossil fuels)

- use a research process to investigate how evidence, theories, and paradigms reflecting a range of perspectives have contributed to our scientific knowledge about the environment (e.g., with respect to debates about climate change; regarding the relationship between the cod moratorium and seal populations in Atlantic Canada), and communicate their findings

- use a research process to locate a media report on a contemporary environmental issue (e.g., climate change, melting of the polar ice cap, deforestation), summarize its arguments, and assess their validity from a scientific perspective

- identify some major contemporary environmental challenges (e.g., global warming, acid precipitation), and explain their causes (e.g., deforestation, carbon and sulfur emissions) and effects (e.g., desertification, the creation of environmental refugees, the destruction of aquatic and terrestrial habitats)

- explain how new evidence affects scientific knowledge about the environment and leads to modifications of theory and/or shifts in paradigms (e.g., the impact of evidence of the effects of carbon dioxide emissions on theories of global warming)

- describe a variety of human activities that have led to environmental problems (e.g., burning fossil fuels for transportation or power generation; waste disposal) and/or contributed to their solution (e.g., the development of renewable sources of energy; programs to reduce, reuse, and recycle)

- describe the characteristics of a sustainable energy system (e.g., equitable access to the source, long-term availability, limited environmental impact)

- explain the basic principles and characteristics of various types of renewable (e.g., tidal, geothermal, solar, wind) and non-renewable (e.g., coal, oil, gas) energy production and their impact on the environment

- describe methods of energy production and conservation intended to reduce greenhouse gas emissions (e.g., energy production methods at the Prince Edward Island Wind-Hydrogen Village; charging higher prices for energy used during peak hours)

- **Grade 12 Biology**

  - analyse the effects of human population growth, personal consumption, and technological development on our ecological footprint (e.g., the deforestation resulting from expanding development and demand for wood products causes the destruction of habitats that support biological diversity; the acidification of lakes associated with some industrial processes causes a decrease in fish populations)

- **Grade 12 Science**

  - explain the impact of various threats to public health, including infectious diseases (e.g., hepatitis, HIV/AIDS, tuberculosis, malaria, sexually transmitted diseases), chronic diseases (e.g., cardiovascular disease, diabetes, asthma), and environmental factors (e.g., climate change, air pollution, chemical pollutants, radiation)

1.0 Climate Change 101

Climate change is characterized by an alteration in global or regional climate patterns.

It is currently projected that by 2050 average temperatures will rise between 2.5°C-3.7 °C. It is crucial that countries take united action in order to combat the global increase in temperature. If no action is taken, countries across the globe will experience, among others, degraded water supplies, reduced **biodiversity**, and increased threats to human health as a result of smog and disease intensities.

Beyond environmental concerns, climate change will also come with a significant financial burden. Insurance claims in Canada from severe-weather events–which averaged $373 million over a decade ago–have more than tripled to $1.2 billion annually (Clean Energy Canada, 2016). By 2050, the costs of managing climate change could range between $21 billion and $43 billion annually if emission levels remain static (Government of Canada [1], 2016).

While climate change does present significant challenges ahead, it also provides an opportunity for **innovation** and creative problem solving. Canada has the potential to become a world leader in the fight against climate change thanks to the expansion of the global green economy and increasing public interest.

This module will explore key concepts and questions related to climate change including:

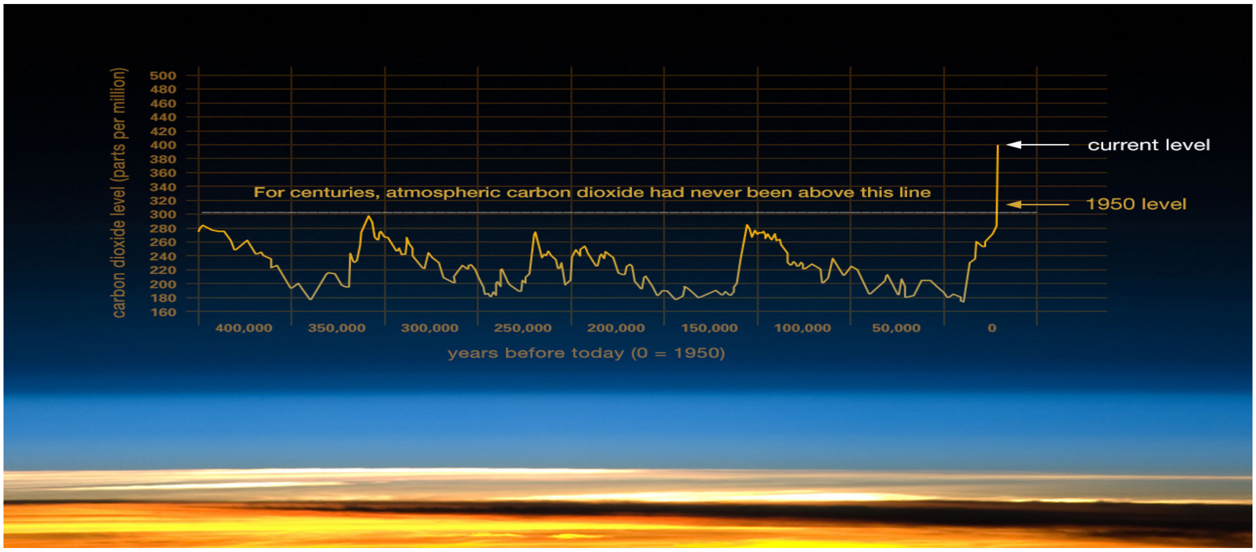
- What impact does climate change have on our environment and our society?
- What actions can we take to reduce Green House Gas (GHG) emissions and increase the resiliency of natural ecosystems?
- What roles do government and citizens have in the fight against climate change?
- How are we innovating to adapt and mitigate?

1.1 Climate Change from a Historical Perspective

Up until the 19th century, the only major contributors that influenced the concentration of carbon dioxide in the atmosphere were volcanoes, mineral weathering and the evolution of photosynthetic plants (the latter occurring over a long geological time scale). It wasn't until the mid-1800's with the start of the Industrial Revolution in Europe that human activity resulted in the mass release of atmospheric gases. The Industrial Revolution was the catalyst for human innovation and development which drove the levels of GHGs to the critical levels that we see today.

Climate change was first identified by Charles David Keeling in the mid 1950's when he produced proof that carbon dioxide (CO_2) levels were rising in the atmosphere. Since the late 1700's CO_2 in the atmosphere have risen from approximately 280 parts per million (ppm) to 401 ppm, a 43% increase (Environmental Protection Agency [1], n.d). This means that for every million molecules in the atmosphere, 401 of them are carbon dioxide (Environmental Protection Agency [1], 2017). Many scientists believe that passing the symbolic 400ppm threshold means that the Earth has reached a global ecological tipping point, and that atmospheric concentration of CO_2 will remain above this milestone for generations to come (Science Daily, 2015).

FIGURE 1. *Atmospheric carbon dioxide levels estimated from ice cores and direct measurements (Schmidt, 2017).*

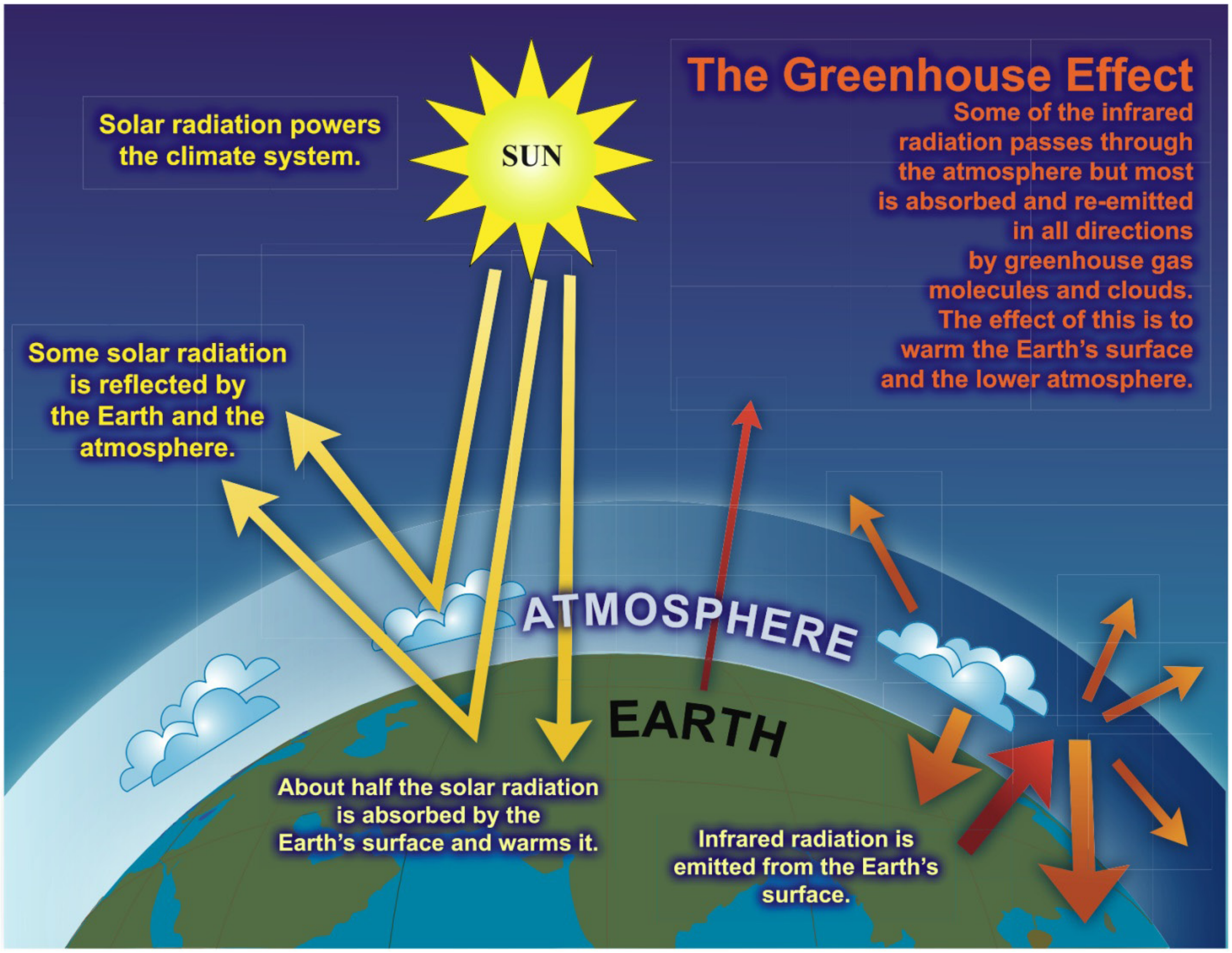


1.2 GHGs and Climate Change

The Earth receives solar radiation from the sun and emits infrared radiation from its surface. Molecules in our atmosphere called **greenhouse gases** (carbon dioxide, methane, nitrous oxide, and water vapour) absorb some of the infrared radiation and re-emit it into the atmosphere. This is called the **greenhouse effect**, and it creates temperatures warm enough to support earth's living organisms. If the concentration of greenhouse gases in the atmosphere increases, the Earth's temperature tends to increase as well, leading the Earth's climate to be in a constant state of change. Naturally occurring variations in climate have occurred throughout history; however, current climate warmings seem drastically more severe and have been strongly linked to increased human greenhouse gas emissions **(**Brinkman and Sombroek 1996**)**.

The primary GHGs in our atmosphere are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, each of which has molecules that have the ability to absorb radiation from the sun and re-emit it throughout the atmosphere. These GHGs enter the atmosphere after being released through both natural processes and human activities. All GHGs have the ability to disrupt natural processes, however increased concentration of certain gases related to human activity (i.e. fossil fuel use) is a leading factor for climate change. GHGs can remain in the atmosphere anywhere from a few years to thousands of years, depending on the gas.

FIGURE 2. *An idealised model of the natural greenhouse effect. (IPCC, n.d)*



In 2014, the Intergovernmental Panel on Climate Change (IPCC) presented methods of calculating **global warming potentials** to allow for comparison of each gas's contribution to climate change (Environmental Protection Agency [2], 2017). As a result each GHG was assigned a global warming potential, which indicates the molecule's capacity to absorb radiation, as well as how long it stay in the atmosphere. A gas's GWP is determined by comparing how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to 1 ton of carbon dioxide. The larger the GWP, the more that gas will contribute to warming the Earth. GWP provides a common unit of measure to compare across sectors and add up emissions.

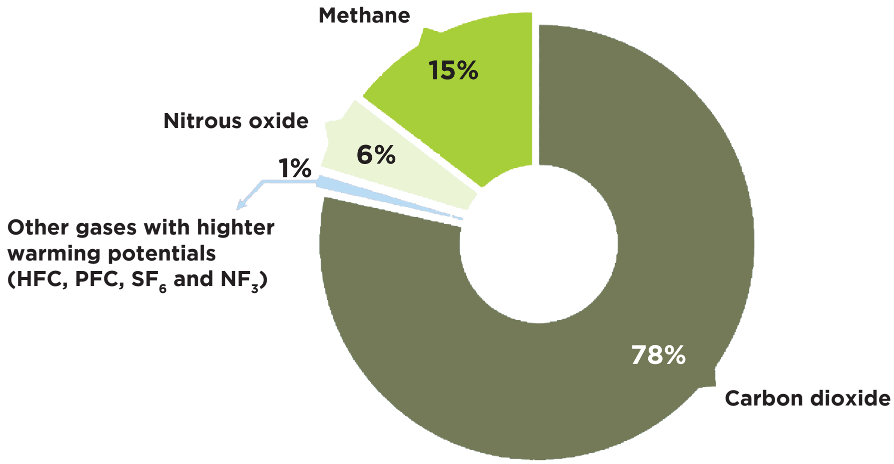
Global Warming Potentials:

- Carbon dioxide (CO_2): 1—used as the baseline
- Methane (CH_4): 28-36 over 100 years; although it only lasts for 10 years in the atmosphere it has higher energy potential
- Nitrous Oxide (N_2O): 265-298 over 100 years; this GHG emitted today on average lasts for more than 100 years in the atmosphere

1.3 Types of GHGs

The largest contributor of GHG emissions in Canada, and globally, is carbon dioxide. The current data is collected from monitoring stations around the world; whereas measurements of past air quality are acquired through ice core sampling in Antarctica and Greenland (see section 5 for more information). While carbon dioxide is naturally present as part of the carbon cycle it is emitted into the atmosphere through human activities such as the combustion of fossil fuels for energy, decomposition of solid waste and as the result of some chemical reactions (i.e. manufacturing of cement) (Environmental Protection Agency [2], n.d)

FIGURE 3. *Greenhouse Gas Emissions in Canada by Type of Gas, 2013. (Environment Canada, 2013)*

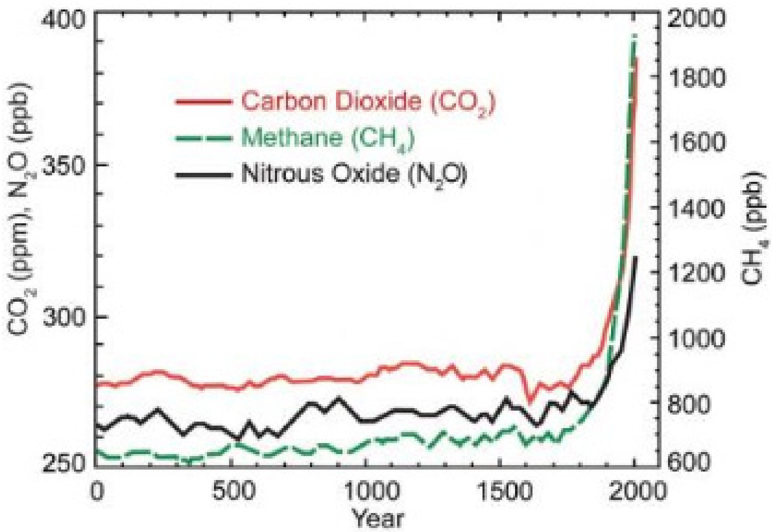


Methane is the second largest contributor of GHGs and has been measured at approximately 1,800 ppb in recent years. Methane is emitted through human activities such as leakage from natural gas systems and livestock farming, though it is also released through natural sources such as wetlands.

On a global scale, human activities are responsible for over 60% of total methane emissions. Despite methane having a shorter lifespan than carbon dioxide, it is much more efficient at trapping radiation and, as a result, methane poses a higher global warming threat.

Nitrous oxide is the third largest contributor, totaling 6% of GHG emissions in Canada. As part of the nitrogen cycle, nitrous oxide is naturally present within oceans, soils, and chemical reactions within the atmosphere. Humans contribute to total nitrous oxide concentrations through activities such as agriculture, fossil fuel combustion, wastewater management and industrial processes (Environmental Protection Agency [1], 2017).

FIGURE 4. *The graph above represents the increase of GHGs in the atmosphere over the span of two thousand years (Environmental Protection Agency [1]. 2016).*



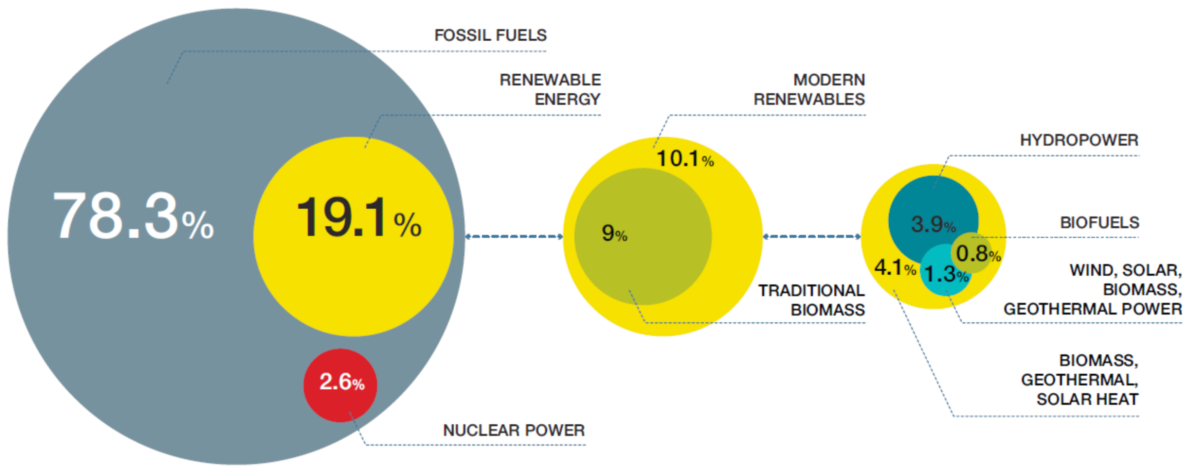
Fluorinated gases are unlike other GHGs because they only come from **anthropogenic** (human) origin. There are many types of fluorinated gases, mainly distinguishable by their function in daily life. Fluorinated gases are commonly found in refrigerants which cool buildings and vehicles, and electrical transmission equipment as a by-product of aluminum production. Compared to other GHGs, fluorinated gases are the most potent and contain the largest global warming potential. This potency is due to the fact there are no natural sources of these gases, so the Earth and its atmosphere are not accustomed to the chemicals, resulting in drastic impact. Though very harmful to the Earth, fluorinated gases have among the lowest concentrations in the atmosphere, measuring at only 1% of total GHGs in Canada in 2013.

