Environmental Studies: From New Jersey to the Globe

ENVIRONMENTAL STUDIES: FROM NEW JERSEY TO THE GLOBE

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INTRODUCTION

Title: Environmental Studies: From New Jersey to the Globe

An Open Educational Resource for Students

Welcome to "Environmental Studies: From New Jersey to the Globe," an open educational resource designed to provide students with a comprehensive and engaging overview of the environmental challenges facing society internationally. Portions of the text will also focus on environmental issues in New Jersey, one of the most ecologically diverse and densely populated states in the United States. This resource aims to empower students with knowledge about the intricate relationship between human activities and the natural world, fostering a deeper understanding of the environmental issues that shape the local and global landscapes. With this background, students will develop the tools necessary to critically analyze any environmental issue they are interested in and make informed choices about their own lifestyles.

Why Open Educational Resource (OER)?

The cost barriers have been removed to relieve students of the financial burdens associated with purchasing a textbook. This allows students to concentrate more on the content of the course without feeling any elevated stress and emotions associated with the price of a textbook. We developed this book with the hopes of reaching a wider student audience, as well as educators and individuals who dedicated to environmental changes in and around their community.

Unveiling New Jersey's Environmental Landscape

New Jersey, often referred to as the Garden State, boasts a rich natural heritage that spans from the picturesque shores of the Atlantic Ocean to the tranquil forests of the Appalachian Mountains. However, alongside its natural beauty, New Jersey also grapples with a multitude of environmental issues that stem from urbanization, industrialization, and various human activities. In this resource, we will delve into a range of topics, including:

1. Sustainability and Environmental Science
2. Water: A Necessity for Life
3. Solid and Hazardous Waste
4. Environmental Toxins: What are We Exposed To?!
5. Air Pollution
6. Conservation and Biodiversity
7. Climate Change: Are you part of the problem or part of the solution?

We have chosen these topics because they are particularly relevant to our lives here in New Jersey, as well as being applicable to other regions around the world. These topics also allow us to explore environmental issues through the lens of our collective contributions to environmental issues as individuals, as well as the contributions of institutions, and what role both individuals and institutions can play in solving those problems. Through this textbook and your environmental studies or science course at RVCC, you will develop your ability to understand and analyze the environmental topics included in this text, and then you can apply those same tools to understanding and analyzing any environmental issue that you're interested in.

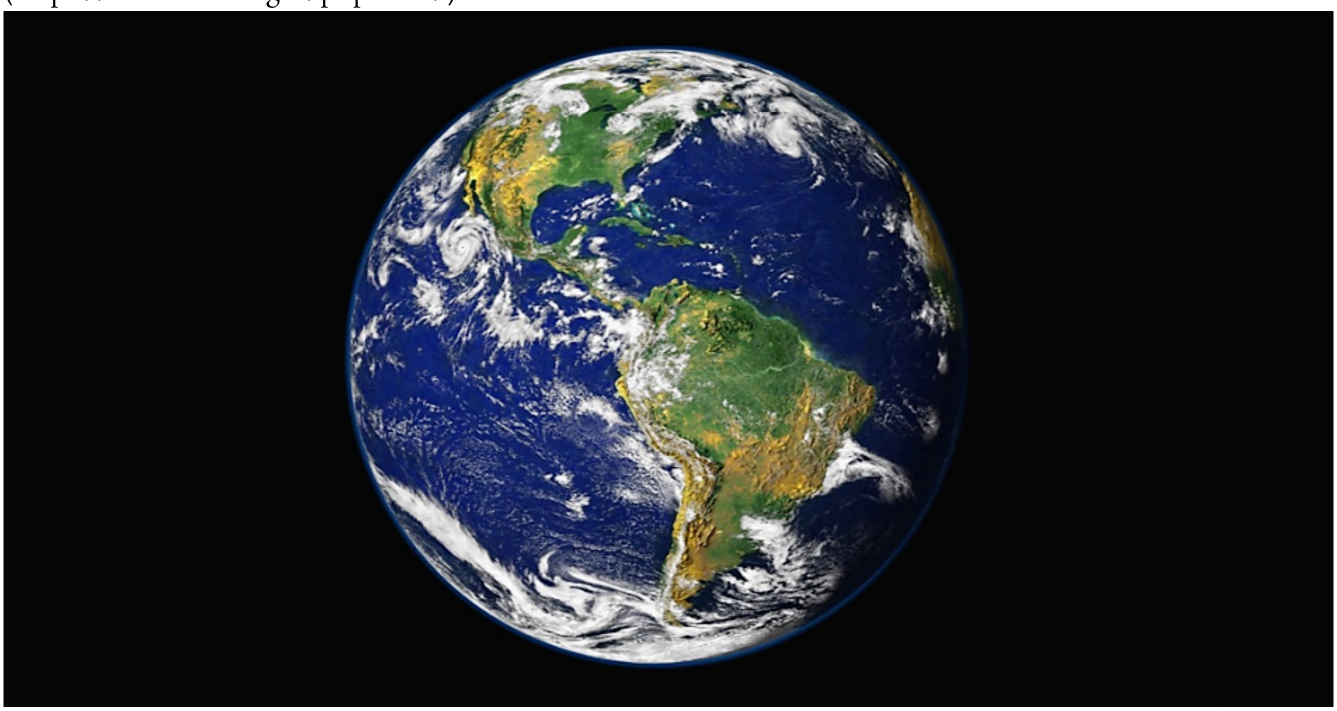
Embark on Your Environmental Journey

As you begin your journey through "Environmental Studies: From New Jersey to the Globe," we invite you to deepen your understanding of the intricate interplay between human society and the natural world. Through this open educational resource, we hope to inspire you to take an active role in shaping a more sustainable future for New Jersey and beyond. Whether you are a student, educator, or concerned citizen, your engagement with these topics is a step towards positive change. So, let's embark together on this enlightening exploration of environmental issues and solutions in the Garden State.

1.

SUSTAINABILITY AND ENVIRONMENTAL SCIENCE

Viewed from space, Earth offers no clues about the diversity of lifeforms that reside there. The first forms of life on Earth are thought to have been microorganisms that existed for billions of years in the ocean before plants and animals appeared. The mammals, birds, and plants so familiar to us are all relatively recent, originating 130 to 200 million years ago. Humans have inhabited this planet for only the last 2.5 million years, and only in the last 200,000 years have humans started looking like we do today. There are around 7.35 billion people today (https://www.census.gov/popclock/).



This NASA image is a composite of several satellite-based views of Earth. To make the whole-Earth image, NASA scientists combine observations of different parts of the planet. (credit: NASA/GSFC/NOAA/USGS)

The word **environment** describes living and nonliving surroundings relevant to organisms. It incorporates physical, chemical and biological factors and processes that determine the growth and survival of organisms, populations, and communities. All these components fit within the ecosystem concept as a way to organize all of the factors and processes that make up the environment. The ecosystem includes organisms and their environment within a specific area. Review the previous section for in-depth information regarding the Earth's ecosystems. Today, human activities influence all of the Earth's ecosystems.

Environmental science studies all aspects of the environment in an **interdisciplinary** way. This means that it requires the knowledge of various other subjects including biology, chemistry, physics, statistics, microbiology, biochemistry, geology, economics, law, sociology, etc. It is a relatively new field of study that has evolved from integrated use of many disciplines. **Environmental engineering** is one of the fastest growing and most complex disciplines of engineering. Environmental engineers solve problems and design systems using knowledge of environmental concepts and ecology, thereby providing solutions to various environmental problems. **Environmentalism**, in contrast, is a social movement through which citizens are involved in activism to further the protection of environmental landmarks and natural resources. This is not a field of science, but incorporates some aspects of environmental knowledge to advance conservation and sustainability efforts.

The Process of Science

Environmental science is a science, but what exactly is science? **Science** (from the Latin scientia, meaning "knowledge") can be defined as all of the fields of study that attempt to comprehend the nature of the universe and all its parts. The **scientific method** is a method of research with defined steps that include experiments and careful observation. One of the most important aspects of this method is the testing of hypotheses by means of repeatable experiments. A **hypothesis** is a suggested explanation for an event, which can be tested. A **theory** is a tested and confirmed explanation for observations or phenomena that is supported by many repeated experiences and observations.

The scientific method

The scientific process typically starts with an observation (often a problem to be solved) that leads to a question. The scientific method consists of a series of well-defined steps. If a hypothesis is not supported by experimental data, a new hypothesis can be proposed. Let's think about a simple problem that starts with an observation and apply the scientific method to solve the problem. One Monday morning, a student arrives in class and quickly discovers that the classroom is too warm. That is an observation that also describes a problem: the classroom is too warm. The student then asks a question: "Why is the classroom so warm?"

Proposing a Hypothesis

Recall that a hypothesis is a suggested explanation that can be tested. To solve a problem, several hypotheses may be proposed. For example, one hypothesis might be, "The classroom is warm because no one turned on the air conditioning." But there could be other responses to the question, and therefore other hypotheses may be proposed. A second hypothesis might be, "The classroom is warm because there is a power failure, and so the air conditioning doesn't work." Once a hypothesis has been selected, the student can make a prediction. A prediction is similar to a hypothesis but it typically has the format "If . . . then . . . ." For example, the prediction for the first hypothesis might be, "If the student turns on the air conditioning, then the classroom will no longer be too warm."

Testing a Hypothesis

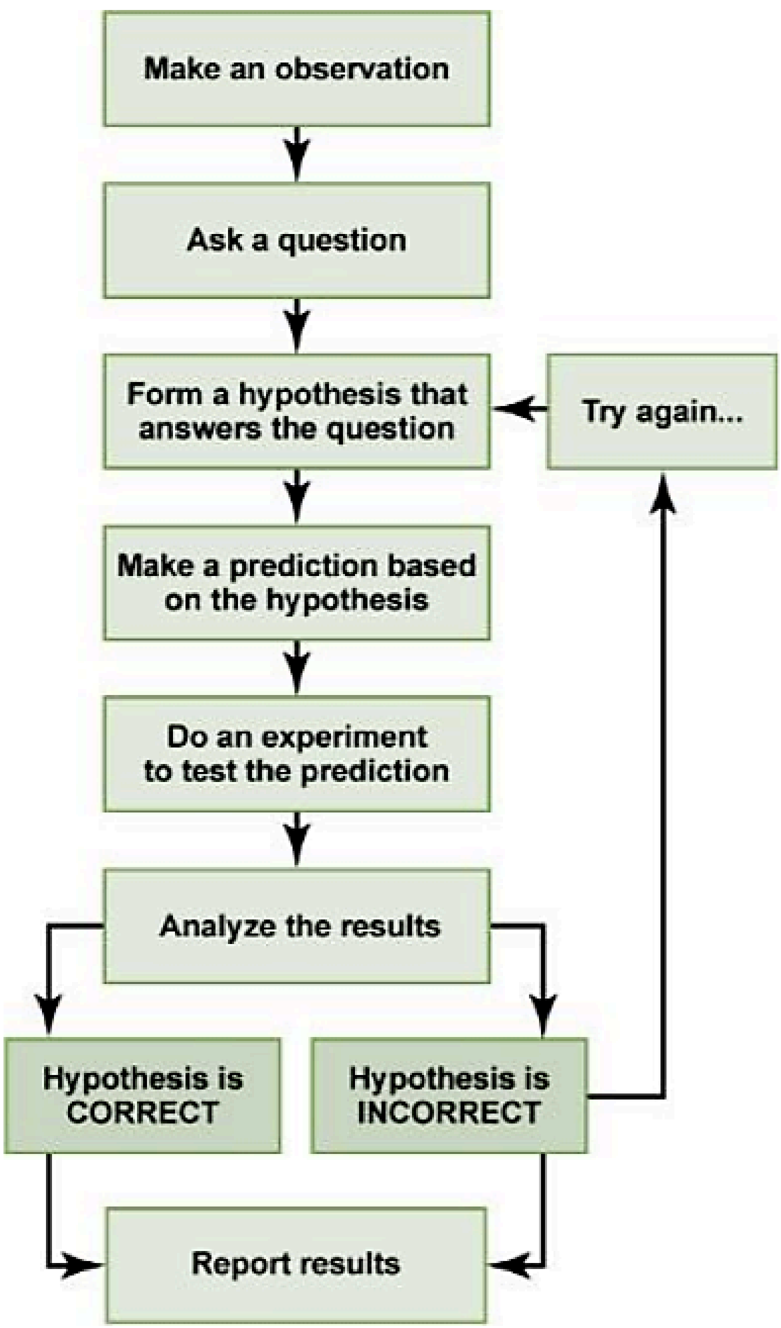
A valid hypothesis must be testable. It should also be falsifiable, meaning that it can be disproven by experimental results. Importantly, science does not claim to "prove" anything because scientific understandings are always subject to modification with further information. This step — openness to disproving ideas — is what distinguishes sciences from non-sciences. The presence of the supernatural, for instance, is neither testable nor falsifiable.

To test a hypothesis, a researcher will conduct one or more **experiments** designed to eliminate, or disprove, the hypotheses. Each experiment will have one or more variables and one or more controls. A **variable** is any part of the experiment that can vary or change during the experiment. The **independent variable** is the variable that is manipulated throughout the course of the experiment. The **dependent variable**, or response variable is the variable by which we measure change in response to the independent variable. Ideally, all changes that we measure in the dependent variable are because of the manipulations we made to the independent variable. In most experiments, we will maintain one group that has had no experimental change made to it. This is the **control group**. It contains every feature of the **experimental group** except it is not given any manipulation. Therefore, if the results of the experimental group differ from the control group, the difference must be due to the hypothesized manipulation, rather than some outside factor. Look for the variables and controls in the examples that follow.

To test the hypothesis *"The classroom is warm because no one turned on the air conditioning,"* the student would find out if the air conditioning is on. If the air conditioning is turned on but does not work, there should be another reason, and this hypothesis should be rejected. To test the second hypothesis, the student could check if the lights in the classroom are functional. If so, there is no power failure and this hypothesis should be rejected. Each hypothesis should be tested by carrying out appropriate experiments. Be aware that rejecting one hypothesis does not determine whether or not the other hypotheses can be accepted; it simply eliminates one hypothesis that is not valid

Using the scientific method, the hypotheses that are inconsistent with experimental data are rejected.

The scientific method may seem too rigid and structured. It is important to keep in mind that, although scientists often follow this sequence, there is flexibility. Sometimes an experiment leads to conclusions that favor a change in approach; often, an experiment brings entirely new scientific questions to the puzzle. Many times, science does not operate in a linear fashion; instead, scientists continually draw inferences and make generalizations, finding patterns as their research proceeds. Scientific reasoning is more complex than the scientific method alone suggests. Notice, too, that the scientific method can be applied to solving problems that aren't necessarily scientific in nature.



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Sustainability and Sustainable Development

In 1983 the United Nations General Assembly passed a resolution that established the Special Commission on the Environmental Perspective to the Year 2000 and Beyond (www.un.org/documents/ga/res/38/a38r161.htm).

Their charge was:

1. To propose long-term environmental strategies for achieving sustainable development to the year 2000 and beyond;
2. To recommend ways in which concern for the environment may be translated into greater co-operation among developing countries and between countries at different stages of economic and social development and lead to the achievement of common and mutually supportive objectives which take account of the interrelationships between people, resources, environment and development;
3. To consider ways and means by which the international community can deal more effectively with environmental concerns, in light of the other recommendations in its report;
4. To help define shared perceptions of long-term environmental issues and of the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community, taking into account the relevant resolutions of the session of a special character of the Governing Council in 1982.

The Brundtland Commission

The commission later adopted the formal name "World Commission on Environment and Development" (WCED) but became widely known by the name of its chair Gro Harlem Brundtland, a medical doctor and public health advocate who had served as Norway's Minister for Environmental Affairs and subsequently held the post of Prime Minister during three periods. The commission had twenty-one members drawn from across the globe, half representing developing nations. In addition to its fact-finding activities on the state of the global environment, the commission held fifteen meetings in various cities around the world seeking firsthand experiences on the how humans interact with the environment. The Brundtland Commission issued its final report "Our Common Future" in 1987.

Although the Brundtland Report did not technically invent the term "sustainability," it was the first credible and widely-disseminated study that probed its meaning in the context of the global impacts of humans on the environment. Its main and often quoted definition refers to sustainable development as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The report uses the terms "sustainable development," "sustainable," and "sustainability" interchangeably, emphasizing the connections among social equity, economic productivity, and environmental quality. The pathways for integration of these may differ nation by nation; still these pathways must share certain common traits: "the essential needs of the world's poor, to which overriding priority should be given, and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

The Brundtland Report makes it clear that while sustainable development is enabled by technological advances and economic viability, it is first and foremost a social construct that seeks to improve the quality of life for the world's peoples: physically, through the equitable supply of human and ecological goods and services; aspirationally, through making available the widespread means for advancement through access to education, systems of justice, and healthcare; and strategically, through safeguarding the interests of generations to come. In this sense sustainability sits among a series of human social movements that have occurred throughout history: human rights, racial equality, gender equity, labor relations, and conservation, to name a few

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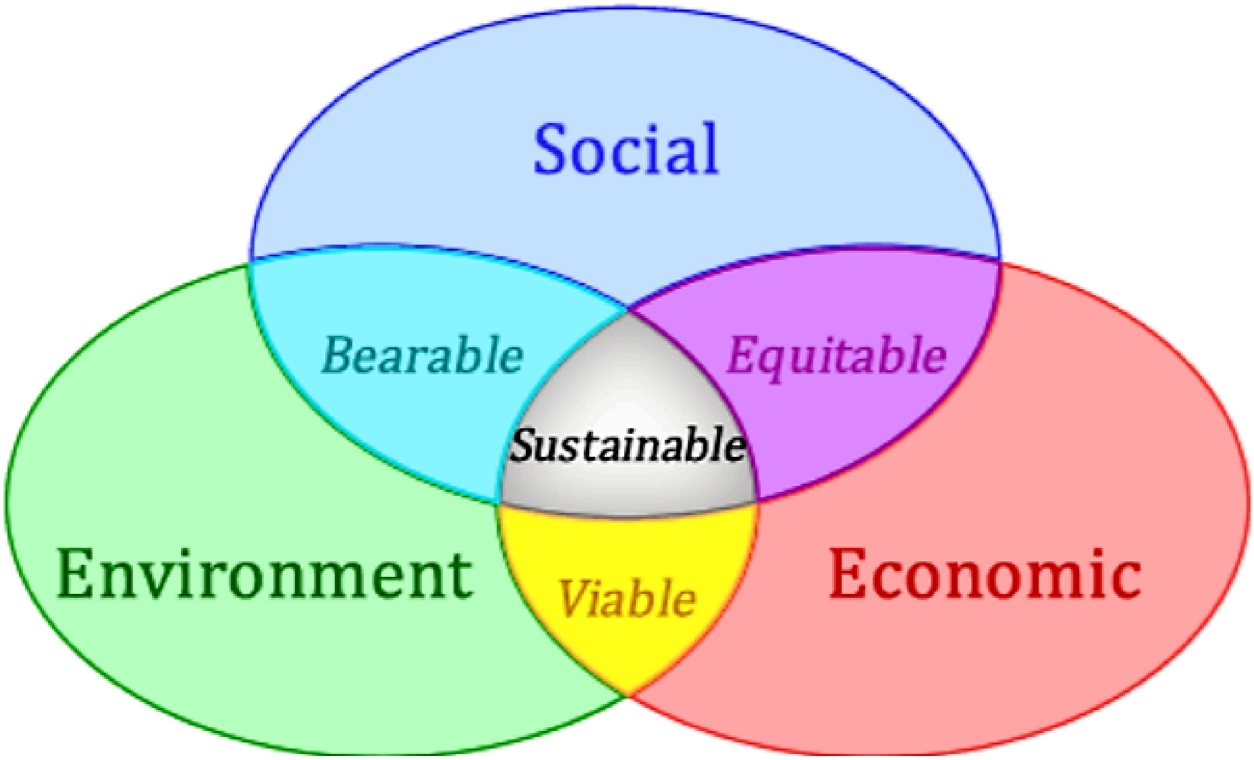
This three-pronged approach to sustainability is now commonly referred to as the **triple bottom-line**. Preserving the environment for humans today and in the future is a responsibility of every generation and a long-term global goal. Sustainability and the triple bottom-line (meeting environmental, economic, and social goals simultaneously) require that we limit our environmental impact, while promoting economic well-being and social equity.

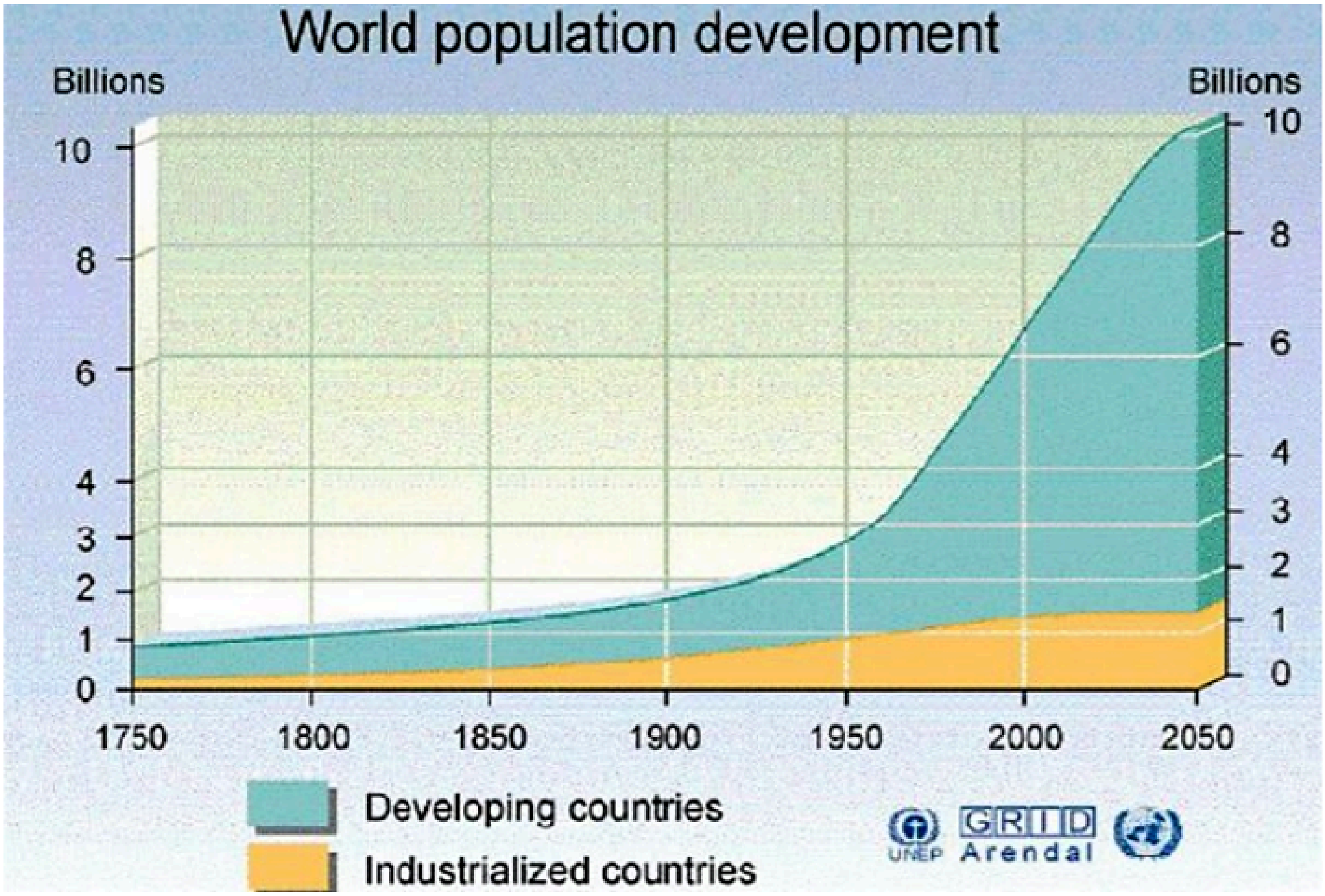


A depiction of the sustainability paradigm in terms of its three main components, showing various intersections among them. Source: International Union for the Conservation of Nature.

Examples of sustainable development include sustainable agriculture, which is agriculture that does not deplete soils faster than they form and does not destroy the biodiversity of the area. Sustainable farming and ranching do not reduce the amount of healthy soil, clean water, genetic diversity of crop plants and animals. Maintaining as much ecological **biodiversity** as possible in the agro-ecosystem is essential to long-term crop and livestock production.

Demography

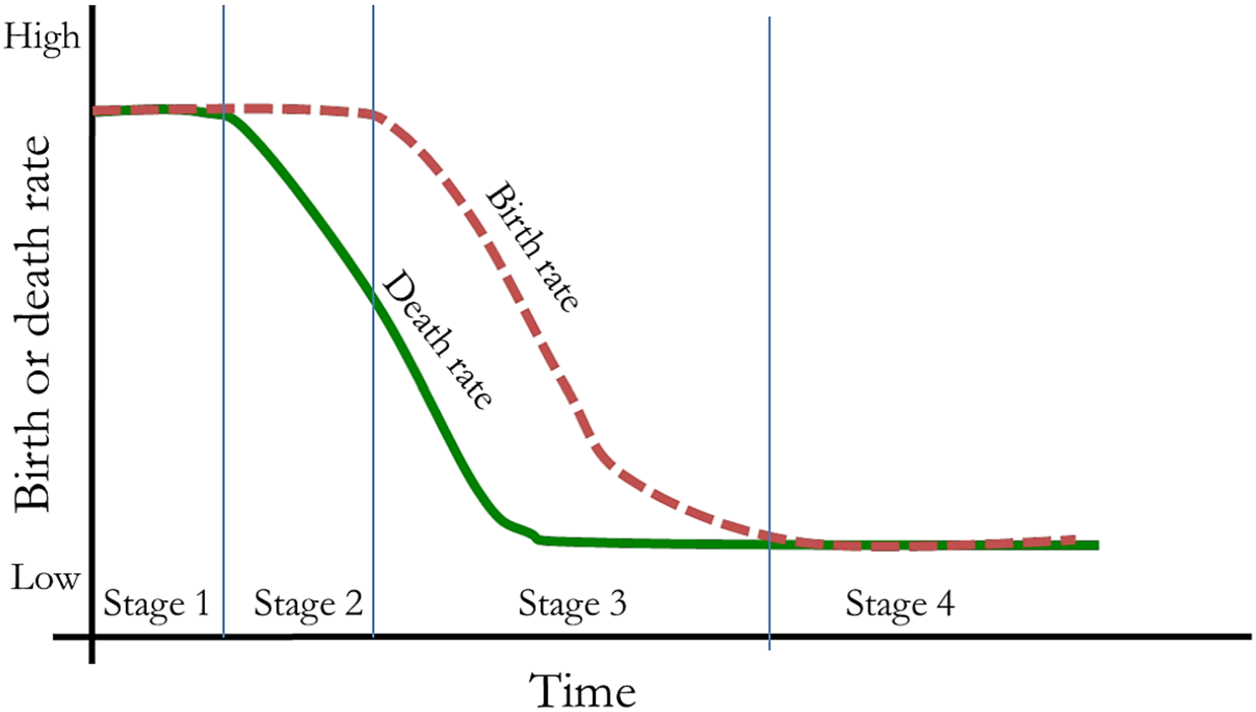
Demography applies the principles of population ecology to the human population. Demographers study how human populations grow, shrink, and change in terms of age and gender compositions. Demographers also compare populations in different countries or regions.



Shows the increase in human population size starting in 1750 and predicted out to 2050. The orange area represents the human population in industrialized countries and the blue/green area represents the human population in less-industrialized (developing) countries. The greatest amount of human population growth will be in less-industrialized countries.

Demographic Transition Model

The demographic transition model shows the changes in the patterns of birth rates and death rates that typically occur as a country moves through the process of industrialization or development. The demographic transition model was built based on patterns observed in European counties as they were going through industrialization. This model can be applied to other countries, but not all countries or regions fit the model exactly. And the pace or rate at which a country moves through the demographic transition varies among countries.



The demographic transition model shows how birth rates and death rates change over time as a country becomes more developed. The demographic transition model is typically divided into four stages. The green line represents death rates and the dashed red line represents birth rates .

In the demographic transition model, a country begins in Stage 1, the preindustrial stage. In Stage 1 both birth rates and death rates are high. The high death rates are because of disease and potential food scarcity. A country in Stage 1 of the demographic transition model does not have good health care; there may not be any hospitals or doctors. Children are not vaccinated against common diseases and therefore many children die at a young age. Infant and childhood **mortality rates** (death rates) are very high. A society in Stage 1 is likely based upon agriculture and most people grow their own food. Therefore, droughts or flood can lead to widespread food shortages and death from famine. All of these factors contribute to the high death rate in Stage 1. Partly to compensate for the high death rates, birth rates are also high. High birth rates mean that families are large and each couple, on average, has many children. When death rates are high, having many children means that at least one or two will live to adulthood. In Stage 1, children are an important part of the family workforce and are expected to work growing food and taking care of the family.