1.4 Climate Change and Our Behaviours

1.4.1 ENERGY USE

78.3% of global energy is derived from fossil fuels, one of the main contributors to GHG levels (Greenpeace, 2015). Increasing human energy demands are directly correlated to spiking GHG emissions. Within Canada, 29% of energy is extracted from crude oil and 7% from coal (Statistics Canada, 2016). Renewable energies are increasing in the landscape, however overall demand continues to also increase.

FIGURE 5. *Global Final Energy Shares by source in 2013 (Greenpeace. 2015)*



In Canada, it is estimated that 40% of food is wasted, half of which is produced by households. This translates to $27 billion worth of food being discarded annually (McGinn, 2012).

1.4.2 WASTE

The decomposition of waste, in particular organic materials, releases a gas composed primarily of methane, a significant contributor to climate change (Environment and Climate Change Canada, 2017). It is estimated that 20% of all methane emissions in Canada originate at landfill sites (Environment and Climate Change Canada, 2017).

Methane recovery can be employed on landfills already containing organic matter to capture emissions before they enter the atmosphere. However diversion from landfill is the ideal outcome for new organic waste. Organic waste diverted from landfill can be used to generate renewable energy and useful products such as compost (Environment and Climate Change Canada, 2017).

1.4.3 TRANSPORTATION

Roughly 11 million passenger and commercial vehicles regularly travel Ontario roads (Government of Ontario [1], 2017).

Transportation is a significant contributor of GHG emissions in Canada and globally. In Ontario more than 1/3 of GHG emissions can be attributed to the transportation industry which includes personal vehicles, domestic aviation, rail, marine and off-road forms of transportation (Government of Ontario [1], 2017).

Given the increase in population and vehicle ownership in Ontario, emissions from this sector are likely to continue to grow without intervention (i.e. improved emissions, reduction in driving)

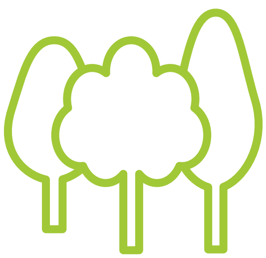
1.4.4 AGRICULTURE AND FOOD PRODUCTION

GHGs from agricultural sources account for roughly 5% of all emissions in Ontario (OMAFRA, 2016). Primary agricultural sources of GHG emissions are ruminant livestock and the release of nitrous oxide from fertilizer application (OMFRA, 2016). Additionally there are indirect sources (i.e manufacturing of fertilizers, combustion from farm equipment engines) but these are often accounted for by transportation (OMFRA, 2016).

1.4.5 INDUSTRIAL

The processing of raw materials and manufacturing of goods emit GHGs. Industrial GHG emissions are categorized in two different ways. **Direct emissions** are produced at the facility, typically by burning fuel for power or producing heat through chemical reactions. The primary direct emission produced is the consumption of fossil fuels for energy. As well, all industrial facilities require electricity to power buildings and machinery. This is categorized as **indirect emissions**, where electrical power plants are required to burn fossil fuels in order to supply electricity to the facilities.

1.4.6 LAND USE CHANGE



In Ontario, the 50 Million Tree Program focuses on re-establishing forest cover by supporting landowners in reducing costs to plant trees. This program has helped to successfully plant over 25 million trees in Ontario, leading to important carbon storage potential today and in to the future.

The carbon cycle is a natural balance of sinks and sources; however, **land use changes** have impacted the equation. Carbon is held in vegetation and soil, therefore any changes in the type of land use inevitably impacts the release or absorption of carbon from the atmosphere. The conversion of forests and grasslands to pasture, cropland, development or other managed uses can significantly change carbon stored in vegetation and soil as important woody **biomass** stocks are being removed from the landscape. Alternatively, abandoned croplands, pastures, plantation forests or other managed lands that regrow to their prior condition may increase carbon storage.

In Canada, the establishment of new forests (or afforestation) is only around 9,000 hectares annually (Natural Resources Canada, 2017). However this limited afforestation results in the removal of around 1 million tonnes of carbon dioxide from the atmosphere each year. This rate of sequestration will slowly increase over time as new trees grow.

Deforestation has a bigger impact, and can be an important issue with regards to carbon and climate change. The area deforested annually in Canada has fallen from just over 64,000 hectares in 1990 to 45,000 hectares in 2009 (Natural Resources Canada [1], 2016). This is equivalent to about 0.02% of our forests – among the world's lowest amount. Deforestation in Canada is caused mainly by the conversion of forest land for agriculture, industrial development, resource extraction and urban expansion.

1.5 Discussion Questions

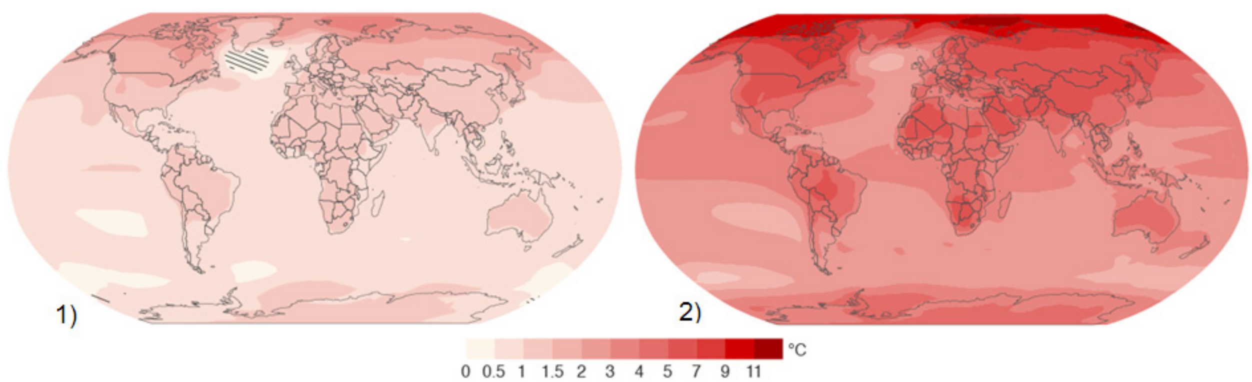
1. What is climate change?
2. What are the GHGs that are accumulating in the atmosphere?
3. What are some of the contributors of GHG emissions in Ontario, Canada and the world?
4. What are some ways that we can limit our impact on climate change in our daily lives?

2.0 Impacts of Climate Change on Ecosystem Components

Climate change affects many aspects of our world. When we look into how different aspects are affected, we start to see the complex relationships that exist in the natural environment.

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (2014) states that warming is unequivocal, and that many of the observed global changes are unprecedented over past decades to millennia. It has been observed, that each of the last three decades has been successively warmer than any since 1850, and that the 30 years between 1983-2012 was the warmest the Northern Hemisphere has been in the last 1400 years.

FIGURE 6. *Projected temperature change (1986-2005 to 2081-2100) according to two scenarios: 1) if GHG emissions peak between 2010 to 2020 and then decline substantially (RCP2.6); and 2) if GHG emissions continue to rise throughout the 21st century (RCP8.5). (IPCC [1], 2014)*



2.1 Climate Change and Soils

Soil plays an important role in climate change because it can serve as both a greenhouse gas source (when the soil produces more than it stores) and sink (when the soil stores more than it emits), especially for carbon, methane and nitrous oxide. These gases are natural by-products of soil microbial processes, including some of the same processes (e.g. respiration and nitrification) that provide plant-available nutrients and contribute to ecosystem stability. However, if the equilibrium of these microbial processes is disrupted by a changing climate, the rate of greenhouse gas emissions could change rapidly.

2.1.1 SOIL FORMATION

Climate greatly influences soil formation through precipitation, temperature, and wind. In Canada, the soil formation process is slower because of our colder climate which slows many weathering processes and winter precipitation.

It is predicted that climate change will directly affect **soil organic matter** supply, temperatures and **hydrology**. One major change will be the poleward retreat of the **permafrost** boundary as a result of increased soil temperatures due to warmer climatic conditions. As permafrost melts, carbon is released as methane (CH_4) into the atmosphere contributing to the existing levels of GHGs (Zhang, et al. 2012).

2.1.2 GROWING SEASON

In some areas of Canada, a warming climate will also result in an expansion of the growing season. These effects will be most obvious in areas with higher temperatures and greater rainfall variability. Some of these effects will include an increase in plant growth and water-use due to a shift in vegetative cover, and a change in human influence on soils.

2.1.3 ORGANIC MATTER

With anticipated climate change, temperatures high enough for microbial activity would occur for longer periods of time, leading to higher organic matter decomposition. This loss of organic matter would likely not be fully compensated for by higher net photosynthesis and the longer growing period (net primary production). Increased organic matter decomposition in turn can release more GHGs into the atmosphere through decomposition.

In some areas soils are also expected to be water-saturated (anaerobic) more frequently as a result of climate change. If these areas are sufficiently warm to support microbial activity it can result in nutrient leaching.

For more information about soil and climate change see "What Lies Beneath...Your Feet!"

2.2 Climate Change and Aquatics

Climate change has a drastic impact on the health of aquatic ecosystems as it will influence **evaporation** rates and ice-free periods, temperatures and growing seasons, as well as the amount of water available to streams and lakes. An increase in evaporation and decrease in precipitation will cause lower water levels in downstream lakes; the timing of snow and rainfall will be altered causing changes to soil moisture and therefore groundwater levels.

Climate change also accounts for increased concentration of nutrients and contaminants in aquatic ecosystems through desalinization. Desalinization is the process through which salt and minerals are removed from a water system as a result of evaporation and freezing. This is significant as water movement through systems is impacted by temperature and salinity (i.e. colder, saltier water is more dense than warm fresh water). The rapid melting of ice and snow is causing the desalinization of global ocean water which can result in the water cycling to stop.

2.2.1 EXTREME EVENTS

Unusual, unpredicted, severe, or unseasonal weather can be defined as an extreme weather event. This can include, but is not limited to, prolonged periods of drought, unseasonal weather and heavy downpours. Climate change has increased the frequency and presence of many extreme weather events. For example, "global analyses show that the amount of water vapor in the atmosphere has in fact increased due to human-caused warming" (The National

Climate Assessment US Global Change Research Program, 2014). This is because warmer air temperatures retain more water vapour, allowing the moisture to be available for storm systems to access. This excess of available moisture has increased the frequency of heavier rainfall, which in turn can cause local flooding. In response to this, cities have needed to develop and plan storm water management systems that can manage increased rainfall in hopes of preventing flooding in local areas.

2.2.2 THREATS TO WETLANDS

Wetlands are ecologically and socially important ecosystems that are also vulnerable to climate change. Wetlands provide significant ecological services including helping to reduce erosion, decreasing flood damage, improving water quality, storing carbon, supporting stable groundwater, and habitat for sensitive flora and fauna.

Climate change can threaten wetlands by altering their size, quality and location, or drying them through increased air temperatures, changes in water availability, and changes in precipitation and evaporation rates (MNR, 2011).

2.2.3 DISTRIBUTION AND ABUNDANCE OF FISH

Climate change is increasing stream and lake water temperatures, which in turn impacts the natural habitats of fish and other aquatic organisms. Water temperature is "one of the most important environmental factors influencing fish habitat", and fish that prefer cold water are at risk in an environment where water temperature is rising (MNRF, 2016). As water temperatures increase, cold water fish will be restricted to specific habitats that remain cold enough for them to live within. This will increase the presence of cold water fish in smaller areas, which in turn will increase diseases/parasite occurrence, and the competition for necessary resources such as habitat and food

Increasing water temperatures also pose a risk to fish abundance. Fish body temperature is directly correlated to water temperature, with increasing water temperature correspondingly increasing fish body temperature. Sustained increasing body temperature can impact important biological functions such as growth, reproduction and swimming ability. As well, unstable water temperatures pose risk for fish that lay eggs, impacting the eggs incubation period. As water temperature can dictate fish gender, increased temperature can cause a higher presence of one gender of fish, cause fish deformities and high levels of mortality. As a result, fish that typically rear a lot of young would significantly decrease. This is especially concerning for fish species found on the endangered species list, as it would be tremendously difficult to rebuild populations.

2.2.4 CHANGES IN NUTRIENT CYCLING

Nutrient cycling in aquatic systems is dependent on water temperature. Bodies of water are made up of layers which are separated by temperature change. These layers are divided by a thermocline, which is defined as the largest temperature change with increasing water depth. The thermocline separates the layers of water and allows for mixing within them. When seasonal change begins, the thermocline disappears as the entire water column cools, or warms (depending on season). This allows nutrients, minerals and oxygen to become mixed along the entire water column during lake turnover. As the seasonal changes continue, a thermocline will become present again, preventing mixing throughout the entire water column.

With increased water temperatures due to climate change, the presence of thermoclines may not exist. This would cause nutrient cycling to constantly occur. This would disrupt the aquatic systems, impact water quality and prevent a variety of species from being able to inhabit and thrive in waters that they previously could.

2.2.5 INVASIVE SPECIES

Increasing temperatures would allow for species introduction into new habitats, expanding the spread of invasive species. With increasing water temperatures, areas that would typically experience a freeze or reach colder temperatures would no longer do so. This would allow warm water species to travel and inhabit new habitats that previously were considered cold water environments. The introduction of new species to an environment can have many consequences such as increased competition with native species, disruption of food webs, degradation of habitat and the most severe, eradication of native species.

2.3 Climate Change and Wildlife

Global climate change is already having significant effects on species biodiversity. Effects include: shifts in species distribution, changes on demographic rates (survival and fecundity), increased spread of **zoonotic diseases** and invasive species (Mawdsley, et al. 2009).

Climate change is shifting ecosystems, increasing air and water temperatures, and changing precipitation levels, and these impacts are pushing plants and animals outside of their natural habitat ranges.

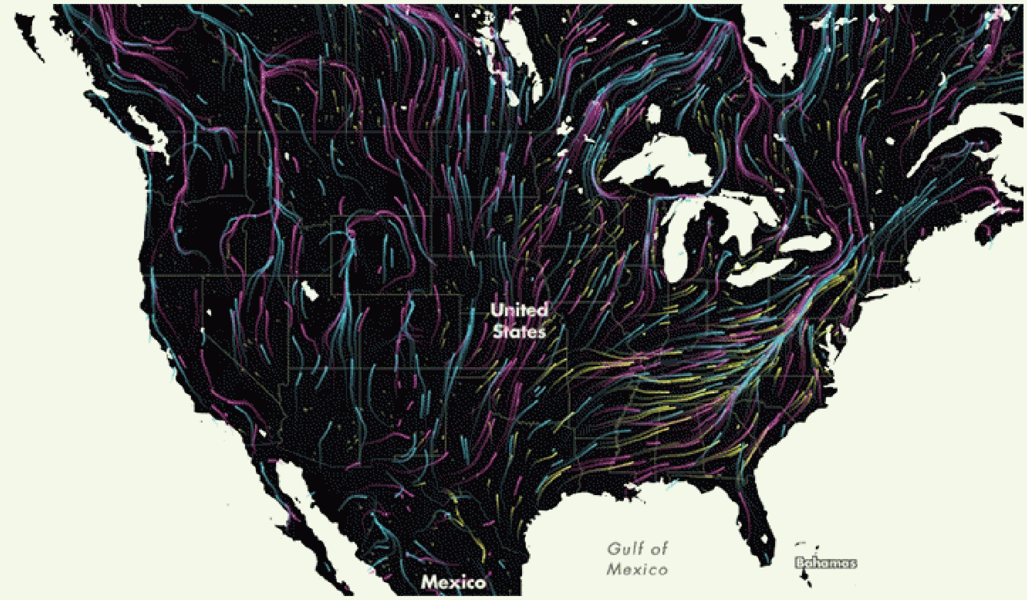
2.3.1 WILDLIFE CASE STUDY

One Glorious Map Shows the Future of Animal Migrations
By Brian Kahn, Climate Central

The natural world is under siege by climate change. Rising temperatures are pushing plants and animals outside their current range. To keep pace with climate change, species will need a path to follow northward or up in elevation, minimally interrupted by human development.

This map shows shows the several paths that species would be able to travel to find colder climates to inhabit.

FIGURE 7. *A map showing the different pathways wildlife could use to migrate northward or higher in elevation as the climate warms. Credit:* The Nature Conservancy



It uses the dreamy Earth wind map for inspiration. But rather than using temperature, wind and sea level pressure data, Dan Majka, a web developer at The Nature Conservancy, used data from two studies to show all the feasible paths that mammals, birds and amphibians can use to find their way to a more suitable climate as their habitat becomes too hot.

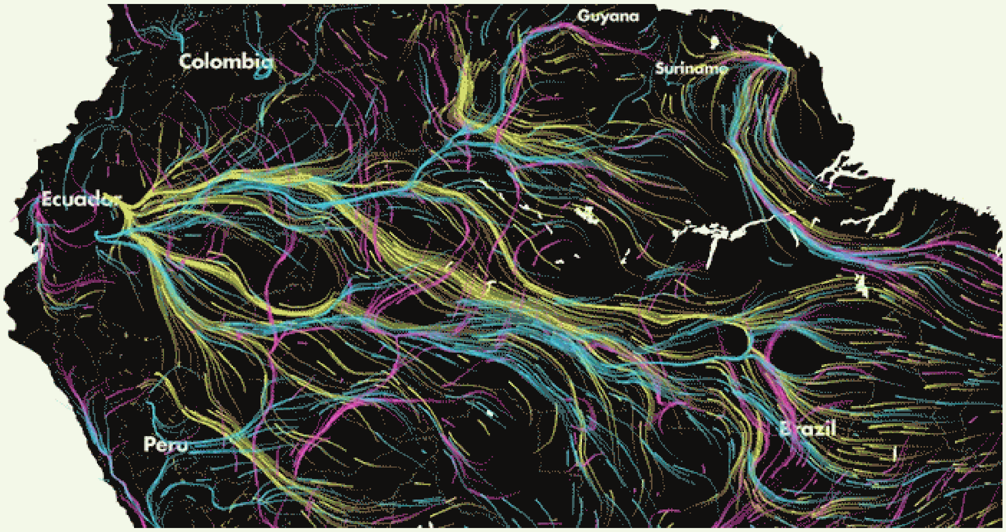
The map doesn't show specific species (for example, you are not able to predict the path grizzly bears would take), but rather shows the general patterns scientists expect animals to follow as the world warms.

The visualization is stunning, but also hopeful. It shows that despite the challenges of climate change and increased urbanization, there are still pathways for the natural world to deal with those threats.

Zoomed out, it's clear that the Appalachians are a crucial funnel for climate-induced migration. They're smack dab in one of the most developed parts of the country and represent some of the last wild land in the eastern U.S.

“Much of the land outside of the mountain range is developed or in agriculture,” Brad McRae, an ecologist with the Nature Conservancy, said. “So as species ranges shift north, the Appalachians are providing some of the least-developed routes for movement. They also provide some climate relief due to their high elevation.”

FIGURE 8. *Amphibians—represented by yellow lines—are likely to migrate westward out of the Amazon as the world warms. Credit:* The Nature Conservancy



Those high elevation lands will take on added importance and zooming in on the map only reinforces that reality. In South America, there’s a bright swath of yellow moving west out of the Amazon basin to higher elevations. In the Catskills of upstate New York, it’s the same story.

Beyond high elevations, zooming in anywhere on the map gives a glimpse into not just the geography of where and how species will move to beat the heat, but where humans live, work and grow things. New York may be the most populous city in the U.S. but it’s a veritable ghost town when it comes to animal migrations spurred by rising temperatures.

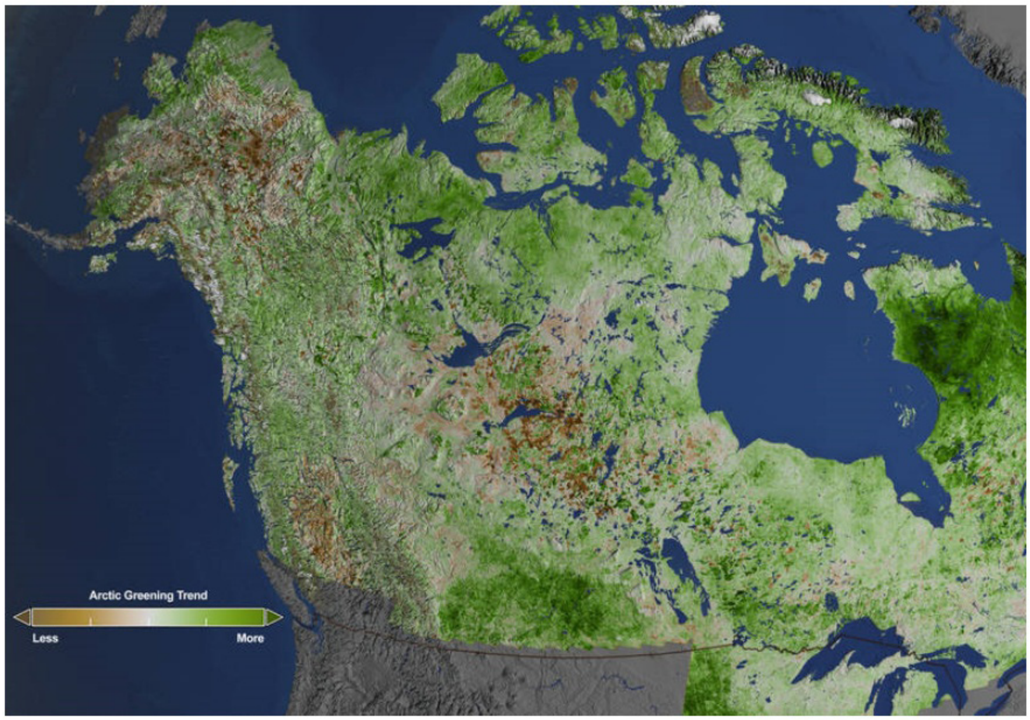
FIGURE 9. *New York City is a relatively quiet spot on the climate migration corridor but the Catskills located northwest of the city will be an important climate migration pathway for wildlife. Credit:* The Nature Conservancy

According to one of the studies on which the map is based, only 2 percent of natural areas east of the Mississippi are connected in a way that allows species to migrate north or up in elevation. Because of the dismal state of connectivity, a small increase in conserved land could provide major benefits in the region.

National Parks are the lynch pins of wild land out West and could be part of a future solution in the East to ensure species can handle climate change. The recently dedicated Maine North Woods National Monument is a step in that direction, but more land will be needed if plants and animals are going to find new homes.

2.4 Climate Change and Forests

FIGURE 10. *Using 29 years of data from Landsat satellites, researchers at NASA have found extensive greening in the vegetation across Alaska and Canada. Rapidly increasing temperatures in the Arctic have led to longer growing seasons and changing soils for the plants. Scientists have observed grassy tundras changing to scrublands, and shrub growing bigger and denser. From 1984–2012, extensive greening has occurred in the tundra of Western Alaska, the northern coast of Canada, and the tundra of Quebec and Labrador. (NASA, 2016)*



Forests are important habitats for fish and wildlife, and are vital components of the natural carbon cycle. Forests can be carbon sinks, as they help remove carbon dioxide from the atmosphere and store carbon in trees, plants and soils. Forests can also be carbon sources if they emit more carbon than they remove, for example through forest fires and organic decomposition of wood and leaves. How forests are utilized, managed or conserved can play a role in climate change **mitigation** by improving the carbon storage potential and removing it from the atmosphere.

Like other living things, forests will be affected by climate change through increases in air temperature, changes in seasons, and fluctuations in precipitation levels. Forests and other vegetation are experiencing earlier leaf out and longer growing seasons, and as climates shift, forest composition may change for species that are better suited to the changing environment. This means that different species can grow in areas they never have before, and it can alter forest and wildlife biodiversity.

Scientists have observed that North America's far north is getting greener, as ice and permafrost is melting, and the Arctic tundra is looking more like landscapes found in warmer ecosystems to the south, such the Boreal forest (NASA, 2016). As permafrost melts it allows previously frozen organic matter to decompose, allowing trapped carbon to be released as CO_2 into the atmosphere, thereby contributing more to climate change.

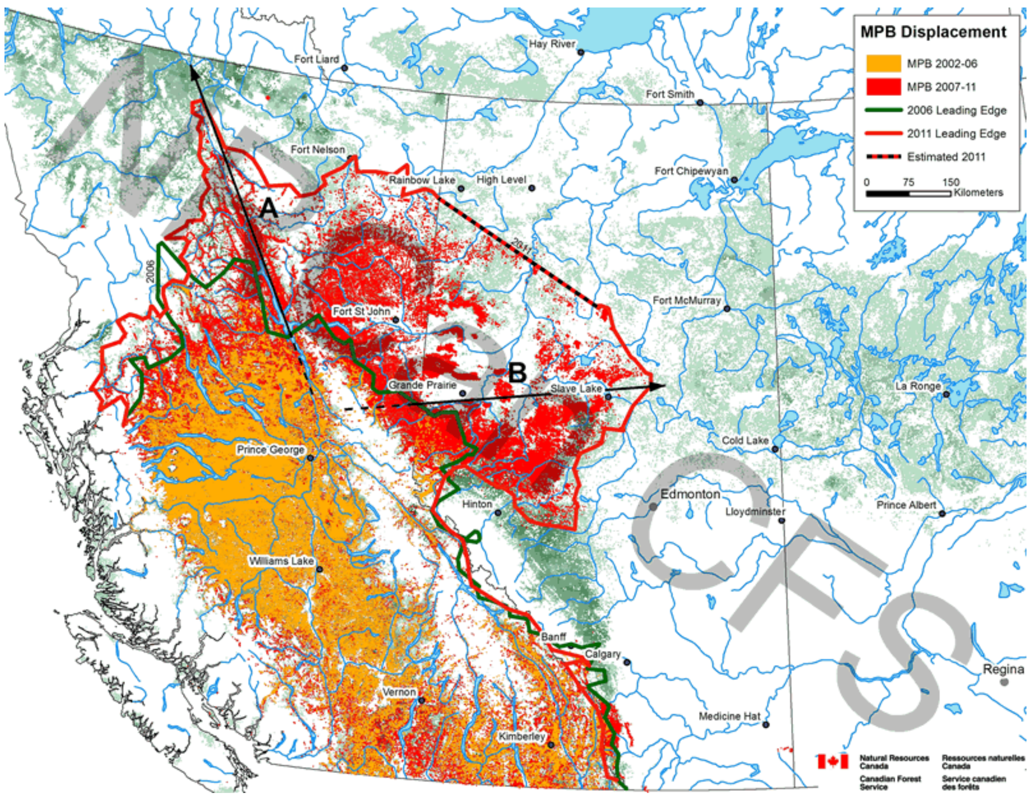
2.4.2 NATURAL DISTURBANCES AND EXTREME WEATHER EVENTS

Extreme weather events and natural disasters are a key concern for forests, especially as climate change is increasing their frequency and intensity over time. Forest fire seasons are lasting longer than previously observed and lightning-strike fires have also increased in frequency. As forests burn they emit carbon they were storing, leading to increased CO_2 in the atmosphere. A study found that 70% of total tree cover loss in Canada and Russia in recent years is due to fire. It was found that in some regions Boreal forests are burning faster than at any time in the last 10,000 years (World Resources Institute, 2015).

2.4.3 INVASIVE SPECIES

The impacts that increasing temperatures have on ecosystems is detrimental. Higher temperatures lead to accelerated insect development and reproductive capacities. Due to a successive mild winters, the Mountain Pine Beetles populations have grown exponentially resulting in habitat expansion and therefore widespread decimation to native pine forests in Western Canada (Moore, B. & Allard, G. 2008).

FIGURE 11. *Spread of the Mountain Pine Beetle in Western Canada. (Natural Resources Canada [2], 2016)*



2.5 Discussion Questions

1. How is permafrost affected by climate change? What are the consequences that come from this?
2. Identify two (2) impacts of climate change on each of the following: soils, forestry, aquatics, wildlife.

3.0 What does Climate Change Mean to Me?

"In Canada and abroad, the impacts of climate change are becoming evident. Impacts such as coastal erosion; thawing permafrost; increases in heat waves, droughts and flooding; and risks to critical infrastructure and food security are already being felt in Canada. The science is clear that human activities are driving unprecedented changes in the Earth's climate, which pose significant risks to human health, security, and economic growth" (Government of Canada [2], 2016).

Climate change is responsible for major biome shifts. These drastic changes are set to negatively impact North America's Great Plains and Great Lake Areas by altering they biodiversity, soil fauna, and microbial activity (Smith et al., 2013). In order to stabilize climates and stop biome shifts, GHGs need to become net zero.

3.1 Growing Food

Human populations are projected to reach 10 billion by 2100 (Sakschewski, 2014). This exponential growth requires an increase in food production to accommodate forecasted populations. While the demand for food continues to rise, climate change can either impair the productivity of agricultural practices or improve them, depending on geographical location and available technology.

Due to increasing temperatures, new technological advancements, and improved management practices, Canada has seen an increase in productivity for yields of corn and wheat by 64% and 57% respectively (Smith et al., 2013). Although productivity is forecasted to further rise, increasing amounts of pests and extreme weather conditions will likely impact production. Tropical and subtropical ecosystems are forecasted to receive hits in productivity.

Global warming and climate change is projected to affect soil temperature, moisture regimes, carbon & nitrogen dynamics, and nitrogen dioxide emissions (Smith et al., 2013). Additionally, soil carbon is often lost due to greater rates of decomposition which makes agricultural soils vulnerable to environmental changes. Greater rates of decomposition occur due to rising atmospheric temperatures and CO_2 levels.

A study by Frazer stated that global warming may change present-day decomposition patterns by altering soil microbial communities and activities, thus changing the overall flow of carbon in and out of soil as well as soil fertility (Frazer, 2009). Soil organic carbon (SOC) which is necessary for plant growth is projected to decrease. This will lead to negative impacts on the plant's nutrient release, growth structure for stability, and its ability to buffer harmful substances. When SOC is depleted, there is a decrease in soil quality biomass productivity, and water quality (Lal, 2004). These factors are crucial for the success and productivity of natural ecosystems.

3.1.1 CASE STUDY: AGRICULTURAL PRODUCTION IN A CHANGING CLIMATE

Agricultural production and climate change are interrelated processes. Evidence has shown that a changing climate, specifically increases in annual average temperatures and the occurrence of extreme precipitation events has and will continue to occur in Ontario and on a global scale (Agriculture and Agri-Food Canada, 2015). Agricultural production in Ontario is undeniably reliant on weather. Farmers need adequate moisture and temperature throughout the growing season to seed, grow and harvest a bountiful and high quality crop. Within a changing climate there are many obstacles for farmers to manage to consistently produce high quality and high yield crops, as well as potential opportunities that result from longer growing seasons and increases in average temperatures.

Opportunities

A changing climate presents an opportunity for agricultural production in Ontario. With a changing climate comes increased average temperatures, these increased temperatures have the potential to allow farmers to plant crops with longer growing periods that generally result in higher yields that previously they were not able to consistently grow in regions of Ontario. Furthermore, through research and technology development new crop varieties and genetic hybrids are being commercialized to adapt to changing climate conditions in Ontario by reducing yield losses during periods of drought and optimizing available water to allow the plant to become more tolerant of drought.

Challenges

A changing climate also presents challenges for Ontario farmers. With increased average temperatures and sporadic and sometimes extreme rainfall patterns, drought conditions can have severe negative impacts on a crops ability to grow and subsequently produce high yield and quality crops.

An example of severe drought conditions occurred during the 2016 growing season when much of Ontario was facing drought like conditions with intense heat and little rain resulting in lower than average crop yields.

Furthermore, weather extremes in the form of severe storms have the potential to flatten crops through excessive wind, damaging hail and heavy rain. An example of severe storms impacting crops occurred during the early 2017 growing season where regions in southwestern Ontario experienced severe thunderstorms which virtually flattened crops with hail and severe winds. Additionally, other regions of the province experienced excessive rainfall over small periods of time which resulted in flooding of fields and the destruction of crops.

FIGURE 13. *Field flooded by intense rain. (GFO, n.d)*

Mitigation Strategies

In an effort to mitigate the impacts of climate change farmers employ Best Management Pratices (BMP's). BMP's provide a sustainable solution to specific issues such as increased rates of erosion.

With the recent rise in intense weather events the potential for soil erosion is increased due to excessive rain carrying loose soil away from fields into ditches, rivers and streams. Ontario farmers are taking action to help reduce soil loss from their field by implementing certain BMP's on their farm.

Examples of BMP's that help reduce soil erosion include conservation tillage, which leaves approximately 30% of the prior year's crop residue on the surface of the field. By leaving residue on the soil surface, soil erosion is greatly reduced as the previous crop residue acts as a buffer to protect the soil from excessive rain keeping soil in place.

In Canada, between 1991 and 2006 the use of conservation and no till on cropped land doubled. In Ontario, cropland identified as very high risk for soil loss has decreased from 33% to 17% (Serecon Inc, 2015).

FIGURE 14. *Example of no-till system with ground covered in residue. (Hayes, n.d)*

Another BMP that farmers use to reduce soil loss from their farms is the planting of cover crops. Cover cropping is a practice where non-harvestable crops are planted in a field after a crop is harvested. These cover crops help to provide soil protection from severe rain events and aid in the enrichment of the soil structure. By improving the soil structure water infiltration is increased along with water retention which provide for optimal growing conditions for crops.

FIGURE 15. *Cover crop planted into winter wheat residue (GFO, n.d)*

Over the years Ontario farmers have made significant strides to be more resilient to a changing climate through the adoption of BMP's and by growing crops that are better suited to the changing environment. Undeniably, farmers understand the risk factors a changing climate can play on producing a high yielding, high quality crop and the environmental, social and economic benefits of incorporating sustainable production practices into their farm operation. Sustainable agriculture production practices are vitally important to Ontario farmers today and in the future to meet the challenges and embrace the opportunities that result from a changing climate.

For more information:

- Grain Farmers of Ontario (www.gfo.ca)
- Canadian Roundtable for Sustainable Crops (www.sustainablecrops.ca)
- Canadian Field Print Initiative (www.fieldprint.ca)

3.2 Water Resources

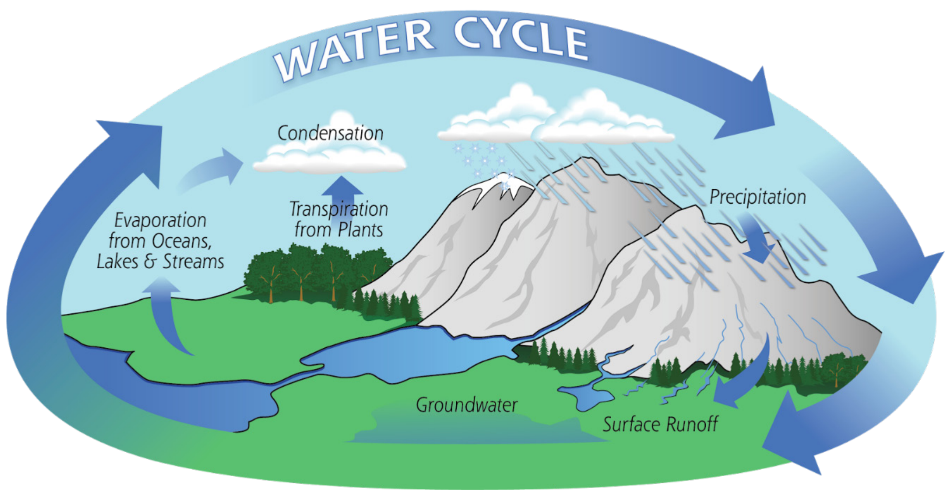
Humans depend on reliable, clean sources of drinking water to sustain health. We require water for agriculture, energy production, recreation, and manufacturing. Climate change is likely to increase water demand while simultaneously depleting water supplies, potentially leading to conflict. This changing balance will influence how water consumption is managed (IPPC [2], 2014).