As you are examining the stages of the demographic transition model, remember that:

Population Growth Rate=Birth Rate−Death Rate">Population Growth Rate=Birth Rate−Death Rate

$$\text{Population Growth Rate} = \text{Birth Rate} - \text{Death Rate}$$

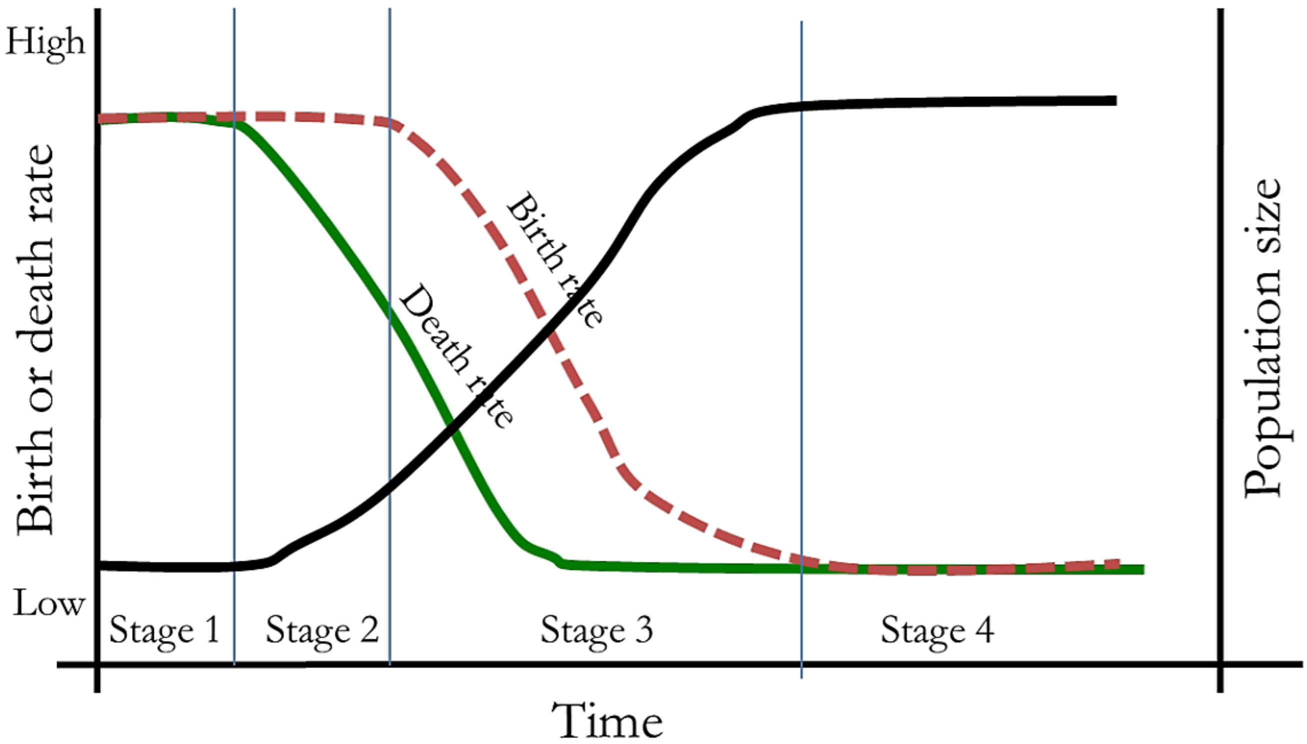
In Stage 1, birth rates are high, but death rates are high as well. Therefore, population growth rate is low or close to zero

As a country develops, medical advances are made such as access to antibiotics and vaccines. Sanitation improvements, such as proper waste and sewage disposal, and water treatment for clean drinking water also progress. Food production also increases. Together these changes lead to falling death rates which marks the beginning of Stage 2

Death rates continue to fall throughout Stage 2 as conditions improve. This means that people are living longer and childhood morality drops. However, birth rates are still high in Stage 2. There is a time lag between the improving conditions and any subsequent changes in family size, so women are still having many children and now more of these children are living into adulthood. In Stage 2, the birth rate is higher than the death rate, so population growth rate is high. This means that population size increases greatly during Stage 2 of the demographic transition model

A falling birth rate marks the beginning of Stage 3 in the demographic transition model. As a country continues to industrialize, many women join the workforce. Additionally, raising children becomes more expensive and children no longer work on the family farm or make large economic contributions to the family. Individuals may have access to birth control and choose to have fewer children. This leads to a drop in birth rates and smaller family sizes. Death rates also continue to drop during Stage 3 as medicine, sanitation and food security continue to improve. Even though both birth rates and death rates are falling throughout Stage 3, birth rates are higher than death rates. This means that population growth rate is high and that population size continues to increase in Stage 3 of the demographic transition model

Birth rate and death rates drop to low, stable, approximately equal levels in Stage 4. Death rates are low because of medical advances, good sanitation, clean drinking water and food security. Birth rates are low because of access to birth control and many women delay having their first child until they have worked. Childhood mortality is low, life expectancy is high, and family size is approximately two children per couple. With low birth rates and low death rates, population growth rate is approximately zero in Stage 4.



With the changes in population size (y-axes on the far right) shown by the black line. Population size is low and stable in Stage 1, increases rapidly in Stage 2 and 3 because birth rates are higher than death rates, and then is high and stable again in Stage 4.

The IPAT Equation

As attractive as the concept of sustainability may be as a means of framing our thoughts and goals, its definition is rather broad and difficult to work with when confronted with choices among specific courses of action. One way of measuring progress toward achieving sustainable goals can be with the application of the **IPAT equation.** This equation was designed in an attempt to define the different ways that a variety of factors contribute to the environmental degradation, or impact, of a particular setting. Importantly, IPAT tells us that there are more ways we impact our environment than just through pollution:(1.5.1)I=P×A×\T">×A×\T.

$$I = P \times A \times \T$$

I represents the impacts on an environment

P is the size of the relevant human population

A is the affluence of the population

T is the technology available to the population

Affluence, or wealth, tells us the level of consumption per person. Wealthy societies consume more goods and services per person. Because of this, their environmental impact is multiplied. Technology, or impact per unit of consumption, interpreted in its broadest sense. This includes any human-created tool, system, or organization designed to enhance efficiency. As societies gain greater access to technology, they are able to do more work with fewer individuals. This equates to a greater impact per person. While this equation is not meant to be mathematically rigorous, it provides a way of organizing information for analysis.

The proportion of people living in cities has greatly increased over the past 50 years. We can use the IPAT equation to estimate the impact of these urban populations. When the impact of technology, which is much easier to access in urban settings, is combined with the impact of population, the impact on the environment is multiplied. In an increasingly urban world, we must focus much of our attention on the environments of cities and on the effects of cities on the rest of the environment. This equation also has large-scale applications in the environmental sciences and was included in the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (2001) to project future greenhouse gas emissions across the globe.

The Ecological Footprint

The Ecological Footprint (EF), developed by Canadian ecologist and planner William Rees, is basically an accounting tool that uses land as the unit of measurement to assess per capita consumption, production, and discharge needs. It starts from the elementary assumption that 'every category of energy and material consumption and waste discharge requires the productive or absorptive capacity of a finite area of land or water. If we (add up) all the land requirements for all categories of consumption and waste discharge by a defined population, the total area represents the Ecological Footprint of that population on Earth whether or not this area coincides with the population's home region.

Land is used as the unit of measurement for the simple reason that 'Land area not only captures planet Earth's finiteness, it can also be seen as a proxy for numerous essential life support functions from gas exchange to nutrient recycling … land supports photosynthesis, the energy conduit for the web of life. Photosynthesis sustains all important food chains and maintains the structural integrity of ecosystems.'

Although the size of an Ecological Footprint, also termed Appropriated Carrying Capacity (ACC) would vary according to socioeconomic and technological factors one point is constant: the flows and capacities 'occupied' by one population are not available for another as these resources are finite. What does the Ecological Footprint tell us? Ecological footprint analysis can tell us in a vivid, ready-to-grasp manner how much of the Earth's environmental functions are needed to support human activities. It also makes visible the extent to which consumer lifestyles and behaviours are ecologically sustainable calculated that the Ecological Footprint of the average American is – conservatively – 5.1 hectares per capita of productive land. With roughly 7.4 billion hectares of the planet's total surface area of 51 billion hectares available for human consumption, if the current global population were to adopt American consumer lifestyles we would need two additional planets to produce the resources, absorb the wastes, and provide general life support functions.

Ecological footprints have been calculated for numerous nations, cities, communities, and even individuals. The London-based IIED has calculated that London's ecological footprint is 120 times the size of the city. The footprint of the average Dutch person is slightly less at 3.3 hectares per capita but still import 'land services' fifteen times the territory of the Netherlands itself. The message of the ecological footprint is that lifestyles and behaviour, industrial production and trade, institutions and politics must change. Humanity must learn to live off the income of the 'natural capital', and maintain natural stocks rather than continuing to mine them. Wackernagel and Rees suggest that one way would be to focus 'more on living locally than on consuming globally.

The precautionary principle

The precautionary principle or the precautionary approach is one perspective of environmental risk management. The precautionary principle stakes that "When the health of humans and the environment is at stake, it may not be necessary to wait for scientific certainty to take protective action". In other words, better to be safe than sorry. Proponents of the precautionary principle also believe that the burden of proof should be on the individual, company or government who is proposing the action, not on the people who will be affected by it. For example, if environmental regulations concerning pesticides were based on the precautionary principle (in the United States, they are not), then any pesticide that could potentially harm the environment or human health would not be used. Overuse of the precautionary principle can have negative consequences as well. If federal regulations concerning medicines for human use were based on the precautionary principle (again, in the United States, they are not), then any medicine that could potentially harm any person would not be used. This would effectively ban nearly all medical trials leading to new medications.

What is the environment worth to you?

The environment, and its benefits to individuals or groups, can be viewed and justified from multiple perspectives. A **utilitarian justification** for environmental conservation means that we should protect the environment because doing so provides a direct economic benefit to people. For example, someone might propose not developing Georgia's coastal salt marshes because the young of many commercial fishes live in salt marshes and the fishers will collapse without this habitat. An **ecological justification** for environmental conservation means that we should protect the environment because doing so will protect both species that are beneficial to other as well as other species and an ecological justification for conservation acknowledges the many ecosystem services that we derive from healthy ecosystems. For example, we should protect Georgia's coastal salt marshes because salt marshes purify water, salt marshes are vital to the survival of many marine fishes and salt marshes protect our coasts from storm surges. An **aesthetic justification** for conservation acknowledges that many people enjoy the outdoors and do not want to live in a world without wilderness. One could also think of this as recreational, inspirational, or spiritual justification for conservation. For example, salt marshes are beautiful places and I always feel relaxed and calm when I am visiting one, therefore we should protect salt marshes. And finally, a **moral justification** represents the belief that various aspects of the environment have a right to exist and that it is our moral obligation to allow them to continue or help them persist. Someone who was arguing for conservation using a moral justification would say that it is wrong to destroy the coastal salt marshes.

Global perspective

The solution to most environmental problems requires a global perspective. Human population size has now reached a scale where the environmental impacts are global in scale and will require multilateral solutions. You will notice this theme continue as you move through the next seven chapters of this text. As you do so, keep in mind that the set of environmental, regulatory, and economic circumstances common in the United States are not constant throughout the world. Be ready to investigate environmental situations and problems from a diverse set of viewpoints throughout this semester.

United Nations Sustainable Development Goals

In 2015, the United Nations adopted a list of 17 goals for the world to achieve by the year 2030 if we wish to achieve true sustainability on our planet (Figure 3). Each goal has an associated set of measurable targets that allow the tracking of progress towards meeting the goal. For example, the goal of "No Poverty" includes a target of ending extreme poverty around the world by 2030. Extreme poverty, defined as an income of less than $1.90 per day, has been cut in half since 1990, but still more than 1 in 10 people live below the extreme poverty line. Details about each goal and its associated targets can be found at the United Nations websiteLinks to an external site..

The UN Sustainable Development Goals were developed with the three pillars of sustainability in mind. Goals related to the social pillar include Quality Education and Gender Equality. Economic goals include No Poverty, Decent Work and Economic Growth, and Reduced Inequalities. Environmental goals include Affordable and Clean Energy, Climate Action, and Life on Land.

The United Nations Sustainable Development Goals are a set of 17 global goals for the world to meet by the year 2030 to ensure true sustainability.

Natural Capital = Natural Resources + Ecosystem Services

One of the main goals sustainability is to maintain the Earth's **natural capital**, which is made up of the natural resources and ecosystem services that sustain all life on the planet. **Natural resources** are any *materials* in nature that satisfy a human need. **Ecosystem services**, also known as natural services, are *processes* in nature that support life and human economies. They include processes such as water purification, waste recycling, and even recreational and spiritual benefits.

Ecosystem services are processes or actions, but natural resources are physical materials. They can be classified based on whether they can be used up by humans and how quickly they can be replenished by nature. Energy from the sun is an example of a **perpetual resource** because it will exist for billions of years and will never be depleted. **Nonrenewable resources**, such as iron, coal, and oil, are finite and cannot be replenished on normal human time scales. **Renewable resources**—such as water, soil, and plants—can be replenished over time. However, unlike perpetual resources, renewable resources can become nonrenewable if they are used up faster than nature can replenish them. For example, the trees in a forest are only renewable if they are replanted after being cut down.

More than 6000 km2 (2316 sq. miles) of the Amazon Forest are cut down every year, mostly to provide pasture for cattle. At the current rate of deforestation, 27% of the trees in the Amazon will be cut down by 2030.

Protecting the Earth – What Can You Do?

Consider the following facts from the American Museum of Natural History's Center for Biodiversity and Conservation (AMNH-CBC) and the Environmental Protection Agency (EPA):

Every year, Americans:

- Throw away at least 2 billion disposable razors
- Discard enough paper and wood to heat 5 million homes for 200 years
- Drink more than two billion gallons of bottled water, costing 900 times more money than tap water – not counting the energy and toxics involved in packaging and shipping
- Retire up to 130 million cell phones, containing toxic metals such as arsenic, cadmium, and lead
- Generate about 3 million tons of toxic electronics waste (e-waste), and recycle only about 11%

Do any of these everyday experiences apply to you?

You may be surprised to learn there is quite a lot you can do to help. Read carefully through the suggestions below, noting those that appeal to you strongly and those which seem most feasible. Many involve little more than awareness in decisions you already or will soon make.

Consume Thoughtfully and Wisely: Reduce Your Consumption Where Possible. Re-use, and Recycle. Make Durability and Efficiency Your Criteria for Product Purchases.

In general, when you buy:

- Buy locally whenever possible to reduce transportation costs for you and for the environment.
- Be aware of the natural resources used to make and transport any product you buy.
- Substitute other materials for plastics – which are made from petroleum and produce toxic waste.