The hydrological cycle is a delicate balance of precipitation, evaporation, **transpiration** and all the steps in between. The cycle begins with evaporation of water from lakes and the ocean's surface. As moisture is lifted into the air, it cools and then condenses into clouds. The moisture is transported around the globe until it returns as precipitation. Once the precipitation returns to earth's surface, one of two processes will occur:

1. Some of the water will evaporate back into the atmosphere or;
2. Water will penetrate earth's surface and become groundwater.

The balance of water that remains on the Earth's surface is runoff which eventually makes its way back to the ocean to repeat the cycle.

FIGURE 12. *The Hydrological Cycle (. n.a)*



Climate change is affecting the hydrological cycle. As temperatures increase, water evaporates at a quicker rate. Impacting one process disrupts the whole cycle as the steps are codependent. Increased evaporation means increased quantity and duration of precipitation. This is accompanied by a decrease in groundwater recharge because of less percolation of water since there is more surface run off. Climate change also has the potential to increase the severity of weather events leading to extreme flood or drought conditions.

For more information about the hydrological cycle refer to the Ontario Envirothon Aquatics Study Module.

3.3 Pollination

Research has shown that climate change is influencing how pollinator species are interacting with plants. Pollinators and plants interact through **phenological shifts**, increased temperature, fragmented landscape, decreased natural habitat, and shifts in vegetation which are increasing the chance for species extinction for both the plant and pollinator species (**interspecific relationships**) (Bellard, 2012). When pollinator species shift in distribution, there is a temporal and spatial co-occurrence mismatch. This means that as pollinator species shift in location or are extirpated from the area, surrounding ecosystems suffer morphologically and physiologically because the pollinators provided a niche service that allowed growth to occur in the ecosystem (Potts et al., 2010).

Studies indicate that butterflies are extremely sensitive to climate change as a result of their wide distribution. However, studies also show that impacts will be similar in bee populations. Humans and pollinators have an important **symbiotic** connection and without remediation, both groups will be impacted.

Pollinators provide an **ecosystem service** to crops and wild plants that is threatened by climate change and other anthropogenic impacts (Tong, 2016). It is estimated that, "…the food crops that benefit from pollination services by animals provide more than a third of the global agricultural production" (Stewart et al, 2016). Although 75% of the crops that are used for human food worldwide require insect pollination, the highest volume of crops (rice and wheat) utilize wind-pollination (Potts et al., 2010). There was a steady incline between 1961 and 2006 with crops becoming more pollinator-dependent (Potts et al., 2010). Insect-driven pollination is estimated to have an annual economic value of roughly 2-trillion in Canadian dollars. Research and evidence still proves that pollinators, especially **primary pollinators**, are vital in maintaining native plant communities and agricultural crop production. However, there has been a decline in pollinator populations which impacts the productivity of crop agriculture. Fruit crops often require insect pollination to produce fruit. Some fruit and vegetable crops will see a deficit in productivity or fail altogether if their specific insect pollinators disappear; for example, only specific species of bee can pollinate squash. If the insect pollinators are not available to pollinate crops of fruit and vegetables, then our dinner plates will look drastically different!

3.4 Forests: Lungs of Our Planet

Forests provide the world with water filtration, air filtration, carbon storage, wildlife habitat, climate regulation, and a variety of timber and non-timber products. Forests, through the process of photosynthesis (converting water and carbon dioxide into sugar and oxygen), provide much of the oxygen that we need to breath. In Canada, the forest management techniques ensure that forests remain healthy and are managed sustainably. By embracing this approach, Canada is able to minimize impacts on forests (such as erosion) to ensure that biodiversity and ecosystem functions can continue to provide us with its goods and services.

As climate change continues to affect our world, it directly and indirectly affects forest ecosystems and their overall health by increasing the risk of pest outbreaks, fires, and drought. These effects may lead to alterations in temperature and rainfall that will reduce forest productivity (Environmental Protection Agency [2], 2016).

3.5 Human Displacement and Social Security

Climate change and its impacts on coastal erosion, crop yields, water shortages, sea-level rise, and extreme weather events are impacting communities and their ability to live in certain areas. Climate change refugees are becoming more common, and an average 22.5 million people were displaced globally by climate change and weather-related events between 2008 and 2015 (UNHCR, 2015). Climate change has been deemed an "acute threat to poorer people across the world, and has the power to push more than 100 million people back into poverty by 2030" (World Bank, 2015). Climate change has also been linked to significant international conflict, like the civil war in Syria which was partly triggered by severe drought worsened by a changing climate (PNAS, 2015).

3.6 Discussion Questions

1. Explain the hydrological cycle in your own words.
2. What is the importance of pollinators in an ecosystem?
3. How can climate change impact communities?

4.0 Measuring Change

4.1 Paleoclimatology

The Earth has maintained records of its climatic conditions in glaciers and ice caps, sediments from lakes and oceans, within the skeletons of coral reefs, as well as in tree rings. The study ofthese samples is known as paleoclimatology. These environmental recorders can be used by scientists to estimate past conditions. Common findings from paleoclimatologists (those who study environmental evidence to gain insight on what the past climate was like and why) indicate that the Earth's climate is always changing. Further examination shows that the Earth's climate is able to drastically shift in a matter of years or decades. A main focus in paleoclimatology is to distinguish whether the change occurring is due to the natural environment or caused by human influence. The 20th century has seen unprecedented warming compared to the last 1200 years, and paleoclimatic records allows us to explain why and how the change is occurring (National Oceanic and Atmospheric Administration[2], 2017).

4.2 Ice and Sediment Cores

Long core samples from ice caps and glaciers are commonly known as ice cores. Ice cores have the ability to preserve histories of local, regional and broader climate conditions. As snow and ice accumulates on top of ice caps and sheets, layers are formed that record the environmental conditions at the time they are created. Evidence that can be extracted from ice cores includes the amount of snowfall, temperature, composition of atmospheric gases trapped in air bubbles, as well as wind-blown dust. The analysis of ice cores begins with determining the depth to age relationship (Alley, 2000). The oldest and deepest annual layers on ice cores become difficult to detect due to thinning and distortion through pressure from the ice above. The top and more recent layers are formed when a sufficient amount of snow falls during the year to create recognizable annual layers, which are marked by seasonal variations in physical, chemical, electrical and isotopic properties. With the layers marked they can then be counted to determine an age.

As the layers are marked based on seasonal variations in snow, the isotopic composition of the precipitation is examined further to determine the temperature when and where the snow fell. Similarly, examining the isotopic properties of wind-blown dust allows for the material to be traced back to its origin. Anything that is within the atmosphere has the potential to end up in an ice core, and more often than not remains unchanged over time. Trapped gases in air bubbles are highly reliable records of atmospheric composition. Slight differences between bubbles and air composition caused by gravitational and thermal effects are well understood and recognizable. Certain chemical reactions in impure ice can possibly produce abnormal compositions for some gases. However, due to the close association of the gas and ice-chemistry, it is a clear indicator of climate change (Óskarsson, 2004). Ice core records are generally cross-referenced with other ice core records along with other methods of instrumental climate records to confirm findings. Statistical and physical analyses are needed to put small, one-time changes into perspective. Meanwhile, large changes in the concentrations of most materials in ice, reflect changes in their atmospheric loading.

Similar to layers of snow accumulating on top of glaciers or ice caps, billions of tons of sediment accumulate on the ocean floor and in lake basins each year and these sediments can be used to determine past climates. These sediments consist of biological and other materials that were present in the water body or that entered as runoff from another source nearby. These materials are preserved as individual fossils as they are deprived of oxygen. The most important findings that scientists are looking for within sediment cores are fossilized shells from the **Foraminifera** family, also known as forams, which are tiny ocean dwellers that produce shells which fall to the bottom of the ocean after the creature dies. Different forms of this creature are known to inhabit different temperatures of water, meaning creatures found in different sediment layers are a measure of the temperature at a certain time. Additionally, the carbon and **isotope** content of the shells provides information regarding the composition of the atmosphere in the past (Jan Oosthoek, 2015).

4.2.1 CASE STUDY

Study of Antarctic ice cores reveals atmospheric CO2 history over past thousand years
By Bob Yirka

A small team of researchers with affiliations to institutions in the U.S., Switzerland and Korea have found links between atmospheric carbon dioxide levels, the land carbon reservoir and climate over the past thousand years. They have determined this by examining ice cores taken from the West Antarctic Ice Sheet Divide. In their paper published in *Nature Geoscience*, the team describes the levels of CO_2 they found and why they believe that most of the level changes they observed were likely due to terrestrial sources. Jed Kaplan, with the University of Lausanne offers a News & Views piece on the work done by the team in the same journal issue, comparing CO_2 level changes found by the researchers with historical human events putting the ice core data into perspective.

To learn more about atmospheric carbon levels over the past millennium the researchers analyzed ice core samples taken by workers on the Antarctic WAIST Divide Ice Core project—looking for both CO_2 concentrations and their isotopic composition. In doing so they were able to see levels rise and fall at both decadal and centurial level of detail, for the years 760 to 1850. The data showed two main "events" during that period, the first was a slow decline running from the start of the twelfth century to the start of the nineteenth century—the other was decadal level ups and downs of levels attributable to unknown, but speculative causes. The researchers also believe that most of the level changes came about due to terrestrial sinks and sources, not activity in the oceans.

Kaplan suggests some of the ups and downs could be traced back to natural causes, such as increases or decreases in peat deposits due to temperature variations. Although, these changes could just as easily be blamed on human activities such as soil erosion in Eastern Europe due to agricultural activities. He also highlights that the sharp drop in CO_2 levels that occurred around 900, almost undoubtedly came about due to population drops in Mesoamerican cultures after the introduction of European diseases. Likewise, the sharp increase in carbon levels from 975 to 1080, can almost certainly be attributed to events in both Europe and Asia. He also notes a dip right around the time shortly after the onset of the Black Plague, which happened to coincide with widespread draughts in Asia. He concludes by suggesting that studies of ice cores such as that done by this new team not only help reveal trends in the past, but will likely prove useful for helping to predict trends in the future.

More information: Links between atmospheric carbon dioxide, the land carbon reservoir and climate over the past millennium, Nature Geoscience 8, 383–387 (2015)
DOI: 10.1038/ngeo2422

The stability of terrestrial carbon reservoirs is thought to be closely linked to variations in climate, but the magnitude of carbon–climate feedbacks has proved difficult to constrain for both modern and millennial timescales. Reconstructions of atmospheric CO_2 concentrations for the past thousand years have shown fluctuations on multidecadal to centennial timescales, but the causes of these fluctuations are unclear. Here we report high-resolution carbon isotope measurements of CO_2 trapped within the ice of the West Antarctic Ice Sheet Divide ice core for the past 1,000 years. We use a deconvolution approach to show that changes in terrestrial organic carbon stores best explain the observed multidecadal variations in the δ13C of CO_2 and in CO_2 concentrations from 755 to 1850 CE.

If significant long-term carbon emissions came from pre-industrial anthropogenic land-use changes over this interval, the emissions must have been offset by a natural terrestrial sink for 13C-depleted carbon, such as peatlands. We find that on multidecadal timescales, carbon cycle changes seem to vary with reconstructed regional climate changes. We conclude that climate variability could be an important control of fluctuations in land carbon storage on these timescales.

4.3 Coral Reefs

Coral reefs are marine systems with one of the highest levels of biodiversity worldwide, and provide humans with abundant goods and services. Reefs build their hard skeletons from calcium carbonate ($CaCO_3$), a mineral that can be extracted from seawater. Each year coral reefs build another layer of carbonate, though the density of the layers differs between years due to seasonal variations in environmental conditions (National Oceanic and Atmospheric Administration [1], 2017). Scientists are able to study these layers and determine climatic conditions for the time period the coral was alive. Additional evidence regarding past climates can be obtained from these skeletons, because contained within the carbonate is oxygen along with the isotopes of oxygen, as well as traces of metals (Jan Oosthoek, 2015). Analysis of the isotopes and state of metals can be used to determine certain characteristics such as the temperature of the water at the time the coral was formed.

These forms of evidence though, are at risk due to the change in climate that is occurring. The growing threat is from ocean acidification, which is a chemical consequence of increasing carbon dioxide concentrations in the atmosphere. Ocean acidification is the reduction of pH throughout the ocean, as carbon dioxide is taken up by the ocean's surface. This drop in pH leads to a loss of carbonate ions, which are required for reefs to generate their skeletons. As a result, the Great Barrier Reef has declined by 14.2% since 1990 (World Meteorological Organization, 2010).

4.4 Tree Rings

Tree-rings are used as a tool for aging trees. Each year trees form new cells on its outer portion just under the bark. These cells form annual growth rings or tree-rings, and each are composed of two parts. At the beginning of the growing season the tree produces many large cells with thin walls that appear light in colour. Towards the end of the growing season trees produce less and much smaller cells with thick walls, which appear darker in colour. This two-part ring ultimately shows how much wood is produced each growing year. As the years progress the rings continue to be added and a timeline is created that shows the variation in growth between the years. Trees are able to develop these rings when they are located in temperate zones, meaning they experience both a winter and a summer. When growing in temperate zones tree growth is ultimately halted during the winter, which helps show the variation between years and more prominent tree-rings (Environmental Science, 2017). Trees that are located in areas that experience the same climate year round, such as areas located near the equator, do not show these rings as they undergo the same growth rate year round.

Tree-rings show more than how much wood was produced though, as they can also be an indication of the nature of the growing season in a particular area. Climate is the main limiting factor that impacts the length and productivity of a growing season, and includes parameters such as temperature and precipitation. This information can be seen in tree-rings as trees generally have more growth during wetter periods with favourable temperatures, producing larger growth rings. In contrast, under certain circumstances such as a drought, growth rings that are created are much smaller in width. Tree-ring measurements can also be used to distinguish anthropogenic from natural environmental change, by determining whether recent climatic changes are unusual or still within the range of natural climate variability. Studies show that a number of temperature-sensitive mid-high latitude tree-ring records from both hemispheres show evidence that the recent warming is abnormal (Jacoby & D'Arrigo, 1997). Other sources of data in several global areas support these indications of unusual warming.

4.5 Historical Stories over Time

First hand experiences and stories that reflect a change in the environment are a valuable way to learn how climate change is impacting communities. Although not conclusive scientific evidence, subtle changes such as decreasing ice extent are more intently noticed within certain parts of the world that rely heavily on the land. Local people that have a history of interacting with their respective environment on a regular basis have developed complex systems of first-hand knowledge of weather and climate variability.

First-hand knowledge, also referred to as traditional knowledge, is commonly passed down through generations of Indigenous communities. Many Indigenous communities worldwide continue to acquire the necessities needed to live from the land they reside on, meaning these groups have developed a unique relationship with the landscape that they interact with. A combination of knowledge from the past and present gives these communities a good understanding of natural climate variability. In addition, since these changes are noticed early and often within Indigenous communities, there is potential for using their observations to improve monitoring and management techniques (Weber & Schmidt, 2016).

One community example are the Inuvialuit people of Canada's western Arctic that expected to experience a large shift in their current landscape due to warming, requiring them to change major aspects in their daily life. The change is presently happening, and has already been noticed by the Inuvialuit community as they are an active hunting group and regularly use sea-ice as travel corridors for hunting. Their daily observations include noting the thinning of sea-ice and longer ice-free seasons. These observations are in line with scientific studies demonstrating significant warming trends in the Arctic region (Barber et al, 2008). The change in ice will have direct implications on the community as they depend on certain wildlife species like polar bears and seals which move with the ice. Additional changes are backed through similar accounts and suggest that the region is not as cold as it once was, and has less overall snow.

4.6 Discussion Questions

1. How were climate conditions recorded before the introduction of instrumental measurements?
2. How can scientific evidence and historical perspectives be combined to aid management of a changing climate?

5.0 Managing Climate Change

5.1 Mitigation

Mitigation refers to efforts to reduce or prevent emissions of GHGs. Mitigation can occur by using more efficient technology, making older equipment more efficient, using renewable energy, or changing management practices and behaviour. Mitigation can also be achieved by increasing the capacity of carbon sinks such as forests.

Approaches to mitigating climate change:

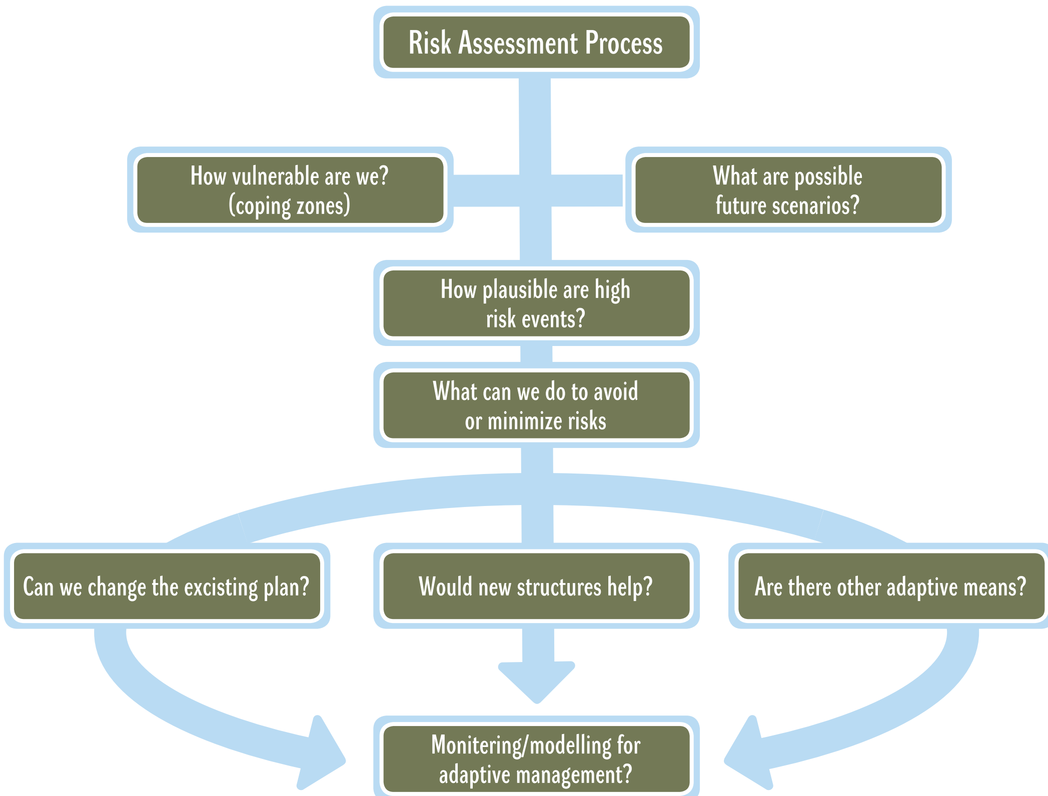
- Phase out fossil fuels and switching to low-carbon energy sources
- Increase sinks such as afforestation to increase forest cover
- Improve energy efficiency such as insulation of buildings and using advanced technologies
- Reduce energy demand by increasing efficiency
- Implement sustainable development policies
- Evaluate the economy with respect to climate change efforts
- Intersect climate policy and other societal goals to have a cohesive goal
- Improve research to better measure risk (events of low probability but significant impact)
- Work toward educating the public on climate change so that climate policy is not biased
- Improve livestock management to reduce methane production and improve manure management
- Improve carbon storage by improving land use
- Improve management on existing land-use types
- Recycle to reduce production of new products from raw materials
- Improve workers knowledge to prevent emissions leakage
- Reduce travel demand

5.2 Adaptation

Adaptations are the changes we make to limit the damage that may occur by adjusting ecological, social, or economic systems to become more resilient to climate change impacts (National Climate Assessment, 2014). Adaptation efforts include: changing infrastructure design, behaviour patterns, practices and zoning restrictions to ecosystem-based approaches (UNEP, 2016). Every sector is taking progressive action to decrease the impacts from climate change but it requires significant research, engagement from a variety of stakeholders, and the modification of policies and regulations.

There are processes that assess the risk climate change imposes on different sectors and aspects of the environment. The risks assessment processes are vulnerable to **perceived risk.** If the organizations or stakeholders do not believe that there is an immediate or possible risk then actions will not be taken to increase adaptability. When vulnerabilities are found to be of concern, then the risk assessment process is executed (Figure 16).

FIGURE 16. *Adaptive Management Assessment Process (Government of Canada, 2014)*



Across Canada, there are many adaptive strategies that are put in place to decrease climate change impacts. The forestry sector is currently implementing several modern standards that will reduce climate change. An example is planned forest adaptations. This entails assisted migration (human-assisted movement of species to maintain healthy levels of biodiversity), alongside more emphasis on health and productivity of forest land. Although changes have resulted in high success rates, forestry is not the only industry battling climate change. Other key industries include mining, industry, and tourism.

5.3 International Collaboration

5.3.1 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC) is an international organization that assesses climate change by reviewing the most recent scientific, technical and socio-economic information. The IPCC was established in 1988 by United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The IPCC is comprised of 195 member countries. Additionally, there are scientists around the world that contribute to the work that IPCC undertakes.

IPCC outlines the importance of climate change and brings nations together on an international level to minimize the consequences of climate change. The IPCC generates the most comprehensive scientific assessment reports which are open to the public. To date, five assessment reports have been published with the newest version being projected in 2022 (IPCC, 2017).

5.3.2 KYOTO PROTOCOL

In 1992, The United Nations Framework Convention on Climate Change (UNFCC) created an international treaty to reduce GHG emissions. The Kyoto negotiations occurred as a result of countries uniting to combat climate change through progressive policies. The protocol recognizes the substantial role developed countries have played in GHG emissions. The legally binding document aimed to collectively reduce emissions by 5.2% by 2012 (Bloch, M., N.A).

Looking back, it quickly becomes apparent that the Kyoto protocol was a failure. Since 1992 countries have taken steps backwards by increasing GHG emissions even further. The years between 2000 and 2010 hold the highest recorded anthropogenic GHG emissions in human history, reaching 49 (±4.5) GtCO2eq / year in 2010 (IPCC [3], 2014). The Kyoto Protocol was established through International Emissions Trading, Clean Development Mechanism (CDM), and Joint Implementation (JI). While these mechanisms were deemed a failure they did established grounds in reducing future GHG emissions.

5.3.3 PARIS AGREEMENT

The Paris Agreement (also known as the Paris Climate Accord or Paris Climate Agreement) was created at the 21st annual Conference of Parties (COP21) which ran from November 4th to December 12th, 2015. The Paris Agreement aims to join countries together to combat the threats posed by climate change and strengthen the ability of countries to deal with impacts. The COP21 represents the first time in over 20 years where UN negotiations achieved a legally binding and universal agreement on climate. A major goal of the Paris Agreement is to keep global warming to 2 degrees Celsius above the pre-industrial era, peaking GHG emissions as soon as possible, and achieving a balance between GHG sources and sinks in the 2nd half of the century.

Of the 197 nations which attended the COP21, 167 have ratified the Paris Agreement (United Nations Framework Convention on Climate Change, n.d). However in 2017 Present Donald Trump announced the USA would withdraw from the agreement over fear of economic impacts. Under the agreement, which the USA ratified, the earliest withdrawal date is Nov. 2020; 4 years after the agreement came into effect.

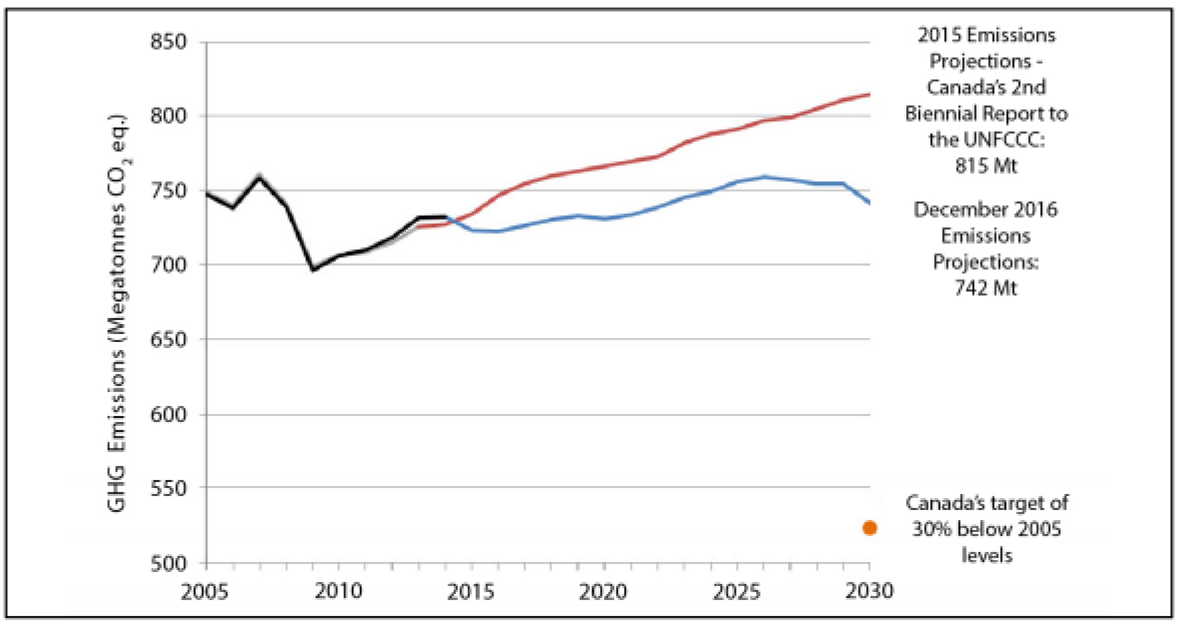
5.3.4 PAN-CANADIAN FRAMEWORK

The Pan-Canadian Framework on Clean Growth and Climate Change is a commitment to the world and Canadian citizens to reduce emissions and build **resilience** through adaptation, while still enabling sustainable economic growth. The Paris Agreement, under the negotiations of the United Nations Framework Convention on Climate Change, established the need to shift human activity to a sustainable low carbon future. As a first step, to implement commitments made by Canada at the Paris Agreement, the Pan-Canadian Framework was established. The Framework was developed by bringing together representatives such as Indigenous people, members of the public, scientists, businesses and civil society from across Canada.

The Pan-Canadian Framework is a comprehensive plan focused on four pillars. The first pillar is pricing carbon pollution as an initiative to reduce emissions, grow innovation, and encourage a reduction in pollution. The second pillar focused on complementary climate actions that help reduce emissions such as limiting the amount of vehicles that are able to access downtown cores by pricing based on density. This would encourage individuals to engage in other forms of public or active transportation. The third pillar is adapting and building resilience to the impacts from climate change with an emphasis on vulnerable regions, such as Indigenous, northern, coastal, and remote communities. The fourth pillar is investing in clean technology, innovation, and jobs so that Canada can build a thriving low carbon economy while promoting a sustainable future.

The overarching goal the Pan-Canadian Framework works towards reducing GHG emissions to 523 Mt (Megatonnes CO2 eq.) a year by 2030. This goal is 30% lower than 2005 recorded levels and is well below the projected 742 Mt for 2016. This framework and its goals are a symbol of unity between different levels of Canadian government. As a nation Canada is embodying its diversity to tackle climate change (Government of Canada [2], 2016).

FIGURE 17. *Emissions Projections to 2030 from December 2016 through revised GDP, oil, and gas prices and production forecasts (Government of Canada [2], 2016).*



Additionally there are complementary actions to reduce emissions in a variety of sectors that the Pan-Canadian Framework outlines. These actions for reduction are catered to sectors that have the largest volume of GHG emissions. These sectors are acknowledged and outline by all three tiers of Canadian government.

TABLE 1. *Pan-Canadian Framework—Actions for Reduction in different Sectors*

SECTORS	ACTIONS FOR REDUCTION
Electricity	1. Increasing renewable and non-emitting energy sources 2. Connecting clean power with places that need it 3. Modernizing electricity systems 4. Reducing reliance on diesel working with Indigenous People and northern and remote communities.
Built Environment	1. Making new buildings more energy efficient 2. Retrofitting existing buildings 3. Improving energy efficiency for appliances and equipment 4. Supporting building codes and energy efficient housing and Indigenous Communities.
Transportation	1. Setting emissions standards and improving efficiency 2. Putting more zero-emission vehicles on the road 3. Shifting from higher- to lower-emitting modes and investing in infrastructure 4. Using cleaner fuels 5. Moving away from auto centric societies by incentivizing people to use other forms of transportation
Industry	1. Reducing methane and HFC emissions 2. Improving industrial energy efficiency 3. Investing in technology
Forestry, Agriculture, and Waste	1. Increasing stored carbon 2. Increasing the use of wood for construction 3. Generating bioenergy and bio products, advancing innovation
Government Leadership	1. Setting ambitious targets 2. Cutting emissions from government buildings and fleets 3. Scaling up cleaning procurement
International Leadership	1. Delivering on Canada's international climate finance commitments 2. Acquiring internationally transferred mitigation outcomes 3. Engaging in trade and climate policy

5.4 Ontario Climate Change Action Plan

Ontario has developed an ambitious five year Climate Change Action Plan, running from 2016–2020, which aims to reduce GHG emissions in the province to 15% below 1990 emissions by 2020. The plan does not to force people to act, but gives the public accessible options to help combat climate change. Collaboration between businesses, industries, municipalities, environmental organizations, and Indigenous communities are included to ensure a future that is environmentally and economically sustainable.

The action plan has identified 8 different areas to be addressed, these are:

- Transportation
- Buildings and Homes
- Land-Use Planning
- Industry and Business
- Collaboration with Indigenous Communities
- Research and Development
- Government
- Agriculture, Forests and Lands

Part of the Ontario Climate Change Action Plan is the Green Investment Fund of $325 million. This fund aims to secure a healthy, clean and prosperous low carbon future by supporting households and businesses in installing energy efficient equipment.

Activities eligible for funding include:

- Household energy reduction though energy audits that will determine the most beneficial retrofits.
- Increase the number of electric vehicle charging stations across Ontario: 500 electric vehicle charging stations are to be built in cooperation with 24 private and public-sector partners.
- Retrofit social housing developments: 35 to 50 high-rise buildings developed between the 1960's and 1970's will be retrofitted by installing energy-efficient boilers, energy efficient windows and lighting, and insulating outer walls.
- Help business reduce emissions and fund local environmental organizations: $74 million to be invested in cleantech innovations which will encourage leading-edge technology to be adopted. $25 million will be invested in SMART Green (energy efficiency program to support small and medium sized businesses).
- Provide Indigenous communities with training, tools and infrastructure to address climate change: $5 million will be invested in the Ontario Centre for Climate Impacts and Adaptation Resources and Ontario First Nations Technical Services Corporation. Additionally $8 million is earmarked for microgrid solution to reduce reliance on diesel fuel, reduce GHGs, and investigate energy reliability. (Ministry of the Environment and Climate Change, 2016).

5.5 Cap and Trade vs. Carbon Tax

Cap and Trade is a form of government regulation that places a limit on how much carbon a business or organization can produce. Various agreements, including the Kyoto Protocol and the Paris Agreement, have recommended a cap of carbon emissions for countries. The cap is dependent on a countries status as developing or developed. Each year, the cap of how many tonnes of GHG can be emitted is reduced so that emissions are reduced gradually as opposed to all at once. This provides companies a transition period to implement operational changes.

A company is able to buy or trade allowances if they go over their emission level or have an excess left on their cap. Allowances are permits which can be traded or bought. For example, if Best Buy goes over their limit, they can buy The Source's excess carbon as long as they have not exceeded their limit (Ministry of the Environment and Climate Change, 2017).

Carbon Tax, also known as a carbon fee, is a tax that is applied to individuals (i.e. taxes on goods such as gas), businesses and organizations. The tax is based on energy use and fossil fuel production. Under the Pan-Canadian Framework, all Canadian jurisdictions will have carbon pricing and taxes put in place by 2018. The tax is calculated by the tonne and starts at $10. Annually, a $10 increase will be implemented until prices have risen $50/tonne in 2022 (Environment of Climate Change Canada, 2016).

Carbon Tax and Cap and Trade are market-based mechanisms to reduce GHG emissions. They offer different levels of maintenance and feasibility when implemented into taxes or into binding action. There are advantages and disadvantages to both but if used together, there will be a greater impact in reducing carbon emissions.

TABLE 2. *Carbon tax and Cap and Trade: Advantages and Disadvantages*

	ADVANTAGES	DISADVANTAGES
Carbon Tax	• Easier and quicker route for governments to implement • Provides environmental and economic incentive for change • A simple method that is not robust in rules or monitoring • Only requires a few months to implement	• Political resistance to introduction of a new tax • Opposition from those who benefit from a cap and trade • Benefit Uncertainty—no assurance that additional tax will result in the desired reduction of GHG emissions • Fear of tax hikes, once a tax is in place, it is easy to increase the tax • Difficult to collaborate • Is susceptible to lobbying and loopholes
Cap and Trade	• Imposes an overall cap on the level of GHG emissions permitted by each economy/country, providing a transparent environmental benefit • The cap is fixed without regard to the economy or the individual polluters • Easier to coordinate with the efforts of other countries • Projected to generate $1.9 billion a year in proceeds that, by law, need to be reinvested in projects that reduce GHG	• Costs get high resulting in pressure to adjust the cap • Suffers from lack of certainty to the cost it imposes

(Avi-Yonah & Uhlmann, 2009; MOECC, 2017; and David Suzuki Foundation, 2014)

5.6 Case Study

Greater Peterborough Area Climate Change Action Plan: Partners For Climate Protection Milestones 2 & 3

The window for avoiding serious climate change impacts—heat waves, droughts, floods and storms, rising sea levels and widespread loss of plant and animal species—is shrinking. We are close to the 2 degree Celsius threshold that many scientists and organizations have identified as the “safe” upper limit for global warming. In order to stay below this limit, global GHG emissions must peak and decline within the next 10 years.

The types of activities that contribute to GHG emissions are influenced, to a large extent, by decisions made locally; by the businesses, schools, and industries in a community and by the people that live and work there. The majority of GHG emissions in the Greater Peterborough Area (GPA) encompassing the City of Peterborough, Peterborough County and its eight member Townships (Asphodel-Norwood, Cavan Monaghan, Douro-Dummer, Havelock-Belmont-Methuen, North Kawartha, Otonabee-South Monaghan, Selwyn, and Trent Lakes), as well as Curve Lake First Nation and Hiawatha First Nation come from community sources, such as homes, places of work and schools, and from how community members travel in and around the area. Other important sources of community emissions include the types of food eaten and where they come from.

Municipalities, First Nations and other public agencies, such as schools and hospitals, as well as residents, business owners/ operators, all have an important role in making decisions that will influence the community’s impact on climate change. In order to take action on climate change, each of the communities in the GPA have established emission reduction targets for both their local government/ internal operations sources of GHG emission and for their community sources of GHG emission. These targets are to reduce emissions by the year 2031 from the 2011 baseline. See below table for more information.

Each member of the GPA has a “local government” and “community” action plan that outlines how they will achieve their targets.

Local Government Sector: Municipal and First Nations Internal Operation—This includes GHG emissions from heating and electricity used to operate buildings, facilities, and other assets that are owned by each local government and waste generated as part of operating those facilities. It also includes GHG emissions from the operation of vehicles and equipment as well as any staff related travel.

Community Sector: This includes how the communities are designed and how people interact and influence their surroundings. Community GHGs are typically emitted from home and business heating and electricity, transportation, and generation of waste.

Local Government emissions are a subset of the overall community emissions. Though local government emissions make up a relatively small amount of the overall community emissions, taking action at the local government level provides an opportunity for municipalities and First Nations in the GPA to demonstrate leadership in climate change action.

For more information please visit https://sustainablepeterborough.ca/ and read the full GPA Climate Change Action Plan and follow the progress of the plan on all social media platforms @ClimatePtbo.