Eat with the environment and your health in mind! In the United States, the Department of Agriculture (USDA) sets standards for organic products and certification. The green-and-white seal identifies products which have at least 95% organic ingredients. The program is helpful to consumers, but not without controversy (read Barbara Kingsolver

- When you buy food plan your diet for your own health and that of the environment.
- Eat low on the food chain. Top carnivores get the least energy and the most poison.
- Buy local produce in season – to reduce transportation costs and the need for pesticides.
- Buy at farmers' markets or a Community Supported Agriculture (CSA) programs to support local farmers and reduce demand for energy-consuming and polluting large-scale agriculture and marketing.
- Choose organic produce – for your own health and to protect the environment from excessive nutrients and pesticides (**Figure** above).

- ***When you buy fish for food or for your aquarium***
- Check to be sure that commercial species are not from overharvested areas,
- Verify that tropical saltwater fish were not collected using cyanide.

- ***When you need paper products,*** be sure they are made of recycled fiber.
- Or consider alternative materials such as hemp, kenaf, cornstarch, or old money or maps.
- Replace paper napkins and paper towels with cloth.
- Reuse envelopes and boxes. Wrap gifts in the comics or reusable cloth gift bags.

- ***When you buy products for cleaning,painting,or washing your car,*** check the ingredients to be sure you are not exposing yourself and the environment to unnecessary toxins. Vinegar and baking soda work wonders!

- ***When you buy wood or wood products*** be sure harvesting followed **sustainable forest management** – practices which ensure future productivity, biodiversity, and ecosystem health.
- Look for SmartWood, FSC (Forest Stewardship Council) or similar labels.
- Consider recycled or salvaged wood.

One drop per second from a dripping faucet wastes 2,700 gallons of water per year and adds to sewer and/or septic costs, as well.

When You Use Water, Remember Its Importance To All Life

- Check for water leaks and repair drips with new washers (**Figure** above).
- Use low-flush toilets and low-flow faucets and shower heads.

- Have your tap water tested; use filters or refillable delivery if needed, rather than bottled water.

When You Must Use Energy, Consider Consequences and Choose Your Source Carefully

- Unplug electronic equipment such as fax machines, power tools, and anything connected to a remote control.
- Turn off power sources and lights when not in use.
- Use your bicycle, and support bike-friendly cities and roads.
- Walk! It's good for you, as well as the environment.
- Use public transportation, and support its expansion.
- Make energy-efficiency your #1 priority when you purchase appliances.
- Make fuel-efficiency your #1 priority if you purchase a car.
- Turn down your thermostat, especially at night. Just 2°F saves 500 pounds of greenhouse-inducing CO_2!
- Weather strip and caulk doors and windows.
- Replace incandescent with fluorescent light bulbs, which are four times as efficient and last far longer.
- The EPA Energy Star Logo helps consumers to identify energy-efficient products. The less fossil fuel energy we use, the fewer greenhouse gases we release, reducing the threat of climate change.

Computer equipment becomes obsolete quickly and contains toxins such as lead and mercury. Consider donating your obsolete equipment, and if you must discard it, be sure you follow specific guidelines for recycling and hazardous waste disposal.

When You Must Dispose of Waste, Learn the Best Practice for Its Disposal

- Reduce or eliminate your use of plastic bags, sandwich bags, and six-pack plastic rings (and don't release balloons!) so that endangered sea turtles do not mistake these for their favorite food – jellyfish.

- Minimize and compost food waste.
- Recycle motor oil and unused paint.
- Use appropriate local hazardous waste facilities for recommended chemicals and medicines.
- Donate obsolete computers and other electronic equipment – or if you cannot, recycle such “e-waste” properly (**Figure** above).

Don’t Contribute to the Burgeoning Problem of Exotic Species

(The following points reference **Figure** below.)

- Don’t release aquarium fish, turtles, birds, or other pets into the wild.

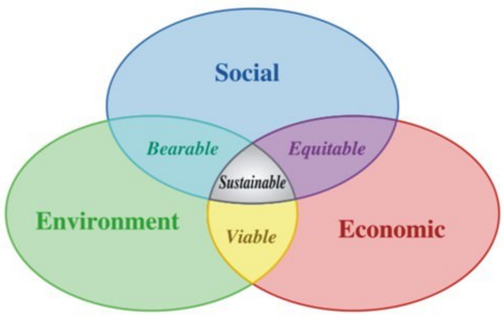
Exotic (invasive or alien) species are often considered the #2 cause of extinction. Learn how to avoid transporting them!

- Clean your boat thoroughly after use, and avoid traveling with wild plants and animals.
- Your pet is also considered to be an exotic species. Don’t let your pets hunt birds or wild animals.

Practice Sustainable Management on Your Own Land, Even If it is “Only” a Small Yard

- Minimize nonpoint source pollution by using organic or natural pesticides and fertilizers.
- Plant shade trees for air-conditioning and to absorb CO_2.

- Water plants and lawns in the evening.
- Better yet, use native and/or drought-tolerant plants for landscaping.
- Remember that City, County, State, and Federal lands are your lands, too. Get involved in local zoning and land use planning to ensure that development follows sustainable guidelines.



Sustainability as a goal in decision-making seeks the intersection of three sets of values. The environmental component includes maintaining ecosystem quality indefinitely.

Adopt and Spread Sustainable Perspectives and Philosophy

- Focus on diversity as a whole – genes, communities and ecosystems – rather than single "poster" species.
- Support the inclusion of ecosystems services in economic valuations.
- Encourage protection of areas large enough to accommodate migration, flooding, buffer zones, pollution from nearby development, and people and their activities.
- Realize that inequitable distribution of population, land, resources, education, and wealth threatens biodiversity.
- Promote the concept of sustainability as a guide for conservation decisions (**Figure** above).
- Join philosophers and religious and community groups to explore environmental ethics.
- Help *everyone* understand basic ecology and the wealth of biodiversity shaped by billions of years of evolution.

Learn More!

- About the species with which you share the Earth.
- About local, national, and international threats to biodiversity
- About more solutions as they develop
- Jump in! Join local groups which monitor ecosystem health: Frog Watch, River Watch, or Bird Counts.
- Educate yourself about complex issues such as government subsidies and new technologies.
- Find out about local protected lands and volunteer your time and energy to restore native ecosystems.

Activate!

- Exercise your citizenship to protect biodiversity. Vote, communicate your views, and push for stronger environmental protection laws.
- Support organizations which promote national reserves, international treaties, and resource conservation.
- Support efforts by zoos, arboretums, museums and seed banks to help maintain genetic diversity through research, breeding, educational, and fundraising programs.

Attributes

This chapter is composed of text taken from of the following sources:

2.

ENVIRONMENTAL POLICIES AND ETHICS

Although environmental laws are generally considered a 20^{th} century phenomenon, attempts have been made to legislate environmental controls throughout history. In 2,700 B.C., the middle-eastern civilization in Ur passed laws protecting the few remaining forests in the region. In 80 A.D., the Roman Senate passed a law to protect water stored for dry periods so it could be used for street and sewer cleaning. During American colonial times, **Benjamin Franklin** argued for "public rights" laws to protect the citizens of Philadelphia against industrial pollution produced by animal hide tanners.

Significant environmental action began at the beginning of the 20^{th} century. In 1906, Congress passed the "Antiquities Act," which authorizes the president to protect areas of federal lands as national monuments. A few years later, **Alice Hamilton** pushed for government regulations concerning toxic industrial chemicals. She fought, unsuccessfully, to ban the use of lead in gasoline.

She also supported the legal actions taken by women who were dying of cancer from their exposure to the radium then used in glow-in-the-dark watch dials. During the early 1960's, biologist **Rachel Carson** pointed out the need to regulate pesticides such as DDT to protect the health of wildlife and humans.

With the establishment of the **Environmental Protection Agency (EPA)**in 1970, environmental law became a field substantial enough to occupy lawyers on a full-time basis. Since then, federal and state governments have passed numerous laws and created a vast network of complicated rules and regulations regarding environmental issues. Moreover, international organizations and agencies including the **United Nations**, the **World Bank**, and the **World Trade Organization** have also contributed environmental rules and regulations.

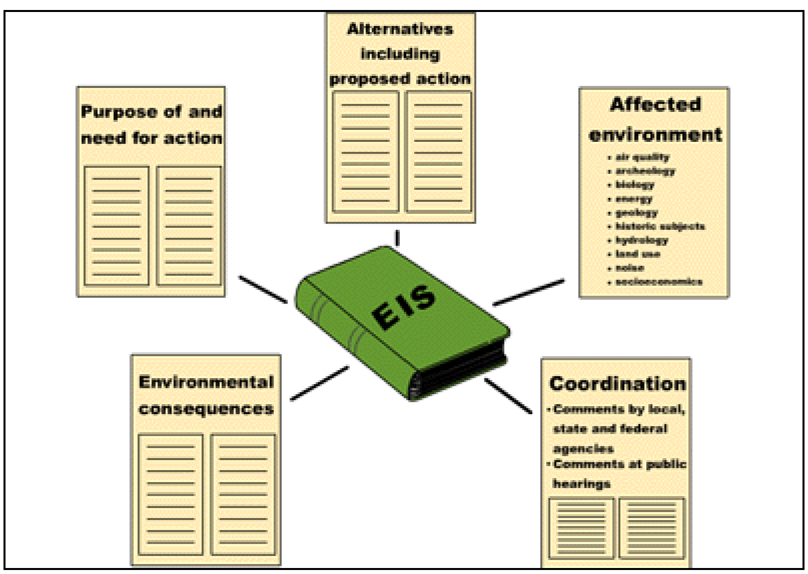
Because of the legal and technical complexities of the subjects covered by environmental laws, persons dealing with such laws must be knowledgeable in the areas of law, science and public policy. Environmental laws today encompass a wide range of subjects such as air and water quality, hazardous wastes and biodiversity. The purpose of these environmental laws is to prevent, minimize, remedy and punish actions that threaten or damage the environment and those that live in it. However, some people believe that these laws unreasonably limit the freedom of people, organizations, corporations and government agencies by placing controls on their actions.

See the video about Environmental Laws and Regulations: Click here.

Federal Laws: USA

Early attempts by Congress to enact laws affecting the environment included the **Antiquities Act** in 1906, the **National Park Service Act** in 1916, the **Federal Insecticide, Fungicide and Rodenticide Act** in 1947 and the **Water Pollution Control Act** in 1956. The **Wilderness Act** of 1964, protected large areas of pristine federal lands from development and ushered in the new age of environmental activism that began in the 1960's. However, it was the **National Environmental Policy Act (NEPA)**enacted in 1969 and the formation of the Environmental Protection Agency (EPA) in 1970 that started environmental legislation in earnest. The main objective of these two federal enactments was to assure that the environment would be protected from both public and private actions that failed to take into account the costs of damage inflicted on the environment.

Many consider NEPA to be the most far-reaching environmental legislation ever passed by Congress. The basic purpose of NEPA is to force governmental agencies to comprehensively consider the effects of their decisions on the environment. This is effected by requiring agencies to prepare detailed **Environmental Impact Statements** (EIS) for proposed projects. The EPA is the government's environmental watchdog. It is charged with monitoring and analyzing the state of the environment, conducting research, and working closely with state and local governments to devise pollution control policies. The EPA is also empowered to enforce those environmental policies. Unfortunately, the agency is sometimes caught up in conflicts between the public wanting more regulation for environmental reasons and businesses wanting less regulation for economic reasons. Consequently, the development of a new regulation can take many years.



ENVIRONMENTAL IMPACT STATEMENT

Since 1970, Congress has enacted several important environmental laws, all of which include provisions to protect the environment and natural resources. Some of the more notable laws include:

- The **Federal Clean Air Act** (1970, 1977 & 1990) established national standards for regulating the emission of pollutants from stationary and mobile sources.

- The **Federal Water Pollution Control Act** (1972) amended by the **Clean Water Act** (1977, 1987), established water quality standards; provides for the regulation of the discharge of pollutants into navigable waters and for the protection of wetlands.

- The **Federal Safe Drinking Water Act** (1974, 1977 & 1986) set drinking water standards for levels of pollutants; authorizing the regulation of the discharge of pollutants into underground drinking water sources.

- The **Toxic Substances Control Act** (1976) provided for the regulation of chemical substances by the EPA and the safety testing of new chemicals.

- The **Resource Conservation and Recovery Act** (1976) established cradle-to-grave regulations for the handling of hazardous wastes.

- The **Comprehensive Environmental Response, Compensation and Liability Act** (1980), also known as the **Superfund** program, provided for the cleanup of the worst toxic waste sites.

- The **Food Security Act** (1985, 1990) later amended by the **Federal Agriculture Improvement and Reform Act** (1996), discouraged cultivation of environmentally sensitive lands, especially wetlands, and authorized incentives for farmers to withdraw highly erodible lands from production.

The application, or enforcement, of an environmental law is not always straightforward, and problems can arise. Often, the biggest problem is that Congress fails to allocate the funds necessary for implementing or enforcing the laws. Administrative red tape may make it impossible to enforce a regulation in a timely manner. It also may be unclear as to which agency (or branch of an agency) is responsible for enforcing a particular regulation. Furthermore, agency personnel decline to enforce a regulation for political reasons.

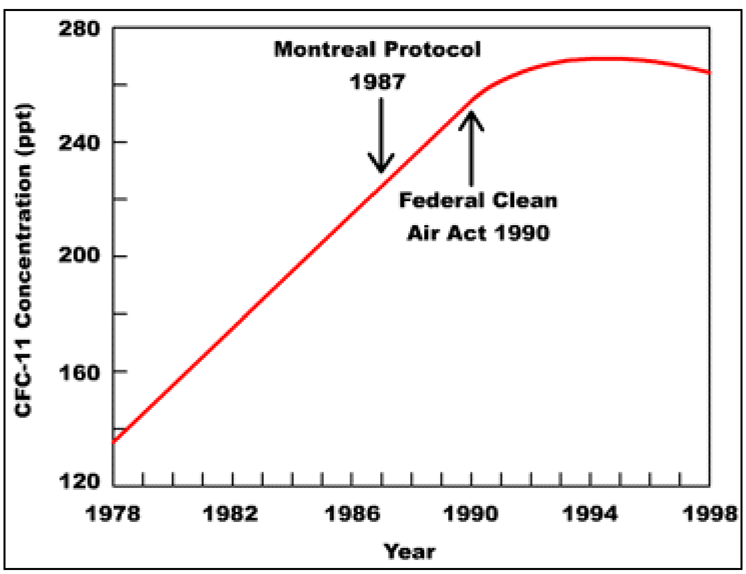
 See the animation about the Super Fund: Click here.

International Treaties and Conventions

Conventions, or treaties, generally set forth international environmental regulations. These conventions and treaties often result from efforts by international organizations such as the **United Nations (UN)** or the**World Bank**. However, it is often difficult, if not impossible, to enforce these regulations because of the sovereign rights of countries. In addition rules and regulations set forth in such agreements may be no more than non-binding recommendations, and often countries are exempted from regulations due to economic or cultural reasons. Despite these shortcomings, the international community has achieved some success via its environmental agreements. These include an international convention that placed a moratorium on whaling (1986) and a treaty that banned the ocean dumping of wastes (1991).