PARTNER	COMMUNITY SECTOR		CORPORATE SECTOR	
	Baseline Emissions (2011)	GHG Emission Reduction Target	Baseline Emissions (2011)	GHG Emission Reduction Target
City of Peterborough	349,743 tonnes CO_2e per year	30%	15,129 tonnes CO_2e per year	30%
Peterborough County	335,051 tonnes CO_2e per year	31%	1,752 tonnes CO_2e per year	26%
Asphodel-Norwood	32,421 tonnes CO_2e per year	25%	592 tonnes CO_2e per year	28%
Cavan Monaghan	54,531 tonnes CO_2e per year	31%	646 tonnes CO_2e per year	29%
Douro-Dummer	48,046 tonnes CO_2e per year	29%	433 tonnes CO_2e per year	32%
Havelock-Belmont-Methuen	37,476 tonnes CO_2e per year	31%	559 tonnes CO_2e per year	40%
North Kawartha	12,128 tonnes CO_2e per year	25%	735 tonnes CO_2e per year	20%
Otonabee-South Monaghan	49,055 tonnes CO_2e per year	25%	498 tonnes CO_2e per year	25%
Selwyn	77,134 tonnes CO_2e per year	39%	1,450 tonnes CO_2e per year	40%
Trent Lakes	24,260 tonnes CO_2e per year	39%	825 tonnes CO_2e per year	26%
Curve Lake First Nation	4,032 tonnes CO_2e per year	15%	(in progress)	15%
Hiawatha First Nation	1,316 tonnes CO_2e per year	15%	124 tonnes CO_2e per year	15%

5.7 Discussion Questions

1. There are plans and agreements that dictate how we reduce our emissions. Compare and contrast the ones mentioned above.
2. Not everyone is a climate change believer. Explore how perceived risk can influence how people adapt themselves to the changing climate and how that can influence whether they choose to reduce their emissions.

6.0 Planning and Innovation

6.1 Land Use Planning - Municipal and Provincial Plans

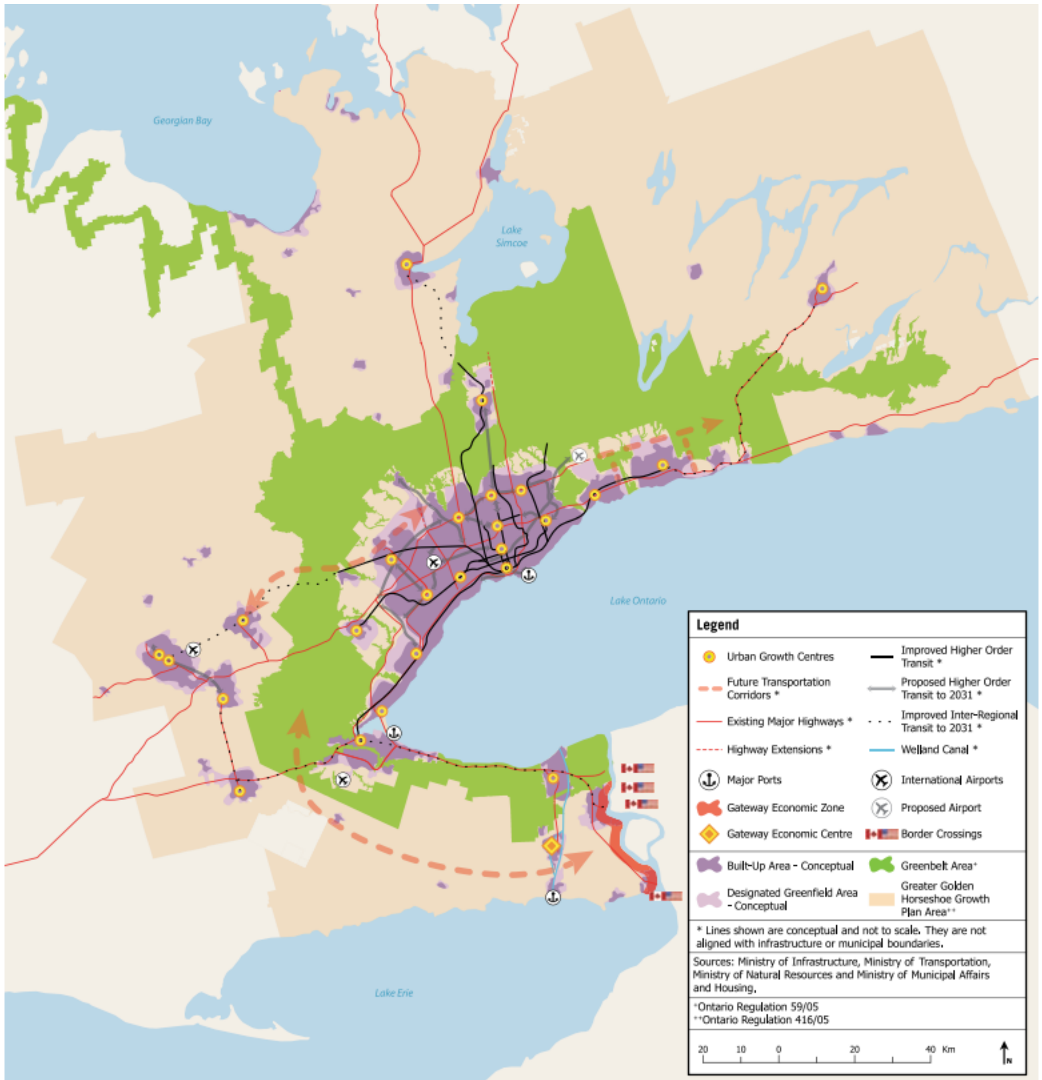
Official municipal plans play a strong role in determining the health of surrounding ecosystems. As many ecosystems span across multiple regions, municipalities are required to work together to create overarching policies. Provincial Policy Statements (PPS) provide province wide direction to promote healthy communities, thriving economies, and a sustainable environment. This type of policy encourages the collaboration of multiple municipalities.

6.1.1 GREATER GOLDEN HORSESHOE

An example of a collaborative area is The Greater Golden Horseshoe (GGH). The plan incorporates 21 upper and single tier, and 89 lower tier municipalities. The Growth Plan aims to build up the area through intensification focused around local transportation, supporting economic competitiveness, and balance jobs.

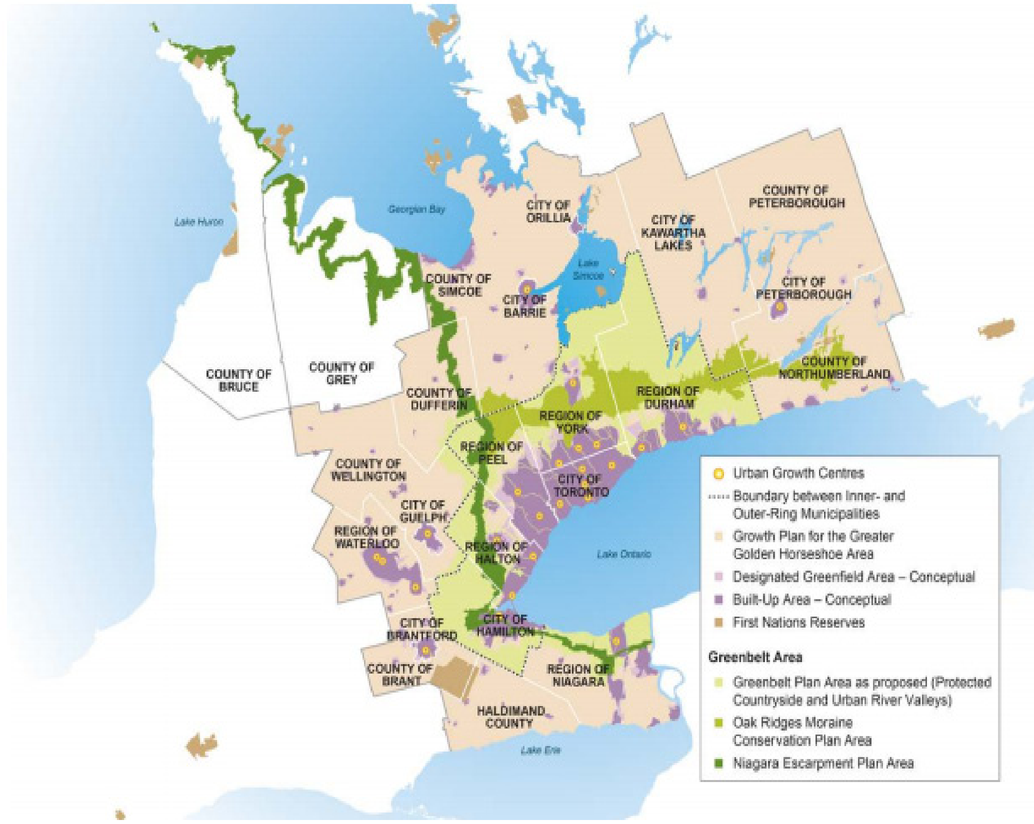
The Growth Plan targets for GGH include increasing intensification while also increasing job opportunities. At least 40% of new residential development must occur by building upwards instead of outwards, this densification will be accompanied by 50 jobs/hectare to ensure future economic prosperity. A target of this plan is to ensure centres have a minimum of 150-400 people and jobs per hectare. By developing multiple smaller city centres, people will need to commute less or encourage greener commuting options which will create healthier environments and stronger local economies. The Places to Grow in the GGH Plan provides the legislative framework for GGH and the Growth Plan. Figures 18 and 19, outline where the areas of growth will occur, such as, urban growth centers, transportation corridors, wastewater systems, and infrastructure (Ministry of Infrastructure, 2013).

FIGURE 18. *Places to Grow Concept, Schedule 2, for the Growth Plan in Greater Golden Horseshoe (Ministry of Infrastructure, 2013).*



The GGH and Niagara Escarpment has multiple areas that need to be protected by local policy and provincial initiatives. The Niagara Escarpment acts as a necessary biodiversity corridor for many species. These areas are crucial to the province as they protect the surface and groundwater. These **protected areas** provide **conservation** for soil and productive lands for agriculture which are vital for local food production. These methods will decrease GHG emissions, preserve carbon sinks, and protect native ecosystems.

FIGURE 19. *The Greater Golden Horseshoe Plan and the Regions Included (Ministry of Municipal Affairs and Housing, 2016)*



6.1.2 GREEN ASSETS AND INFRASTRUCTURE

Green assets are natural vegetation systems that provide vast benefits to a region (Green Infrastructure Ontario Coalition, 2016). Examples include tree canopy, urban forests and woodlots, storm water management ponds, bioswales, xeriscaping, meadows and agricultural lands, green roofs and walls, parks, gardens, turf and landscape areas. Green assets (or infrastructure) are becoming of greater importance in municipal planning because of their value in reducing the impacts of climate change.

The importance of trees and urban forests are becoming increasingly known. Trees play a crucial role in filtering out pollutants, decreasing the urban **Heat Island Effect**, protecting water sources, decreasing flooding, and reducing GHG emissions (Green Infrastructure Ontario Coalition, 2016). However, urban forest health is constantly being challenged through development, pollution and increasing threats of invasive species. As mentioned earlier, climate change has the potential to increase the prevalence and impact of invasive species. In the Greater Toronto Area (GTA), it is estimated that 3 million trees will die as a result of Emerald Ash Borer infestations (Green Infrastructure Ontario Coalition, 2016). It is estimated to cost the GTA $14.2 billion to fix the issues and replace all dead or infested trees.

Green infrastructure helps in water management as it protects, restores or mimics the natural water cycle, and enhances community safety and quality of life (American Rivers, 2016). There is already a wide range of practices in place that embraces the principles of green infrastructure. These include: right-of-way bioswales, stormwater green streets, green roofs, blue roofs, rain gardens, permeable paving, subsurface detention systems and cisterns/ rain barrels (see Table 3 for greater detail on these methods).

TABLE 3. *Green Infrastructure Methods (City of New York. 2017)*

GREEN INFRASTRUCTURE METHOD	WHAT DOES IT ACCOMPLISH?
Right-of-way Bioswales	Planted areas located along sidewalks that are designed to collect and manage stormwater
Stormwater Green streets	Planted areas located along streets that are designed to collect and manage stormwater
Green Roofs	A vegetative layer that grows on top of a drainage layer on a rooftop
Blue Roofs	Consist of roof drain inlets that create temporary ponding and release of stormwater.
Rain Gardens	Vegetated or landscapes depressions designed to promote infiltration of stormwater runoff into the underlying soil
Permeable Paving	Allows water to seep between the paving material and be absorbed into the ground
Subsurface Detention Systems	Provide temporary storage of stormwater runoff underground.
Cisterns and Rain Barrels	Designed to catch and store stormwater off roofs and other impervious surfaces.

Green infrastructure proves to have considerable environmental benefits that in turn improve resiliency of communities. Vegetation based green infrastructure helps mitigate carbon pollution, flooding and lowers the dependence on imported water by allowing groundwater supplies to recharge from storm water management techniques (Environmental Protection Agency [3]. 2016).

6.2 Case Study: Industrial Innovation at Interface

Interface is the world's largest producer of modular carpet which caters to businesses globally, and it is an innovative company that has created a vision for how businesses can embrace **sustainability**. In 1994, Interface founder Ray Anderson, refocused his 21-year-old company with the goal of reaching zero emissions. Anderson, read Paul Hawken's "The Ecology of Commerce" which changed his view on the environment and sustainability. The book informed him of the destructive practices that his business followed and the importance of promoting environmental restoration as well as understanding the role his business plays in the grand scheme. After reading this book, Anderson had an epiphany and started envisioning a new business model for his company. The sustainability vision mimicked a cyclical model that follows nature. Interface is guided by the people, process, product, place and profits. Their mission is to honour the guiding principles in an environmentally sustainable way and with respect while becoming emission free by 2020.

Before Anderson read "The Ecology of Commerce", his business model had no sustainability aspects ingrained in it. Now there are seven key areas that are used to measure and track the business' progress.

TABLE 4. *Seven Key Areas to Measure Progress (Interface, 2016)*

FRONT	KEY AREAS THAT MEASURE INTERFACES PROGRESS
Front 1	Eliminate Waste: Eliminate all forms of waste in every area of business.
Front 2	Benign Emissions: Eliminate toxic substances from products, vehicles and facilities.
Front 3	Renewable Energy: Operate facilities with 100% renewable energy.
Front 4	Close The Loop: Redesign processes and products to close the technical loop using recovered and bio-based materials.
Front 5	Resource Efficient Transportation: Transport people and products efficiently to eliminate waste and emissions.
Front 6	Sensitize Stakeholders: Create a culture that uses sustainability principles to improve the lives and livelihoods of all of our stakeholders—employees, partners, suppliers, customers, investors and communities.
Front 7	Redesign Commerce: Create a new business model that demonstrates and supports the value of sustainability-based commerce.

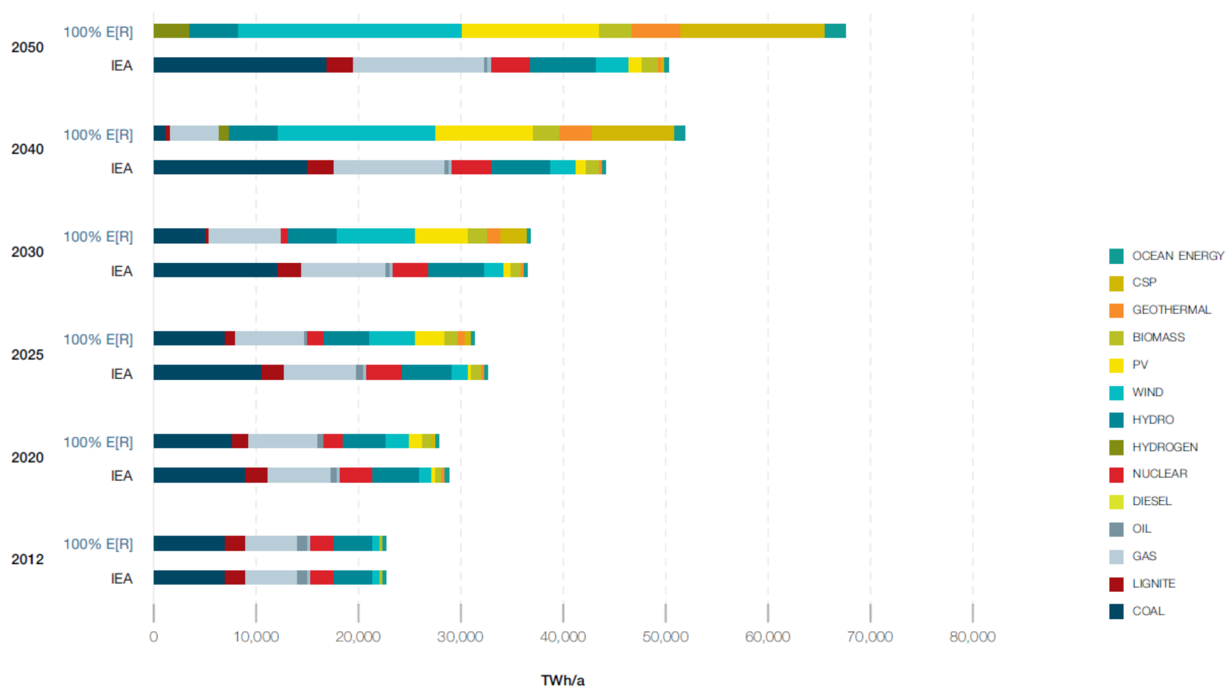
6.3 Local Climate Movements

As climate change continues to alter our world, it is crucial that awareness is raised through local movements. A current example in Ontario is the Toronto Climate Action Network (TCAN). TCAN is a network of action-oriented organizations working together to address the threat of climate change locally. Partner organizations include: Green Neighbours 21, whose goal is to encourage greener living and speaking out for government action; Citizens Climate Lobby which is a local volunteer group that is pressing for progressive climate legislation; Post Carbon Toronto, a group of Toronto citizens working together to envision and transition Toronto and its bioregion into sustainable low energy communities. (Toronto Climate Action Network. n.d.).

6.4 Renewable Energy

In a world dominated by fossil fuel consumption, the idea of transitioning to 100% renewable energy doesn't seem feasible. In reality however, using the model comparing **IEA** current policies and Energy [R]evolution we see that it is possible to phase out not only coal, but other harmful sources of energy production and to switch to 100% renewable energy production of electricity.