The UN often facilitates international environmental efforts. In 1991, the UN enacted an **Antarctica Treaty**, which prohibits mining of the region, limits pollution of the environment and protects its animal species. The United Nations Environment Program (UNEP) is a branch of the UN that specifically deals with worldwide environmental problems. It has helped with several key efforts at global environmental regulations:

- **The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.** As a result of this global agreement, industrialized countries have ceased or reduced the production and consumption of ozone-depleting substances such as chlorofluorocarbons.
- **The Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade**. This agreement enhances the world's technical knowledge and expertise on hazardous chemicals management.



CFC CONCENTRATION IN THE ATMOSPHERE

- **The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).** This agreement protects over 30,000 of the world's endangered species.
- In 1995 **UNEP and the International Olympic Committee (IOC)** signed a partnership agreement to develop environmental guidelines for sports federations and countries bidding to host the Olympic games.
- **The Rotterdam Convention** (1998) addressed the growing trade in hazardous pesticides and chemicals. Importing countries must now give explicit informed consent before hazardous chemicals

can cross their borders.

- **The International Declaration on Cleaner Production** (1998). The signatories commit their countries to implement cleaner industrial production and subsequent monitoring efforts.

In 1992, the UN member nations committed their resources to limiting greenhouse gas (e.g., carbon dioxide) emissions at or below 1990 levels, as put forth by the **UN Framework Convention on Climate Change**. Unfortunately, the agreement was non-binding and by the mid-1990's, it had had no effect on carbon emissions. The 1997 **Kyoto Protocol** was a binding resolution to reduce greenhouse gases. Although the United States initially supported the resolution, the Senate failed to ratify the treaty, and by 2001 the resolution was opposed by President Bush as threatening the United States economy.


See the animation about the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES): click here.

Attributes

3.

LIFE CYCLE ANALYSIS

Problem Solving for Sustainability

It should be clear by now that making decisions and solving problems in support of greater sustainability of human-created systems and their impact on the natural environment is a complex undertaking. Often in modern life our decisions and designs are driven by a single goal or objective (e.g. greater monetary profitability, use of less energy, design for shorter travel times, generation of less waste, or reduction of risk), but in most cases solving problems sustainably requires a more holistic approach in which the functioning of many parts of the system must be assessed simultaneously, and multiple objectives must be integrated when possible. Furthermore, often our decisions require the recognition of tradeoffs — there are many kinds of impacts on the environment and most decisions that we make create more than one impact at the same time. Of course choices must be made, but it is better if they are made with fuller knowledge of the array of impacts that will occur. The history of environmental degradation is littered with decisions and solutions that resulted in unintended consequences.

An illustrative example of the role of sustainability in solving problems is the issue of biofuels — turning plant matter into usable energy (mostly liquid hydrocarbon-based fuels). When viewed from afar and with a single goal, "energy independence," using our considerable agricultural resources to turn solar energy, via photosynthesis, into usable fuels so that we can reduce our dependence on imported petroleum appears to be quite attractive. The United States is the largest producer of grain and forest products in the world. It has pioneered new technologies to maintain and even increase agricultural productivity, and it has vast processing capabilities to create artificial fertilizer and to convert biomass into agricultural products. And, after all, such a venture is both "domestic" and "natural" — attributes that incline many, initially at least, to be favorably disposed. However upon closer examination this direction is not quite as unequivocally positive as we might have thought. Yes it is possible to convert grain into ethanol and plant oils into diesel fuel, but the great majority of these resources have historically been used to feed Americans and the animals that they consume (and not just Americans; the United States is the world's largest exporter of agricultural products). As demand has increased, the prices for many agricultural products have risen, meaning that some fraction of the world's poor can no longer afford as much food. More marginal lands (which are better used for other crops, grazing, or other uses) have been brought under cultivation for fermentable grains, and there have been parallel "indirect" consequences globally — as the world price of agricultural commodities has risen, other countries have begun diverting land from existing uses to crops as well. Furthermore, agricultural runoff from artificial fertilizers has contributed to over 400 regional episodes of hypoxia in estuaries around the world, including the U.S. Gulf Coast and Chesapeake Bay.

In response to such problems, U.S. Congress passed the Energy Independence and Security Act in 2007, which limits the amount of grain that can be converted into biofuels in favor of using agriculturally-derived cellulose, the chief constituent of the cell walls of plants. This has given rise to a large scientific and technological research and development program to devise economical ways to process cellulosic materials into ethanol, and parallel efforts to investigate new cellulosic cropping systems that include, for example, native grasses. Thus, the seemingly simple decision to grow our biofuels industry in response to a political objective has had unintended political, financial, dietary, social, land use, environmental quality, and technological consequences. With hindsight, the multiple impacts of biofuels have become clear, and there is always the hope that we can learn from examples like this. But we might also ask if there is a way to foresee all or at least some of these impacts in advance, and adjust our designs, processes, and policies to take them into account and make more informed decisions, not just for biofuels but also for complex societal problems of a similar nature. This approach is the realm of the field of industrial ecology, and the basis for the tool of life cycle assessment (LCA), a methodology that has been designed to perform holistic analyses of complex systems.

Life Cycle Assessment Basics

LCA is a systems methodology for compiling and evaluating information on materials and energy as they flow through a product or service manufacturing chain. It grew out of the needs of industry, in the early 1960s, to understand manufacturing systems, supply chains, and market behavior, and make choices among competing designs, processes, and products. It was also applied to the evaluation of the generation and emission of wastes from manufacturing activities. During the 1970s and 1980s general interest in LCA for environmental evaluation declined as the nation focused on the control of toxic substances and remediation of hazardous waste sites but increasing concern about global impacts, particularly those associated with greenhouse gas emissions, saw renewed interest in the development of the LCA methodology and more widespread applications.

LCA is a good way to understand the totality of the environmental impacts and benefits of a product or service. The method enables researchers and practitioners to see where along the product chain material and energy are most intensively consumed and waste produced. It allows for comparisons with conventional products that may be displaced in commerce by new products, and helps to identify economic and environmental tradeoffs.

LCA can facilitate communication of risks and benefits to stakeholders and consumers (e.g. the "carbon footprint" of individual activities and life styles). Perhaps most importantly of all, LCA can help to prevent unintended consequences, such as creating solutions to problems that result in the transferal of environmental burdens from one area to another, or from one type of impact to another.

A complete LCA assessment defines a system as consisting of five general stages of the product or service chain, each of which can be further broken down into substages:

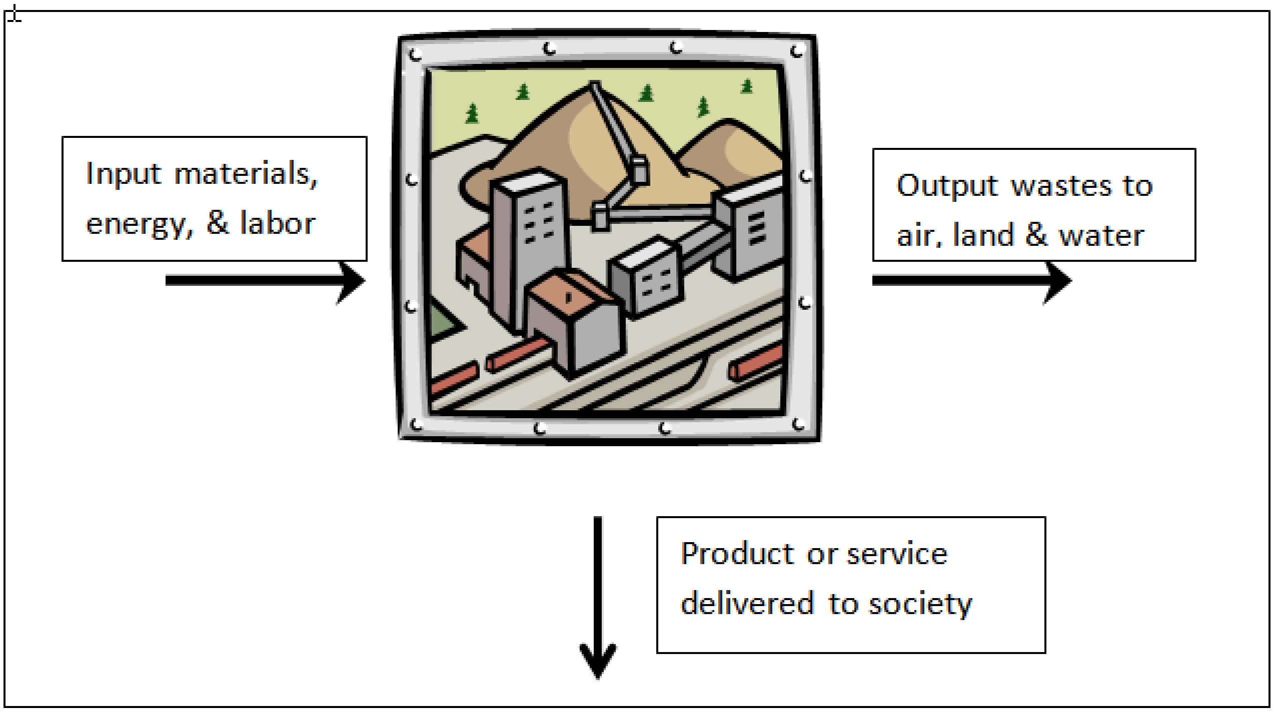
- Acquisition of materials (through resource extraction or recycled sources)
- Manufacturing, refining, and fabrication
- Packaging
- Use by consumers
- End-of-life disposition (incineration, landfilling, composting, recycling/reuse)

Each of these involves the transport of materials within or between stages, and transportation has its own set of impacts.

In most cases, the impacts contributed from each stage of the LCA are uneven, i.e. one or two of the stages may dominate the assessment. For example, in the manufacture of aluminum products it is acquisition of materials (mining), purification of the ore, and chemical reduction of the aluminum into metal that create environmental impacts. Subsequent usage of aluminum products by consumers contributes very few impacts, although the facilitation of recycling of aluminum is an important step in avoiding the consumption of primary materials and energy. In contrast, for internal combustion-powered automobiles, usage by consumers creates 70-80% of the life cycle impacts. Thus, it is not always necessary that the LCA include all stages of analysis; in many cases it is only a portion of the product/service chain that is of interest, and often there is not enough information to include all stages anyway. For this reason there are certain characteristic terminologies for various "scopes" of LCAs that have emerged:

Industrial Ecology

Many systems designed by humans focus on maximizing profitability for the firm, business or corporation. In most cases this means increasing production to meet demand for the products or services being delivered. An unfortunate byproduct of this is the creation of large amounts of waste, many of which have significant impacts if they enter the environment. Figure Human-Designed Industry is a general-purpose diagram of a typical manufacturing process, showing the inputs of materials and energy, the manufacturing of products, and the generation of wastes (the contents of the "manufacturing box" are generic and not meant to depict any particular industry—it could be a mine, a factory, a power plant, a city, or even a university). What many find surprising is the large disparity between the amounts of waste produced and the quantity of product delivered.



Human-Designed Industry Generic representation of a human-designed industry.*Source: Theis, T.*

The life cycle of a t-shirt

Trace the life cycle of a classic white t-shirt to find out how they're made and what is their ultimate environmental impact. — Consider the classic white t-shirt. Annually, we sell and buy 2 billion t-shirts globally, making it one of the most common garments in the world. But how and where is the average t-shirt made, and what's its environmental impact? Angel Chang traces the life cycle of a t-shirt. Lesson by Angel Chang, directed by TED-Ed.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=91#oembed-1

Conclusions

The life cycle approach is a useful way to come to an understanding of the material and energy needed to make a product or deliver a service, see where wastes are generated, and estimate the subsequent impacts that these wastes may have on the environment. It is a good way to improve a product chain, articulate tradeoffs, and make comparisons among alternative processes and products. In these contexts LCA facilitates decision making by managers, designers, and other stakeholders. Most importantly, LCA is a way of framing policy options in a comprehensive and systematic way.

Attributes

This chapter is composed of text taken from the following sources:

Sustainability: A Comprehensive Foundation by Tom Theis, University of Illinois, Chicago and Jonathan Tomkin, University of Illinois, Urbana-Champaign. Copyright Year: 2015. Publisher: OpenStax CNX and is under CC BY license. https://ia601501.us.archive.org/32/items/cnx-org-col11325/sustainability-a-comprehensive-foundation.pd

Life Cycle of a t-shirt video. Lesson by Angel Chang, directed by TED-Ed. –https://www.youtube.com/watch?v=BiSYoeqb_VY

4.

WATER: A NECESSITY FOR LIFE

Introduction:

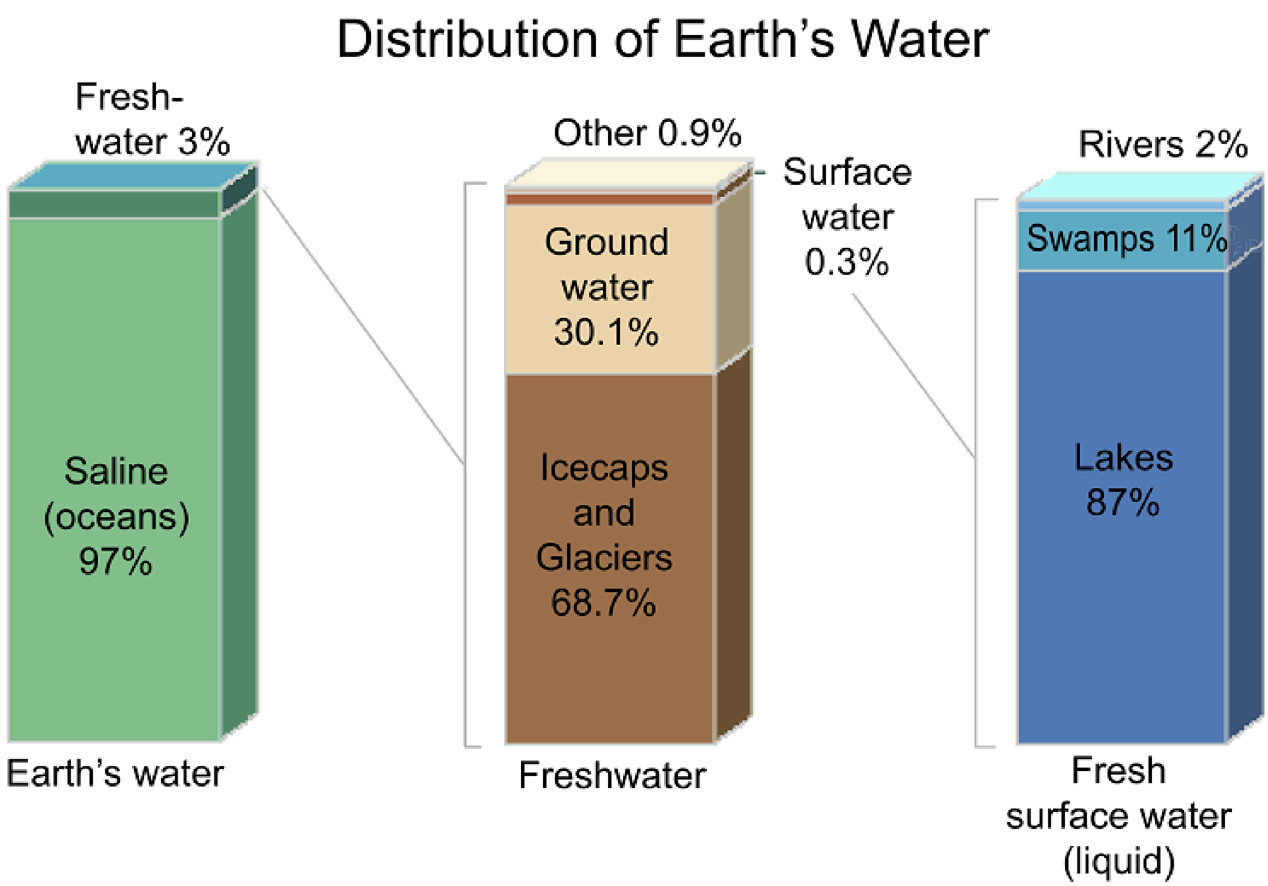
Why do scientists spend time looking for water on other planets? Why is water so important? It is because water is essential for life as we know it. Water is one of the more abundant molecules and the one most critical to life on Earth. Approximately 60–70 percent of the human body is made up of water. Without it, life as we know it simply would not exist. The quote from Mark Twain, "*Whiskey is for drinking. Water is for fighting"* suggests that water was and still is extremely important. In recent years, we have seen a rise in conflicts and dispute about water. Fortunately, most of the conflicts have ended up in the courts instead of the battlefields. Water, air, and food are the most important natural resources to people. Humans can live only a few minutes without oxygen, about a week without water, and about a month without food. Water also is essential for our oxygen and food supply. Plants, which require water to survive, provide oxygen through photosynthesis and form the base of our food supply. Plants grow in soil, which forms by weathering reactions between water and rock.

Water is an important commodity for life on Earth and is something we all need in our daily activities. It is referred to by many people as the "essence of life", "blue gold" and "more precious than oil". What makes water so important is its unique and special properties. These special properties of water include water's high heat capacity and heat of vaporization, its ability to dissolve numerous polar molecules, its cohesive and adhesive properties, and its dissociation into ions that leads to the generation of pH. The abundance of water on Earth distinguishes us from other bodies in the solar system. About 70% of Earth's surface is covered by oceans and approximately half of Earth's surface is obscured by clouds at any time. There is a very large volume of water on our planet, about 1.4 billion cubic kilometers (km3) (330 million cubic miles) or about 53 billion gallons per person on Earth. All of Earth's water could cover the United States to a depth of 145 km (90 mi). From a human perspective, the problem is that over 97% of it is seawater, which is too salty to drink or use for irrigation.

The most commonly used water sources are rivers and lakes, which contain less than 0.01% of the world's water! Understanding these characteristics helps us understand and appreciate its importance in maintaining life on Earth.

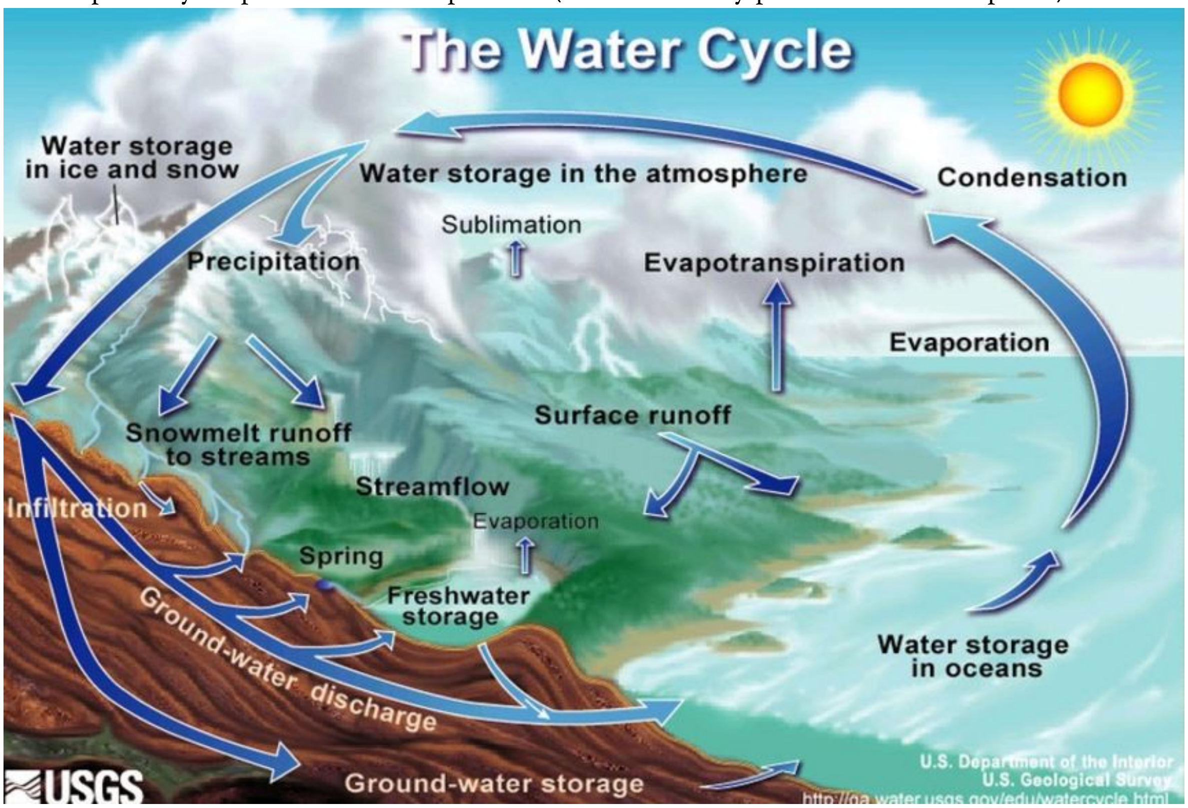
One of our most important environmental goals is to provide a clean, sufficient, and sustainable water supply for the world. Fortunately, water is a renewable resource, and it is difficult to destroy. Evaporation and precipitation combine to replenish our fresh water supply constantly and quickly; however, water availability is complicated by its uneven distribution over the Earth. Arid climate and densely populated areas have combined in many parts of the world to create water shortages, which are projected to worsen significantly in the coming years. Human activities such as water overuse and water pollution have compounded the water crisis that exists today. Hundreds of millions of people lack access to safe drinking water, and billions of people lack access to improved sanitation as simple as a pit latrine. As a result, nearly two million people die every year from diarrheal diseases and 90% of those deaths occur among children under the age of 5. Most of these are easily prevented deaths.

Water is the only substance that occurs naturally on Earth in three forms: solid, liquid and gas. It is distributed in various locations, called water reservoirs. The oceans are by far the largest of the reservoirs with about 97% of all water but that water is too saline for most human uses (see Figure Earth's Water Reservoirs). Ice caps and glaciers are the largest reservoirs of fresh water but this water is inconveniently located, mostly in Antarctica and Greenland. Shallow groundwater is the largest reservoir of usable fresh water. Although rivers and lakes are the most heavily used water resources, they represent only a tiny amount of the world's water. If all of world's water was shrunk to the size of 1 gallon, then the total amount of fresh water would be about 1/3 cup, and the amount of readily usable fresh water would be 2 tablespoons.



Earth's Water Reservoirs Bar chart Distribution of Earth's water including total global water, fresh water, and surface water and other
fresh water

The water cycle shows the movement of water through different reservoirs, which include oceans, atmosphere, glaciers, groundwater, lakes, rivers, and biosphere. Solar energy and gravity drive the motion of water in the water cycle. Simply put, the water cycle involves water moving from the ocean to the atmosphere by evaporation, forming clouds. From clouds, it falls as precipitation (rain and snow) on both water and land, where it can move in a variety of ways. The water on land can either return to the ocean by surface runoff (unchannelized overland flow), rivers, glaciers, and subsurface groundwater flow, or return to the atmosphere by evaporation or transpiration (loss of water by plants to the atmosphere).



The Water Cycle Arrows depict movement of water to different reservoirs located above, at, and below Earth's surface.

An important part of the water cycle is how water varies in salinity, which is the abundance of dissolved ions in water. Ocean water is called salt water because it is highly saline, with about 35,000 mg of dissolved ions per liter of seawater. Evaporation (where water changes from liquid to gas at ambient temperatures) is a distillation process that produces nearly pure water with almost no dissolved ions. As water vaporizes, it leaves the dissolved ions in the original liquid phase. Eventually, condensation (where water changes from gas to liquid) forms clouds and sometimes precipitation (rain and snow). After rainwater falls onto land, it dissolves minerals, which increases its salinity. Most lakes, rivers, and near-surface groundwater have a relatively low salinity and are called fresh water.

One estimate of global water distribution

(Percents are rounded, so will not add to 100)

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of freshwater	Percent of total water
Oceans, Seas, & Bays	321,000,000	1,338,000,000	—	96.54
Ice caps, Glaciers, & Permanent Snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	—	1.69
Fresh	*2,526,000*	*10,530,000*	*30.1*	*0.76*
Saline	*3,088,000*	*12,870,000*	—	*0.93*
Soil Moisture	3,959	16,500	0.05	0.001
Ground Ice & Permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	—	0.013
Fresh	*21,830*	*91,000*	*0.26*	*0.007*
Saline	*20,490*	*85,400*	—	*0.006*
Atmosphere	3,095	12,900	0.04	0.001
Swamp Water	2,752	11,470	0.03	0.0008
Rivers	509	2,120	0.006	0.0002
Biological Water	269	1,120	0.003	0.0001

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

Primary Fresh Water Resources: Precipitation

Precipitation is a major control of fresh water availability, and it is unevenly distributed around the globe (see Figure World Rainfall Map). More precipitation falls near the equator, and landmasses there are characterized by a tropical rainforest climate. Less precipitation tends to fall near 20–30° north and south latitude, where the world's largest deserts are located. These rainfall and climate patterns are related to global wind circulation cells. The intense sunlight at the equator heats air, causing it to rise and cool, which decreases the ability of the air mass to hold water vapor and results in frequent rainstorms. Around 30° north and south latitude, descending air conditions produce warmer air, which increases its ability to hold water vapor and results in dry conditions. Both the dry air conditions and the warm temperatures of these latitude belts favor evaporation. Global precipitation and climate patterns are also affected by the size of continents,
major ocean currents, and mountains.

Total Rainfall:

The global map of (a) generalized average annual precipitation and (b) overall water scarcity risks. Reproduced from Water Science School, Generalized world precipitation map; published by U.S. Geological Survey. Reproduced with permission from Gassert, Francis, et al., Aqueduct Global Maps 2.1: Constructing Decision-Relevant Global Water Risk Indicators; published by World Resources Institute, 2014 [3,52].

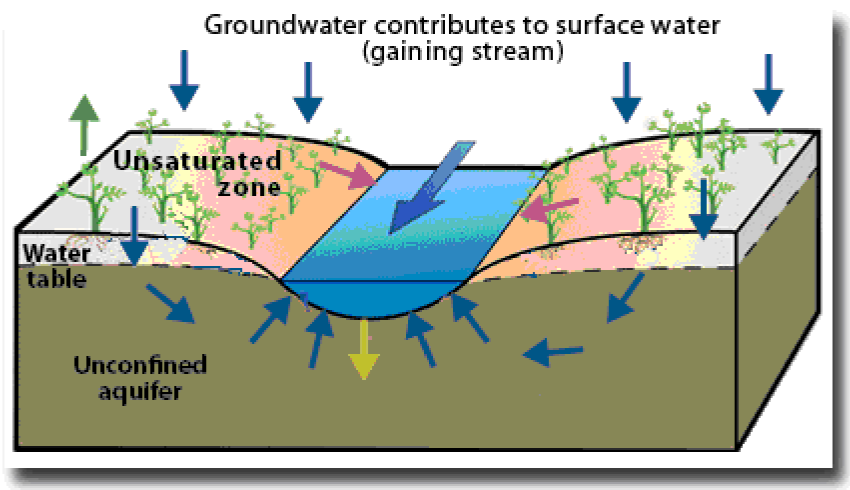
World Rainfall Map The false-color map above shows the amount of rain that falls around the world. Areas of high rainfall include Central
and South America, western Africa, and Southeast Asia. Since these areas receive so much rainfall, they are where most of the world's
rainforests grow. Areas with very little rainfall usually turn into deserts. The desert areas include North Africa, the Middle East,
western North America, and Central Asia.

https://earthobservatory.nasa.gov/global-maps/GPM_3IMERGM

Surface Water Resources: Rivers, Lakes, Glaciers

Flowing water from rain and melted snow on land enters river channels by surface runoff and groundwater seepage. River discharge describes the volume of water moving through a river channel over time. The relative contributions of surface runoff vs. groundwater
seepage to river discharge depend on precipitation patterns, vegetation, topography, land use, and soil characteristics. Soon after a heavy rainstorm, river discharge increases due to surface runoff. The steady normal flow of river water is mainly from groundwater that discharges into the river. Gravity pulls river water downhill toward the ocean. Along the way the moving water of a river can erode soil particles and dissolve minerals, creating the river's load of moving sediment grains and dissolved ions. Groundwater also contributes a large amount of the dissolved ions in river water. The geographic area drained by a river and its tributaries is called a drainage basin. The Mississippi River drainage basin includes approximately 40% of the U.S., a measure that includes the smaller drainage basins (also called watersheds), such as the Ohio River and Missouri River that help to comprise it. Rivers are an important water resource for irrigation and many cities around the world. Some of the world's rivers that have had international disputes over water supply include the Colorado (Mexico, southwest U.S.), Nile (Egypt, Ethiopia, Sudan), Euphrates (Iraq, Syria, Turkey), Ganges (Bangladesh, India), and Jordan (Israel, Jordan, Syria).

Surface Runoff Surface runoff, part of overland flow in the water cycle Source: James M. Pease at Wikimedia Commons



This diagram is a very general schematic of how groundwater contributes water into surface water (streams, rivers, and lakes). In this case, this is a "gaining stream", which generally gains water from the ground.