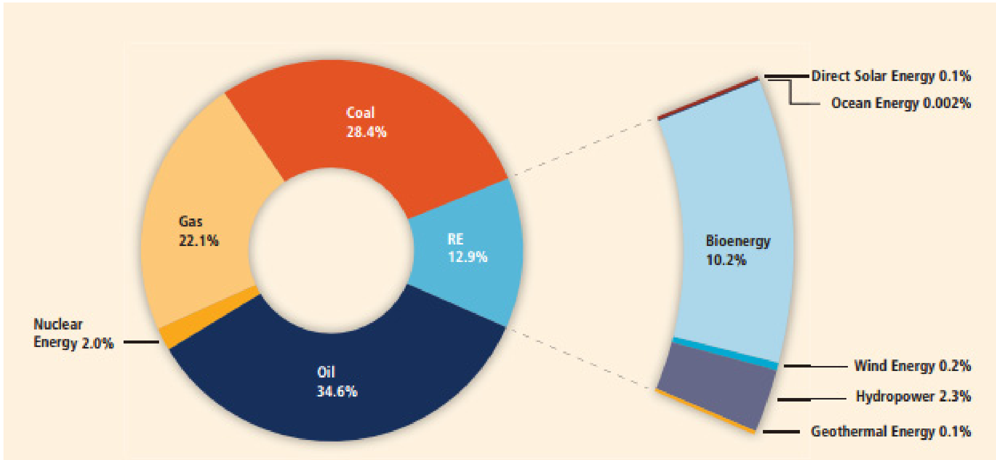
FIGURE 20. *World Development of Electricity Generation under the IEA "current policies and the Energy [R] evolution case (Greenpeace, 2015)*



Transition to renewable energy is crucial for the reduction of GHG emissions. There are also additional benefits to switching to cleaner forms of energy, including an increase in employment opportunities as the green energy sector expands.

The primary renewable energy sources and technologies currently in use are bioenergy, solar, geothermal, hydropower, ocean, and wind energy. Presently, the global energy supply only creates 12.9% of energy from renewable sources.

FIGURE 21. *Total global energy supply in 2008 (IPCC, 2011).*



6.4.1 BIOENERGY

Bioenergy is derived from biological sources - living organisms and/or their by-products (Government of Canada [2], 2017). Global biomass systems use food, fodder, fibre production, forest products, and waste. Biomass is the fuel that is created from organic material which is either converted to heat by combustion or converted to various forms of energy like pellets. Bioenergy plays a critical role in developing countries but is also relevant in countries like Canada given our abundance of natural resources.

Bioenergy accounts for roughly 6% of the total energy supply in Canada (Government of Canada [2], 2017). The main sources of bioenergy in Canada are biogas, biofuels, and biomass resources (Government of Canada [2], 2017). This is a growing field nationally and some of the advancements include converting waste (eg. restaurant grease) into high-quality diesel fuels, diesel blending stocks that can operate at low temperature, and anaerobic digestion processes for the pulp and paper industry etc. (Government of Canada [2], 2017). There is extensive research being conducted to ensure the development of a sustainable Canadian Bio-economy through Canadian Biomass Innovation Network (CBIN). However, there are concerns with the use of Bioenergy systems in regard to health, poverty, biodiversity as well as water scarcity and quality. Therefore, there needs to be strong management of land and water resources to mitigate any risks involved with this type of renewable energy.

There are two forms of biomass:

Low efficiency biomass. This type of biomass includes wood, straw, dung and other manure. It is used for cooking, lighting and heating. Commonly used in developing countries, this form of biomass can have negative impacts on health and living environment given the impact to air quality as a result of combustion.

High efficiency biomass. This type of biomass includes the use of solids, liquids and gases. It uses secondary energy carriers to generate heat, electricity, and combined heat and power (IPCC, 2011). Liquid biofuels are ethanol and biodiesel which are used for road transport and in industry. Gases such as methane are produced through anaerobic digestion of agricultural residues and municipal solid waste (MSW) treatment. These gases can generate electricity if captured. Solids such as chips, pellets, and recovered wood can also act as energy sources.

6.4.2 SOLAR ENERGY

Direct solar energy is a renewable energy source that uses a wide range of technologies to convert solar energy (heat and light) to different types of usable energy. Technologies include:

- Solar thermal—active and passive heating of buildings, domestic and commercial solar water heating, swimming pool heating and processing heat for industry
- Photovoltaic (PV)—electricity generation by direct conversion of sunlight through photovoltaic cells
- Concentrating solar power (CSP)—electricity generation by optical concentrations of solar energy
- Solar fuels production—creating energy using a process mimicing photosynthesis Direct solar energy in Canada is typically photovoltaic (PV). Solar collectors, analogous to solar thermal, is also used, this form of technology heats water or ventilates air throughout buildings.

Areas that experience significant cloud cover have lower solar potential. Central regions in Canada and many major cities have a tendency to have higher solar potential due to their geographic location. When direct sunlight is not impeded by other structures, residents are able to install solar panels on residential roofs. There are also solar farms that capture and produce energy to be utilised by the surrounding area.

While there are many benefits to solar power, there are also challenges in this energy source. Solar energy is an intermittent energy source, meaning that it is not available at all times of the day and is inconsistent because of weather. Solar panels can also take up a significant portion of the landbase and it should be ensured that construction of these facilities is taking place on unproductive land.

6.4.3 HYDROPOWER

Hydropower creates energy from water moving from higher to lower elevations. This source of renewable energy is a form of kinetic power and has been used to generate energy for over 2000 years (IPCC, 2011). Topography and river size determine the magnitude dam requires and the amount of energy produced.

In Canada hydropower is used to generate 63% (2013) of the country's electricity needs used by households and businesses (CHA, 2017). Dams are found in almost every province and territory in Canada, with Quebec and British Columbia producing the greatest amount of hydroelectric electricity nationally. All of the hydroelectric stations in Canada generated almost 400 terawatt hours in 2014 (Government of Canada [3], 2016).

Hydropower is fueled by water which means that it does not rely on non-renewable sources to fuel the production of energy. Unlike power plants such as coal or natural gas, it does not pollute the air with GHG. There is also no excess waste generated from the production of energy and the cost is less expensive when compared to fossils fuels.

There is however controversy surrounding hydroelectric dams and the environmental impacts they cause. The construction of large dams can have consequences on the surrounding aquatic and terrestrial environment. When a dam facility is installed, flooding occurs upstream. This alters habitat and decreases the diversity of species in both river and terrestrial ecosystems. The downstream morphology of the riverbeds, channel, and sediment load changes as well. There is reduced sediment load that flows downstream which not only affects the immediate river but reduces the sediment that reaches the estuaries and deltas which play an important role in the health of ecosystems. Without incoming sediment, an increase in erosion can occur, causing channels to become narrower and deeper. Dams also reduce biodiversity because organisms are unable to move naturally up and down the river (i.e. migrating salmon). However, a mitigation method put in place is to add fish ladders that allow species to pass up and down river (ABS Energy Research, 2009).

6.4.4 WIND ENERGY

Wind energy is a form of kinetic energy generated by converting moving air to electricity through wind turbines. Wind energy is one of the fastest growing sources of electricity generation and should be implemented in areas that have favourable weather patterns. The electricity produced is either used locally or sold to the power grid which allows the electricity to be used further away. Wind farms can reduce the amount of greenhouse gases, air contaminants, and reliance on diesel fuel (Government of Canada [4], 2016).

Wind power in Canada has grown substantially since 1998, from 60 turbines used to produce 27 megawatts, to 5130 wind turbines with installed capacity to produce 9694 megawatts in total in 2014 (Government of Canada [4], 2016). Canada's geography enables large numbers of wind turbines to be installed, particularly in Southern Ontario and regions on the east coast (Newfoundland).

While there are many benefits to wind turbines, there can also be issues for local residents and wildlife. From an anthropogenic point of view some feel that wind farms decrease the natural beauty and aesthetic of the landscape. Unfortunately, studies have also proven that wind turbines can result in substantial bird and bat fatalities. Different sizes and speeds of turbines influence the fatality rates (Barclay, et al., 2007). With climate change exacerbating pests and the spread of disease, birds and bats populations need to be healthy to maintain pest populations. Wind turbine site management practices, as well as research, monitoring, and assessment of sites before wind farms are installed, can help to reduce the number fatalities.

6.5 Top 10 Things You Can Do To Help

1. **Adopt energy-saving habits.**

   Make it a habit to turn off the lights as you leave a room. Also, replace standard light bulbs with energy-efficient compact fluorescent bulbs. Turn off your computer and unplug electronics when they are not in use.

2. **Change the way you think about transportation**

   Walk or bike whenever possible. Not only will you reduce your carbon footprint, but your overall level of health will improve and you will save money on parking and gasoline. Take public transit or carpool whenever possible. When purchasing a vehicle look for one with better mileage. Increase your fuel economy when driving by sticking to posted speed limits and avoiding rapid acceleration and excessive braking. Plan and combine trips and errands. This will save you both time and money as well as reduce wear and tear on your vehicle. When travelling long distances, try to take a train or bus rather than flying or driving.

3. **Insulate your home**

   Insulate yourself and your home. By properly insulating your home, you can ensure that heat stays in or out depending on the season. You can do this by purchasing windows and window coverings that will block out or keep in warmth, and by sealing any existing cracks. In winter, reduce your thermostat by 2 °C to enjoy energy savings and a cozy sweater. In summer, use fans to circulate air, and set air conditioners to make your home a comfortable temperature. Lowering the temperature on your water heater to between 55 and 60 °C and insulating your pipes also makes a difference.

4. **Make every drop count**

   Conserve water by fixing drips and leaks, and by installing low-flow shower heads and toilets. Challenge yourself to a speed shower. Turn off water while brushing teeth or shaving. Treating and transporting water requires energy, while water conservation results in reduced energy requirements and carbon emissions.

5. **Cool wash and hang to dry**

   These are not just washing instructions on a label anymore, but an equation for energy savings. Wash clothing in cold water and hang clothing to dry outside, or indoors on a drying rack. Taking these steps will reduce your electricity bill and also prolong the life of clothing by reducing wear on the fabric caused by dryers.

6. **High efficiency appliances**

   When replacing appliances, look for high efficiency units. Appliances with ENERGY STAR ratings, an international standard for energy-efficient consumer products, typically utilize a minimum of 20 % less energy. This means savings for you and the environment.

7. Switch to "green power"

Research where your power is coming from—wind, water, coal, or solar—and talk to your power provider to determine if a greater percentage could be coming from renewable resources. Encourage power providers to switch to green power and, if possible and/or economically viable, switch to a company offering power from renewable resources.

8. Recycle

Make recycling part of your daily routine. Recycle all packaging and consumer goods that you can. Aim to purchase items with minimal and recyclable packaging. For certain items with large amounts of packaging, ask retailers if they can recycle or re-use it. For electronics, facilities now exist that can dispose of electronics in an environmentally responsible manner.

9. Repurpose

Rather than discarding or recycling clothing and household goods, give them a chance at a second life. Gently used clothing can be donated to charity or exchanged with friends and family. Old T-shirts can be repurposed into rags for cleaning. Household goods can be donated to charity or sold at a garage sale. Through repurposing, the amount of waste being sent to landfill sites is reduced, there is no need to use energy for recycling, and others can benefit from your used items.

10. Plants, our new best friend

When gardening, select plants that are well suited to your climate and require minimal watering and attention. Better yet, plant a tree, and it will provide shade and soak up carbon from the atmosphere.

List sourced from Government of Canada, 2015

6.6 Discussion Questions

1. Research a company or new technology that has values similar to Interface and discuss the similarities and differences.
2. What are actions or innovations that we can apply to our everyday lives to decrease our carbon footprint and the GHG we emit?
3. Choose a group within the TCAN and summarize their goals and what you believe they can do to complete them.

7.0 Conclusion

Climate change is an international concern that has countries across the world joining forces to combat present and future threats. While there are still those who do not believe in climate change, the scientific data and the physical changes we see year to year are living proof. Additionally the accumulation of data from scientists across the world is making it more difficult to dispute. It is not only biologists, chemists, physicists, or environmental scientists that are compiling this data but also citizens, land-use managers, social scientists and anthropologists.

Through the actions implemented in the past few decades, there has been a notable decrease in GHG emissions, but a lot of work is still needed. There has also been a perception change on what climate change means. It is now generally perceived as an issue that needs to be addressed with strong mitigation and adaptation methods. The public continues to be educated on the actions that they can take to reduce their impact at home, and industry leaders around the world are better understanding and implementing changes that are benefiting their businesses. It will take a collective effort globally, and more importantly it will take strong leadership to ensure that effort continues.

8.0 Glossary of Terms

8.1 Definitions

A

Adaptation(s): the actions that humans take to adjust natural or human systems to moderate the expected effects of climate change that have occurred or are expected to occur.

Anthropogenic: relating to or resulting from the influence of human activity. In this case, human being's activity adversely impacting the environment (pollutants, excess emissions).

B

Biodiversity: the variety of all species in a particular environment, or the world, and their interactions with each other and the physical environment.

Biomass: organic materials that are living or previously living. Examples are wood, agricultural crops and different forms of waste.

C

Carbon Tax: a tax that is applied to companies, organizations, or households (depending on where the tax is implemented) based on the GHG emissions generated from burning fossil fuels. This tax is put in place as an incentive to decrease the output of GHG gases.

Cap and Trade: systems that controls the GHG emissions by putting a limit on how much a business, organization, or country is able to produce in a set amount of time (usually annually).

Climate Change: is defined by the UN as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Conservation: the management of a natural resource that prevents its depletion and adverse effects on the natural processes surrounding it.

D

Direct emissions: Emissions that are produced by the facility.

E

Ecosystem Services: The benefits obtained from normal ecosystem function including climate regulation, water purification and pollution control to name a few.

Evaporation: the process of turning from liquid into vapour.

F

Foraminifera: an ocean-dwelling organism whose shell can be analyzed to determine climate conditions due to the variable nature of their shell composition, based off the water they are inhabiting.

G

Greenhouse Effect: a natural process which traps warmth in the planets lower atmosphere. Can be influenced by greenhouse gas emissions.

Greenhouse Gas: a gas which, in the atmosphere, absorbs and emits radiation contributing to the greenhouse effect.

Global Warming Potential: a measurement used to compare the warming impact of different gases. The larger the global warming potential the more said gas warms the earth compared to carbon dioxide over the same time period.

Groundwater Recharge: the hydrological process of water moving downward from the surface. Groundwater recharge is the primary methods through which water enters an aquifer.

H

Heat Island Effect: The phenomenon by which urban centres and built environments experience higher temperatures than nearby rural areas.

Hydrology: A branch of science concerned with water. In particular the movement of water in relation to land.

I

Indirect emissions: Emissions that are a consequence of activities.

Innovation: the act of innovating; introduction of new things or methods

Interspecific Relationships: interactions between organisms that belong to different species. Similar to symbiotic relationships.

Isotope: forms of an element or an atom that have the same number of protons, but have a different number of neutrons. Different forms of isotopic compositions can show information of climate conditions.

L

Land Use Change(s): the process by which humans activity changes the landscape (i.e clearing forest for agricultural use, afforestation in previously unforested areas)

M

Mitigation: the act of reducing the seriousness or impact of an action. With respect to climate change, we reduce the sources of GHG and also enhance the sinks of GHG.

P

Perceived Risk: is what an individual views as a risk, despite facts and scientific data. This can determine whether one believes in something or buys into something.

Permafrost: a layer of permanently frozen soil located under the ground surface.

Primary Pollinators: organisms (insects or mammals) that move pollen from the male anther of a flower to a female stigma resulting in plant reproduction. Primary pollinators are the organisms that are the main species that pollinate that plant (wild flower, fruits, vegetables etc.).

Protected Areas: "A clearly defined geographical space, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (IUCN, 2008).

Phenological Shifts: changes in the lifecycle of plants and animals as the result of external pressures (i.e. earlier migrations, expansion of habitat, changes to growing season)

R

Resilience: the capability to anticipate, prepare for, respond to, and recover from hazardous events while minimizing the damage

S

Soil Organic Matter (SOM): The component of soil comprised of organic matter including plant and animal materials at various stages of decomposition.

Sustainability: the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance

Symbiotic: this is close association or relationship between two or more organisms that either benefit for each other or one benefits from the other

T **Transpiration**: evaporation of water from plant leaves

Z **Zoonotic Disease(s)**: infectious disease that can be transmitted from animals to humans. Example, rabies.

8.2 Acronyms

CBIN: Canadian Biomass Innovation Network

CCS: Carbon Capture Storage

CDM: Clean Development Mechanism

CH_4: Methane

CO_2: Carbon Dioxide

COP: Conference of the Parties

CSP: Concentrating Solar Power

E[R]: Energy [R]evolution

GGH: Greater Golden Horseshoe

GHG: Greenhouse Gases

GTA: Greater Toronto Area

IEA: International Energy Agency

IPCC: Intergovernmental Panel on Climate Change

IUCN: International Union for the Conservation of Nature

JI: Joint Implementation

Mt: Megatonnes CO2eq.

N_2O: Nitrous Oxide

pH: Potential of hydrogen

Ppb: Parts per billion

Ppm: Parts per million

PPS: Provincial Policy Statement

RE: Renewable Energy

TCAN: Toronto Climate Action Network

SOC: Soil Organic Carbon

UN: United Nations

UNEP: United Nations Programme

UNFCCC: United Nations Framework Convention on Climate Change

WMO: World Meteorological Organization

9.0 Appendices

9.1 Appendix 1: Hands-on Activities

9.1.1 ACTIVITY 1: CALCULATING FOREST CARBON

Forests (trees and soils) act as a carbon stores for our planet. Learn to determine the value of these sinks with the following activity, based on a report that specifically focused on creating an equation for this (see Lambert's paper for rationale). You can calculate how much carbon a particular forest holds by following the instructions provided the QR code below.

(Link to protocol, calculations and questions)

(Link to google sheets for the activity)

Lambert, M. -., Ung, C. -., & Raulier, F. (2005). Canadian national tree aboveground biomass equations. *Canadian Journal Of Forest Research*, 35(8), 1996-2018. doi:10.1139/X05-112
(good reference to background information of this activity)

9.1.2 ACTIVITY 2: POLLINATOR SERVICES ACTIVITY

Without insect pollinators, our food supply would be drastically different. In a typical grocery store in Canada, we have access to fruits and vegetables from all over the world that rely on insect pollination as part of their reproduction process. What would happen if all the insect primary pollinators became extinct due to climate change? Below is a photo of a produce section from a typical groccery store. Research what types of fruit and vegetables rely on insect pollination and remove items that would disappear without pollination.

(Pinterest, 2015)

9.1.3 ACTIVITY 3: PERSONAL CARBON CALCULATION ONLINE

This study guide outlines the ways that GHGss can be reduced on a large scale, however, as individuals, we are guilty of contributing to climate change. As a way to calculate our impact, we can determine our carbon and water footprints to identify areas of improvement.