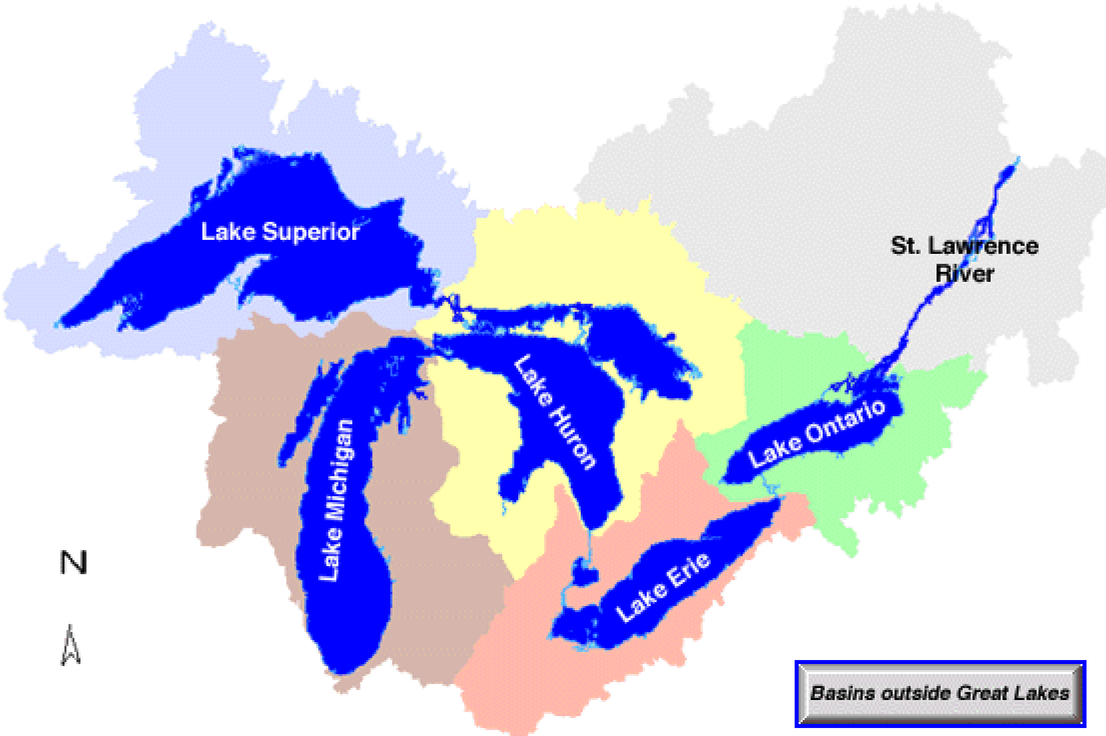
A gaining stream has water seeping into it from the ground.

By Water Science School

River Discharge Colorado River, U.S.. Rivers are part of overland flow in the water cycle and an important surface

water resource. Source Colorado River Basin map. https://www.usgs.gov/media/images/colorado-river-basin-map

Lakes can also be an excellent source of fresh water for human use. They usually receive water from surface runoff and groundwater discharge. They tend to be short-lived on a geological time-scale because they are constantly filling in with sediment supplied by rivers. Lakes form in a variety of ways including glaciation (Great Lakes, North America, recent tectonic uplift (Lake Tanganyika, Africa), and volcanic eruptions (Crater Lake, Oregon). People also create artificial lakes (reservoirs) by damming rivers. Large changes in climate can result in major changes in a lake's size. As Earth was coming out of the last Ice Age about fifteen thousand years ago, the climate in the western U.S. changed from cool and moist to warm and arid, which caused more than100 large lakes to disappear. The Great Salt Lake in Utah is a remnant of a much larger lake called Lake Bonneville.



Lake Superior, the largest of the Great Lakes, has a water surface area of 82,100 sq km and a maximum depth of 406 m. The surface of Lake Superior is large enough to contain the land area of the states of Connecticut, Delaware, Hawaii, Maryland, and New Jersey combined. Lake Huron is the second in size with 59,700 sq km; Lake Michigan, third, with 57,750 sq km; and Lake Erie, fourth, with 25,700 sq km. These lakes provide important water connections between these ports of Michigan, and between these ports and other ports of the United States, as well as of the world. The four lakes represent a freshwater resource for domestic and industry use for many communities along the coast and those that can be reached by pipelines. The commercial fishery resources of the lakes are considerable but have been decreasing in recent years. Fishing for coho and chinook salmon, first introduced into the lakes in 1966 is now a major sports activity on the lakes and in the adjoining rivers. Commercial fishing is handicapped by the fact that there is too high a concentration of undesirable chemicals in a number of fish species, particularly the salmon and lake trout. The Great Lakes hold 21% of the world's surface fresh water. Lakes are an important surface water resource.
Source : https://project.geo.msu.edu/geogmich/watershed.html
Although glaciers represent the largest reservoir of fresh water, they generally are not used as a water source because they are located too far
from most people (see Figure Mountain Glacier in Argentina). Melting glaciers do provide a natural source of river water and groundwater. During the last Ice Age there was as much as 50% more water in glaciers than there is today, which caused sea level to be about 100 m lower. Over the past century, sea level has been rising

in part due to melting glaciers. If Earth's climate continues to warm, the melting glaciers will cause an additional rise in sea level.

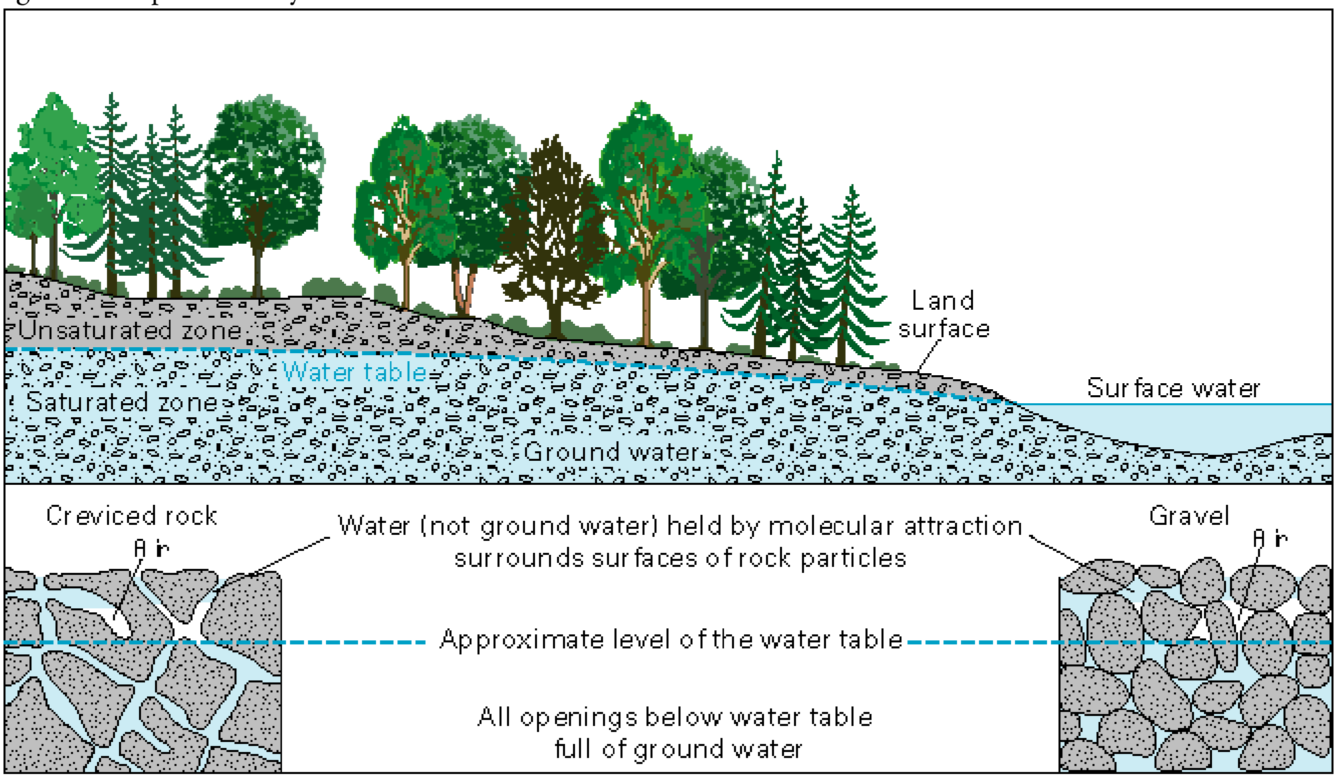
A tourist boat approaches the face of the Perito Moreno glacier, a part of the Southern Patagonian Ice Field, where it feeds into Lago, Argentina. Credit: David Silverman/Getty Images
https://www.scientificamerican.com/article/mountain-glaciers-have-less-ice-than-previously-thought/
By Chelsea Harvey, E&E News on February 8, 2022

Groundwater Resources

Although most people in the U.S. and the world use surface water, groundwater is a much larger reservoir of usable fresh water, containing
more than 30 times more water than rivers and lakes combined. Groundwater is a particularly important resource in arid climates, where
surface water may be scarce. In addition, groundwater is the primary water source for rural homeowners, providing 98% of that water demand in the U.S.. Groundwater is water located in small spaces, called pore space, between mineral grains and fractures in subsurface earth materials (rock or rivers or lakes except where there are caves, which are relatively rare. Between the land surface and the depth where there is groundwater is the unsaturated zone, where pore spaces contain only air and water films on mineral grains (see Figure Subsurface Water Terminology).[1] Below the unsaturated zone is the saturated zone, where groundwater completely fills pore spaces in earth materials. The interface between the unsaturated zone and saturated zone

1.

is the water table. Most groundwater originates from rain or snowmelt, which infiltrates the ground and moves downward until it reaches the saturated zone. Other sources of groundwater include seepage from surface water (lakes, rivers, reservoirs, and swamps), surface water deliberately pumped into the ground, irrigation, and underground wastewater treatment systems, i.e., septic tanks. Recharge areas are locations where surface water infiltrates the ground rather than running off into rivers or evaporating. Wetlands and flat vegetated areas in general are excellent recharge areas. Groundwater is the name for water in the saturated zone and soil moisture describes water in the unsaturated zone. Therefore, groundwater is the underground water resource used by society but soil moisture is the principal water supply for most plants and is an important factor in agricultural productivity.

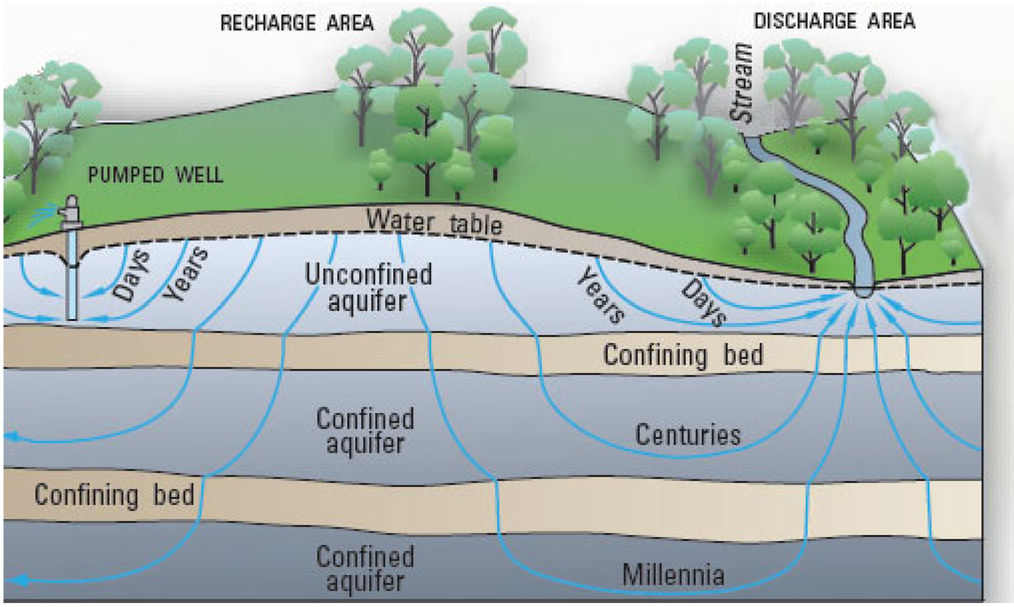


Subsurface Water Terminology Groundwater in pore spaces and fractures of Earth materials, saturated zone, unsaturated zone, and water table, which follows land surface but in a more subdued way. Source: United States Geological Survey

Groundwater is in constant motion due to interconnection between pore spaces. Porosity is the percentage of pore space in an Earth material and it gives a measure of how much groundwater an Earth material can hold. Permeability is a measure of the speed that groundwater can flow through an Earth material, and it depends on the size and degree of interconnection among pores. An Earth material that is capable of supplying groundwater from a well at a useful rate—i.e., it has relatively high permeability and medium to high porosity—is called an aquifer. Examples of aquifers are Earth materials with abundant, large, well-connected pore spaces such as sand, gravel, uncemented sandstone, and any highly fractured rock. An Earth material with low hydraulic conductivity is an aquitard. Examples of aquitards include clay, shale (sedimentary rock with abundant clay), and igneous and metamorphic rock, if they contain few fractures.