Choose one of the links below, and calculate your footprints. Different websites focus on different aspect of your life, so try to do a few and compare. Once you have calculated your footprints, compile a list of lifestyle changes that you can do to reduce your impact.

Carbon Footprint

http://www.livesmartbc.ca/homes/h_calc.html

https://treecanada.ca/en/programs/grow-clean-air/carbon-calculator/

http://www.carbonfootprint.com/calculator.aspx

http://www.nature.org/greenliving/carboncalculator/

http://footprint.wwf.org.uk/

Water Footprint

http://waterfootprint.org/en/resources/interactive-tools/personal-water-footprint-calculator/

http://waterfootprint.org/en/resources/interactive-tools/personal-water-footprint-calculator/personal-calculator-extended/

9.2 Appendix 2: References

ABS Energy Research. (2009). Hydropower Report. *Hydropower Large and Small*. Edition 2.

http://eds.b.ebscohost.com.eztest.ocls.ca/eds/pdfviewer/pdfviewer?sid=e0e40fc9-3f4a-47a7-b18d-11e18dc7a95c%40sessionmgr101&vid=4&hid=108

Alley, R. B. (2000). Ice-core evidence of abrupt climate changes. *Proceedings of the National Academy of Sciences of the United States of America,* 97(4), 1331-1334.

Agriculture and Agri-food Canada. (2015). The Impact of Climate Change on Canadian Agriculture. Retrieved from, http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/agriculture-and-climate/future-outlook/impact-of-climate-change-on-canadian-agriculture/?id=1329321987305

American Rivers. (2016). What is Green Infrastructure. *American Rivers: Rivers Connect Us.* https://www.americanrivers.org/threats-solutions/clean-water/green-infrastructure/what-is-green-infrastructure/

Avi-Yonah, R.S., & Uhlmann, D.M. (2009). Combating Global CLimate Change: Why a Carbon Tax is a Better Response to Global Warming Than Cap and Trade. *Stanford Environmental Law Journal*. 28 (3), 3- 50.

Barber, D. G., Lukovich, J. V., Keogak, J., Baryluk, S., Fortier, L., & Henry, G. R. (2008). The Changing Climate of the Arctic. *Arctic*, *61*7-26.

Barclay, R.M.R., Baerwald, E.F., & Gruver, J.C. (2007). Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. *Canadian Journal of Zoologyl.* 85, 381-387. Doi: 10.1139/Z07-011

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters.* 15 (4), 365-377. doi: 10.1111/j.1461-0248.2011.01736.x.

Bloch, M. (N.A). What is the Kyoto Protocol? Retrieved from, *Carbonify.com*

Brinkman, Robert, and Wim G. Sombroek, 1996: The effects of global change on soil conditions in relation to plant growth and food production. In F. Bazzaz and W. Sombroek, eds., *Global Change and Agricultural Production.* Food and Agricultural Organization of the United Nations and John Wiley & Sons, New York, 345 pp.

City of New York. (2017). Types of Green Infrastructure. *NYC Environmental Protection.* http://www.nyc.gov/html/dep/html/stormwater/combined_sewer_overflow_bmps.shtml

Clean Energy Canada. (2016) The Costs of Climate Change. Retrieved from, http://cleanenergycanada.org/wp-content/uploads/2016/11/Costs-in-Context-Nov16.pdf

David Suzuki Foundation. (2014). Carbon tax or cap-and-trade? Retrieved from, http://www.davidsuzuki.org/issues/climate-change/science/climate-solutions/carbon-tax-or-cap-and-trade/

Environment Canada. (2013). National Inventory Report 1990-2013: Greenhouse Gas Sources and Sinks in Canada – Executive Summary, The Canadian Government's Submission to the UN Framework Convention on Climate Change, 2015, p. 2.

Environment and Climate Change Canada. (2016). Government of Canada Announces Pan-Canadian Pricing on carbon Pollution. *Government of Canada*. Retrieved from, http://news.gc.ca/web/article-en.do?nid=1132149

Environmental and Climate Change Canada. (2017). Soild Waste and Greenhouse Gases. Retrieved from, http://www.ec.gc.ca/gdd-mw/default.asp?lang=En&n=6f92e701-1

Environmental Protection Agency[1]. (2016, December). Causes of Climate Change. *Climate Change Science. https://www.epa.gov/climate-change-science/causes-climate-change*

Environmental Protection Agency[2]. (2016, December). Climate Impacts on Forests. *Climate Change Impacts.* https://www.epa.gov/climate-impacts/climate-impacts-forests

Environmental Protection Agency [3]. (2016, December). Green Infrastructure for Resiliency. *Climate Change Impacts.* https://www.epa.gov/file/green-infrastructure-climate-resiliency-infographic

Environmental Protection Agency[1]. (2017). Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases.
Retrieved from: https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases

Environmental Protection Agency[2]. (2017). Understanding Global Warming Potentials. *Greenhouse Gas Emissions.* Retrieved from: https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Environmental Protection Agency [1]. (n.d). Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases. Retrieved from, https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases

Environmental Protection Agency [2]. (n.d). Overview of Greenhouse Gases. Retrieved from, https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Environmental Science. (2017). Dendrochronology: What tree rings tell us about the past and present. Retrieved from: http://www.environmentalscience.org/dendrochronology-tree-rings-tell-us

Frazer, L., (2009). Climate Change: Will Warmer Soil Be as Fertile? *Environmental Health Perspective.* 117 (2), A59. Retrieved from, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2649242/

Government of Canada. (2014). Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation. Warren, F.J. and Lemmen, D.S. (eds). Retrieved from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf

Government of Canada. (2015). Top 10 Things You Can Do to Help. Retrieved from, http://climatechange.gc.ca/default.asp?lang=En&n=D27052C

Government of Canada [1]. (2016). Economic analysis of the Pan-Canadian Framework. Retrieved from, https://www.canada.ca/en/services/environment/weather/climatechange/climate-action/economic-analysis.html?wbdisable=true

Government of Canada [2]. (2016). The Pan-Canadian Framework on Clean Growth and

Climate Change *Canada's Plan to Address Climate Change and Grow the Economy.* Retrieved from, https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html

Government of Canada [3]. (2016). Drivers and Impacts of Greenhouse Gas Emissions. *Environment and Climate Change Canada.* Retrieved from, https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=D4C4DBAB1

Government of Canada [4]. (2016). Wind Energy. *Natural Resources Canada*. Retrieved from Government of Canada website, http://www.nrcan.gc.ca/energy/renewables/wind/7299

Government of Ontario. [1] (2017). Climate Change Action Plan. Retrieved from, https://www.ontario.ca/page/climate-change-action-plan

Government of Canada. [2] (2017). Bioenergy Systems. Retrieved from, http://www.nrcan.gc.ca/energy/renewable-electricity/bioenergy-systems/7311

Green Infrastructure Ontario Coalition. (2016). Let's Make Green Infrastructure the New Normal. Retrieved on March 28, 2017 from, http://greeninfrastructureontario.org/

Greenpeace. (2015). 100% renewable energy for all: energy [r]evolution. *A Sustainable World Energy Outlook 2015.* Retrieved from, https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/studie_energy_revolution_2015_engl.pdf

Interface. (2016). Sustainability, Interface Story. Retrieved from, http://www.interfaceglobal.com/Sustainability/Interface-Story.aspx

IPCC. (2011). Renewable Energy Sources and Climate Change Mitigation. Summary for Policymakers and Technical Summary. Arvizu, D., Bruckner, T., Chum, H., Edenhofer, O., Estefen, S., Faaij, A., Fischedick, M., Hansen, G., Hiriart, G., Hohmeyer, O., Hollands, K. G. T., Huckerby, J., Kadner, S., Killingtveit, Å., Kumar, A., Lewis, A., Lucon, O., Matschoss, P., Maurice, L., Mirza, M., Mitchell, C., Moomaw, W., Moreira, J., Nilsson, L. J., Nyboer, J., Pichs-Madruga, R., Sathaye, J., Sawin, J., Schaeffer, R., Schei, T., Schlömer, S., Seyboth, K., Sims, R., Sinden, G., Sokona, Y., von Stechow, C., Steckel, J., Verbruggen, A., Wiser, R., Yamba, F., and Zwickel, T. (2011). Technical Summary. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [1]. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC [2]. (2014). Jimenez, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Conley, P. Döll, T Jiang, and S.S. Mwakalila. *Freshwater resources. In: Climate Change 2014: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [3]. (2014). Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2017). Organization. Retrieved from the IPCC website, http://www.ipcc.ch/organization/organization.shtml

IPCC. (n.d). FAQ, What Is the Greenhouse Effect? Retrieved from, https://wg1.ipcc.ch/publications/wg1-ar4/faq/wg1_faq-1.3.html

Jacoby, G. C., & D'Arrigo, R. D. (1997). Tree rings, carbon dioxide, and climatic change. *Proceedings of the National Academy of Sciences of the United States of America, 94(16), 8350-8353.*

Jan Oosthoek, K. (2015). Reconstructing Past Climates. *Environmental History Resources.* Retrieved from: https://www.eh-resources.org/reconstructing-past-climates/

Kahn, Brian. (2016). One Glorious Map Shows the Future of Animal Migrations. *Climate Central.* Retrieved from, http://www.climatecentral.org/news/map-animal-migration-climate-change-20646

Lal, R. (2004). Soil carbon Sequestration Impacts on Global Climate Change and Food Security. *Science*. 304, 1623-1627. doi: 10.1126/science.1097396

Mawdsley, J. R., O'Malley, R., & Ojima, D. S. (2009). A Review of Climate-Change Adaptation Strategies for Wildlife Management and Biodiversity Conservation. *Conservation Biology*, *23*(5), 1080-1089. doi:10.1111/j.1523-1739.2009.01264.x

McGinn, D. (2012, October). How much food do Canadians waste a year? Think billions. *Globe and Mail*. Retreived from the Globe and Mail website, http://www.theglobeandmail.com/life/the-hot-button/how-much-in-food-do-canadians-waste-a-year-think-billions/article4580509/

Ministry of the Environment and Climate Change. (2016). Green Investment Fund. Retrieved from MOECC website, https://www.ontario.ca/page/green-investment-fund

Ministry of the Environment and Climate Change. (2017). Cap and Trade in Ontario. Retrieved from, https://www.ontario.ca/page/cap-and-trade-ontario

Ministry of Infrastructure. (2013). Growth Plan for the Greater Golden Horseshoe, 2006, office consolidation, June 2013. Retrieved from, https://www.placestogrow.ca/content/ggh/2013-06-10-Growth-Plan-for-the-GGH-EN.pdf

Ministry of Municipal Affairs and Housing. (2016). The Greater Golden Horseshoe. Retrieved from, http://www.mah.gov.on.ca/AssetFactory.aspx?did=14910

Ministry of Natural Resources. (2011). A Summary of the Effects of Climate Change on Ontario's Aquatic Ecosystems. Retrieved from, http://files.ontario.ca/environment-and-energy/aquatics-climate/stdprod_088243.pdf

Ministry of Natural Resources & Forestry. (2016). Past, Present and Future Stream Temperature in the Lake Simcoe Watershed: brook trout (*Salvelinus fontinalis*) habitat at Risk. Retrieved from, http://www.climateontario.ca/MNR_Publications/CCRR45.pdf

Moore, B. A., & Allard, G. B. (2008, August). Climate Change impacts on forest health. *Forestry Department: Food and Agriculture Organization of the United Nations*

NASA. (2016). NASA Studies Details of Greening Arctic. Retrieved from, https://www.nasa.gov/feature/goddard/2016/nasa-studies-details-of-a-greening-arctic

NASA. (n.a). The Water Cycle. *Precipitation Education.* Retrieved from, https://pmm.nasa.gov/education/water-cycle

National Climate Assessment. (2014). Adaptation. Retrieved from, http://nca2014.globalchange.gov/report/response-strategies/adaptation#intro-section-2

National Oceanic and Atmospheric Administration[1]. (2017). Picture Climate: How We Can Learn from Corals. *National Centre for Environmental Information.* Retrieved from: https://www.ncdc.noaa.gov/news/picture-climate-how-we-can-learn-corals

National Oceanic and Atmospheric Administration[2]. (2017). What is Paleoclimatology? *National Centers for Environmental Information.* Retrieved from, https://www.ncdc.noaa.gov/news/what-paleoclimatology

Natural Resources Canada [1]. (2016). Indicator: Deforestation and Afforestation. Retrieved from, http://www.nrcan.gc.ca/forests/report/area/16546

Natural Resources Canada [2]. (2016). Mountain Pine Beetle: The Threat of Mountain Pine Beetle to Canada's Boreal Forest. Retrieved from, http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13381

Natural Resources Canada. (2017). Inventory and land-use change. Retrieved from, http://www.nrcan.gc.ca/forests/climate-change/carbon-accounting/13111

Nichols, M.R. (2017). The American Bumblebee makes the Endangered Species List for the First Time. *The Moderator*. Retrieved from, http://themoderatevoice.com/american-bumblebee-makes-endangered-species-list-first-time-guest-voice/

OMAFRA. (2016). Climate Change and Agriculture. Retrieved from, http://www.omafra.gov.on.ca/english/engineer/facts/climatechange.htm

Óskarsson, B., V. (2004) Ice Core Evidence for Past Climates and Glaciation. *Science Institute, University of Iceland.* Retrieved from, *https://notendur.hi.is/oi/Nemendaritgerdir/Ice%20core%20evidence%20for%20past%20climates%20and%20glaciation.pdf*

PNAS. (2015). Climate Change in the Fertile Crescent and Implications of the recent Syrian Drought. Retrieved from, http://www.pnas.org/content/112/11/3241.abstract

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W.E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution*. 25 (6), 345-352. Doi: 10.1016/j/tree.2010.01.007

Sakschewski, B., Bloh, W.v., Huber, V., Muller, C., & Bondeau, A. (2014). Feeding 10 billion people under climate change: How large is the production gap of current agricultural systems? *Ecological Modelling*. 288, 103-111.doi: 10.1016/j.ecolmodel.2014.05.019

Science Daily. (2015). Scientists Identify Climate "Tipping Points". Retrieved from, https://www.sciencedaily.com/releases/2015/10/151015084348.htm

Schmidt, Laurie. (2017). Satellite Data Confirm Annual Carbon Dioxide Minimum Above 400 ppm. Retrieved from https://climate.nasa.gov/news/2535/satellite-data-confirm-annual-carbon-dioxide-minimum-above-400-ppm/

Serecon Inc. (2016, March). Final Report: Application of Sustainable Agriculture Metrics to Canadian Field Crops. Retrieved from, http://fieldprint.ca/wp-content/uploads/2015/03/Canadian-Crop-Sustainability-Indicator-Report-1981-2011.pdf

Smith, W.N., Grant, B.B., Desjardins, R.L., Kroebel,R., Li,C., Qian,B., Worth, D.E., McConkey, B.G., & Drury, C.F. (2013). Assessing the effects of climate change on crop production and GHG emissions in Canada. *Agriculture, Ecosystems and Environment*. 179, 139-150. doi: 10.1016/j.agee.2013.08.015

Statistics Canada. (2016) Energy. Retrieved from, http://www.statcan.gc.ca/pub/11-402-x/2012000/chap/ener/ener-eng.htm

Stewart, R. I., Andersson, G. K., Brönmark, C., Klatt, B. K., Hansson, L., Zülsdorff, V., & Smith, H. G. (2016). Ecosystem services across the aquatic–terrestrial boundary: Linking ponds to pollination. *Basic And Applied Ecology*, doi:10.1016/j.baae.2016.09.006

Tangley, Laura & Bolt, Clay. (2016). Being there for Bees. *National Wildlife Federation.* Retrieved from, https://www.nwf.org/News-and-Magazines/National-Wildlife/Animals/Archives/2016/Bees.aspx

The National Climate Assessment US Global Change Research Program. (2014). Extreme Weather. Retrieved from GlobalChange.gov website, http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather

The World Bank. (2015). Rapid Climate Informed Development Needed to Keep Climate Change From Pushing More than 100 Million People into Poverty by 2030. Retrieved from, http://www.worldbank.org/en/news/feature/2015/11/08/rapid-climate-informed-development-needed-to-keep-climate-change-from-pushing-more-than-100-million-people-into-poverty-by-2030

Toronto Climate Action Network. (n.d). TCAN Member Groups. *TCAN.* Retrieved from, http://tcan.ca/our-members-0

Tong, S., Confalonieri, U., Ebi, K., & Olsen, J. (2016). Managing and Mitigating the Health Risks of Climate Change: Calling for Evidence-Informed Policy and Action. *Environmental Health Perspectives*, *124*(10), A176-A179. doi:10.1289/EHP555

UNEP. (2016). GEO-6 Regional Assessment for North America. *United Nations Environment Programme,* Nairobi, Kenya.

United Nations Framework Convention on Climate Change. (n.d). The Paris Agreement. Retrieved from, http://unfccc.int/paris_agreement/items/9485.php

UNHCR. (2015). In Photos: Climate Change, Disasters and Displacements. Retrieved from, http://www.unhcr.org/en-us/climate-change-and-disasters.html

Weber, A. & Schmidt, M. (2016). Local Perceptions, Knowledge Systems and Communication Problems around the Climate Change Discourse- Examples from the Peruvian Andes. *Erkunde, 70(4), 355-366.*

World Meteorological Organization. (2010). Climate, Carbon and Coral Reefs. *Weather-Climate-Water.* Retrieved from, http://www.wmo.int/pages/prog/wcp/agm/publications/documents/Climate_Carbon_CoralReefs.pdf

World Resources Institute.(2015). RELEASE: New Satellite Data Reveal Massive Tree Cover Loss in Russia and Canada. Retrieved from, http://www.wri.org/news/2015/04/release-new-satellite-data-reveal-massive-tree-cover-loss-russia-and-canada

Yirka, B. (2015). Study of Antarctic ice cores reveals atmospheric CO2 history over past thousand years. *Newcastle University.* Retrieved from, https://phys.org/news/2015-05-antarctic-ice-cores-reveals-atmospheric.html

Zhang, Y., Wang, X., Fraser, R., Olthof, I., Chen, W., Mclennan, D., & ... Wu, W. (2012). Modelling and mapping climate change impacts on permafrost at high spatial resolution for a region with complex terrain. *Cryosphere Discussions*, *6*(6), 4599-4636. doi:10.5194/tcd-6-4599-2012