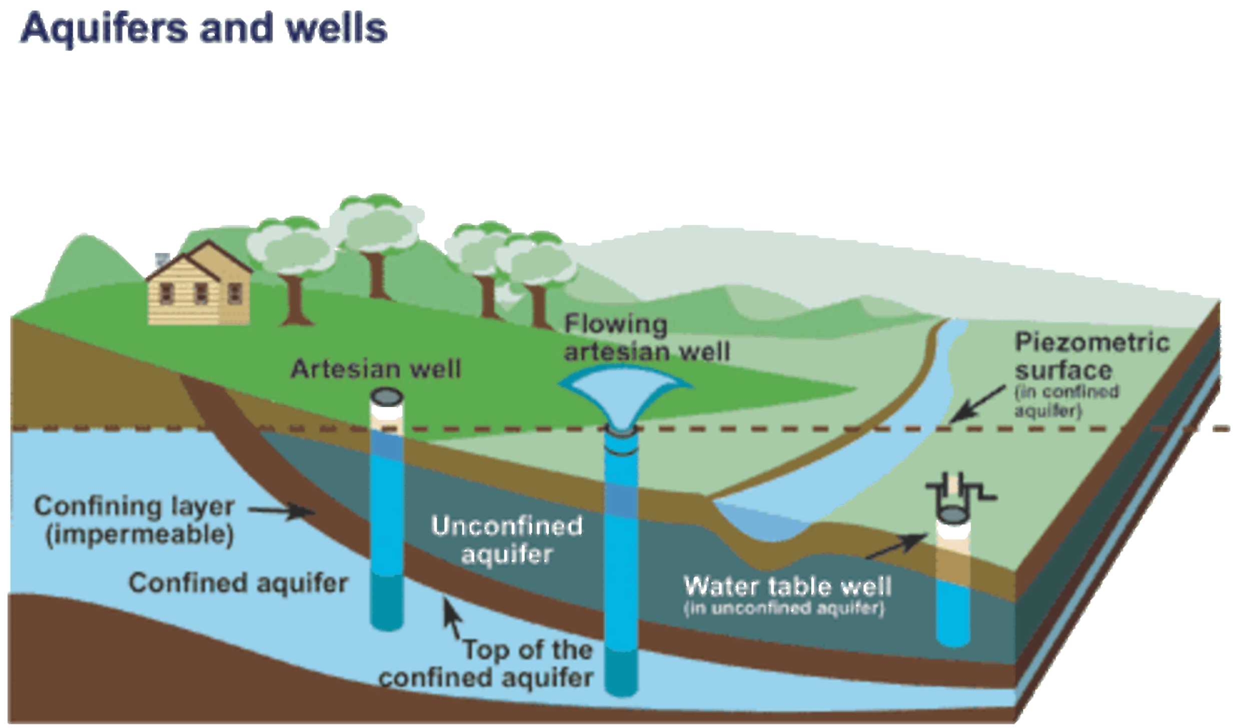
As discussed above, groundwater flows because most Earth materials near the surface have finite (nonzero) porosity and permeability values. Another reason for groundwater movement is that the surface of the water table commonly is not completely flat but mimics the topography of the land surface, especially in humid climates. There is "topography" to the water table because groundwater moves slowly through rock and soil, so it builds up in higher elevation areas. In fact, when groundwater flows slowly through aquitards and deep underground, it can take many thousands of years to move relatively short distances. An unconfined aquifer has no aquitard above it and, therefore, it is exposed to the atmosphere and surface waters through interconnected pores (See Figure Flowing Groundwater). In an unconfined aquifer, groundwater flows because of gravity to lower water table levels, where it eventually may discharge or leave the groundwater flow system. Discharge areas include rivers, lakes, swamps, reservoirs, water wells, and springs . A spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects **groundwater** at or below the local water table, below which the subsurface material is saturated with water. A spring is the result of an **aquifer** being filled to the point that the water overflows onto the land surface. They range in size from intermittent seeps, which flow only after much rain, to huge pools flowing hundreds of millions of gallons daily. Springs are not limited to the Earth's surface, though. Recently, scientists have discovered hot springs at depths of up to 2.5 kilometers in the **oceans**, generally along mid-ocean rifts (spreading ridges). The hot water (over 300 degrees Celsius) coming from these springs is also rich in minerals and sulfur, which results in a unique ecosystem where unusual and exotic sea life seems to thrive. Springs may be formed in any sort of rock. Small ones are found in many places. In Missouri, the largest springs are formed in limestone and dolomite in the karst topography of the Ozarks. Both dolomite and limestone fracture relatively easily. When weak carbonic acid (formed by rainwater percolating through organic matter in the soil) enters these fractures it dissolves bedrock. When it reaches a horizontal crack or a layer of non-dissolving rock such as sandstone or shale, it begins to cut sideways. As the process continues, the water hollows out more rock, eventually admitting an airspace, at which point the spring stream can be considered a cave. This process often takes tens to hundreds of thousands of years to complete.

A confined aquifer is bounded by aquitards below and above, which prevents recharge from the surface immediately above. Instead, the major recharge occurs where the confined aquifer intercepts the land surface, which may be a long distance from water wells and discharge areas (see Figure Schematic Cross Section of Aquifer Types). Confined aquifers are commonly inclined away from recharge areas, so groundwater in a confined aquifer is under greaterthan- atmospheric pressure due to the weight of water in the upslope direction. Similar to river discharge, groundwater discharge describes the volume of water moving through an aquifer over time. Total groundwater discharge depends on the permeability of the earth material, the pressure that drives groundwater flow, and the size of the aquifer. It is important to determine groundwater discharge to evaluate whether an aquifer can meet the water needs of an area.



Blue lines show the direction of groundwater in unconfined aquifers, confined aquifers, and confining beds. Deep groundwater moves very slowly especially through low permeability layers. Source:https://www.usgs.gov/special-topics/water-science-school/science/groundwater-flow-and-water-cycle

Rainbow Springs, Florida, USA Source: https://www.usgs.gov/special-topics/water-science-school/science/springs-and-water-cycle



The illustration shows an artesian well and a flowing artesian well, which are drilled into a confined aquifer, and a water table well, which is drilled into an unconfined aquifer. Also shown are the Piezometric surface in the confined aquifer and the impermeable, confining layer between the confined and unconfined aquifer. Source: https://www.usgs.gov/special-topics/water-science-school/science/aquifers-and-groundwater

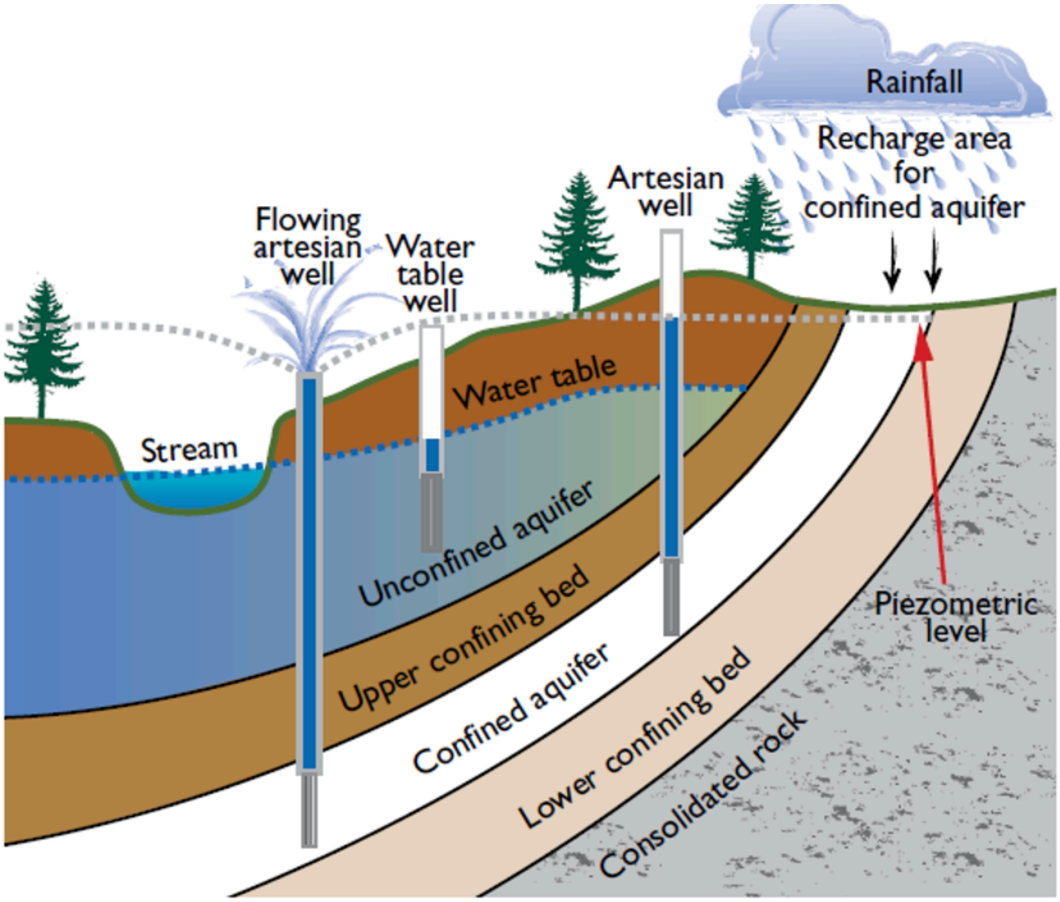


Figure 1. Geological and topographical controls affecting artesian and flowing artesian wells.

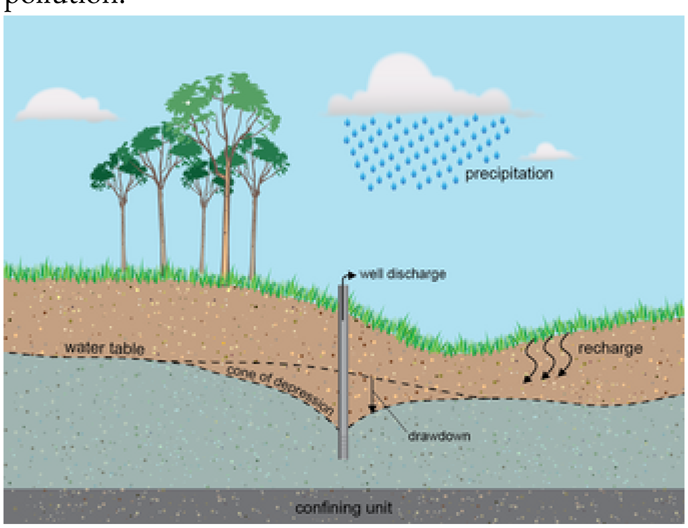
Sources/Usage: Public Domain (https://www.usgs.gov/special-topics/water-science-school/science/artesian-water-and-artesian-wells)

Artesian wells can be sometimes flow to the land surface naturally because of underground pressure.
This diagram shows a conceptual aquifer system having both unconfined and confined aquifers. Generally, the upper layer of an aquifer system is the unconfined aquifer, which does not have a confining layer of solid material above it. The top altitude of this aquifer is called the "water table", below which the ground and rock has all the spaces and voids full of water. Water from this aquifer must be pumped out in a well to get to the land surface.
In some locations there can exist confined aquifers below the unconfined aquifers. These confined aquifers have layers of solid material above and below them and are thus under pressure from the rock weight. As this diagram shows, for water to recharge these aquifers, it much seep down from the surface at a distance away and travel somewhat horizontally into the confined aquifer.
Wells that tap these confined aquifers are "artesian wells". If altitude that the pressurized aquifer pushes water up a well tapping it is the "piezometric level". If this level is below the land surface altitude (right side artesian well in the diagram) the water will not shoot out of the well at the land surface...the well is called an artesian

well. But if the piezometric level is higher than the well head altitude at the land surface (the left side artesian well in the diagram above), the water will be pushed upward in the well and emerge at the land surface, with no pump needed. This kind of well is a flowing artesian well.

Groundwater in **aquifers** between layers of poorly permeable rock, such as clay or shale, may be confined under pressure. If such a confined aquifer is tapped by a well, water will rise above the top of the aquifer and may even flow from the well onto the land surface. Water confined in this way is said to be under artesian pressure, and the aquifer is called an artesian aquifer. Flowing artesian well in Brunswick, Georgia, USA Source: https://www.usgs.gov/media/images/flowing-artesian-well-brunswick-georgia-usa

A confined aquifer tends to be depleted from groundwater pumping more quickly than an unconfined aquifer, assuming similar aquifer properties and precipitation levels. This is because confined aquifers have smaller recharge areas, which may be far from the pumping well. However, an unconfined aquifer tends to be more susceptible to pollution because it is hydrologically connected to the surface, which is the source of most pollution.



Schematic showing a cone of depression around the well, usually the result of overpumping.

Credit: Tara Gross, USGS https://www.usgs.gov/special-topics/water-science-school/science/aquifers-and-groundwater

Groundwater and surface water (rivers, lakes, swamps, and reservoirs) are strongly interrelated because both are part of the same overall resource. Major groundwater removal (from pumping or drought) can lower the levels of surface water and vice versa. We can define two types of streams: gaining (effluent) streams and losing (influent) streams.Streams either gain water from inflow of ground water (gaining stream; Figure 12*A*) or lose water by outflow to ground water (losing stream; Figure 12*B*). Many streams do both, gaining in some reaches and losing in other reaches. Furthermore, the flow directions between ground water and surface water can change seasonally as the altitude of the ground-water table changes with respect to the stream-surface altitude or can change over shorter timeframes when rises in stream surfaces during storms cause recharge to the streambank. Under natural conditions, ground water makes some contribution to streamflow in most physiographic and climatic settings. Thus, even in settings where streams are primarily losing water to ground water, certain reaches may receive ground-water inflow during some seasons.

Losing streams can be connected to the ground-water system by a continuous saturated zone (Figure 12*B*) or can be disconnected from the ground-water system by an unsaturated zone (Figure 12*C*). An important feature of streams that are disconnected from ground water is that pumping of ground water near the stream does not affect the flow of the stream near the pumped well.

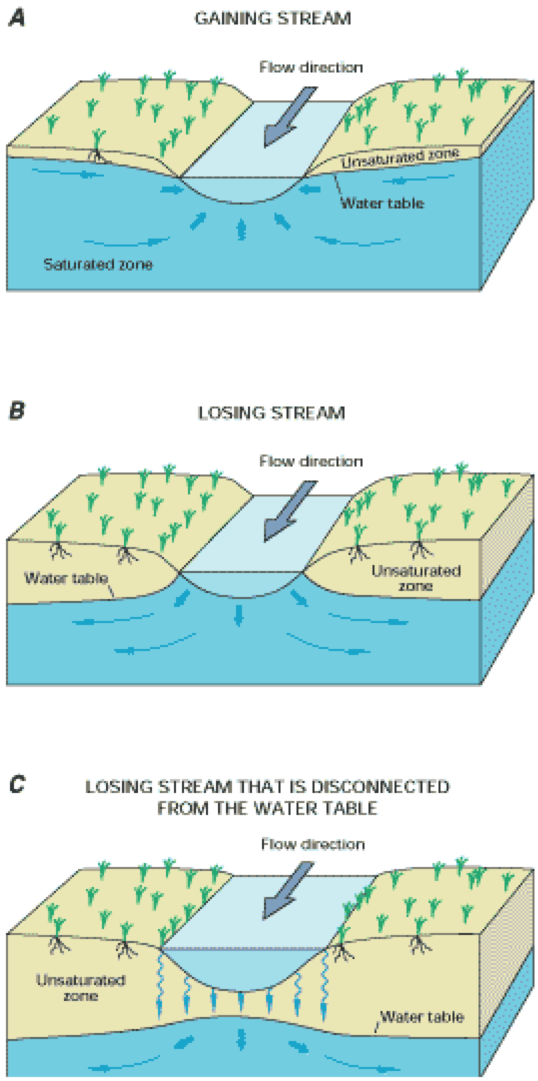


Figure 12. Interaction of streams and ground water. (Modified from Winter and others, 1998.)

Gaining streams (A) receive water from the ground-water system, whereas losing streams (B) lose water to the ground-water system. For ground water to discharge to a stream channel, the altitude of the water table in the vicinity of the stream must be higher than the altitude of the stream-water surface. Conversely, for surface water to seep to ground water, the altitude of the water table in the vicinity of the stream must be lower than the altitude of the stream surface. Some losing streams (C) are separated from the saturated ground-water system by an unsaturated zone. Source: https://pubs.usgs.gov/circ/circ1186/html/gw_effect.html

Comal Springs

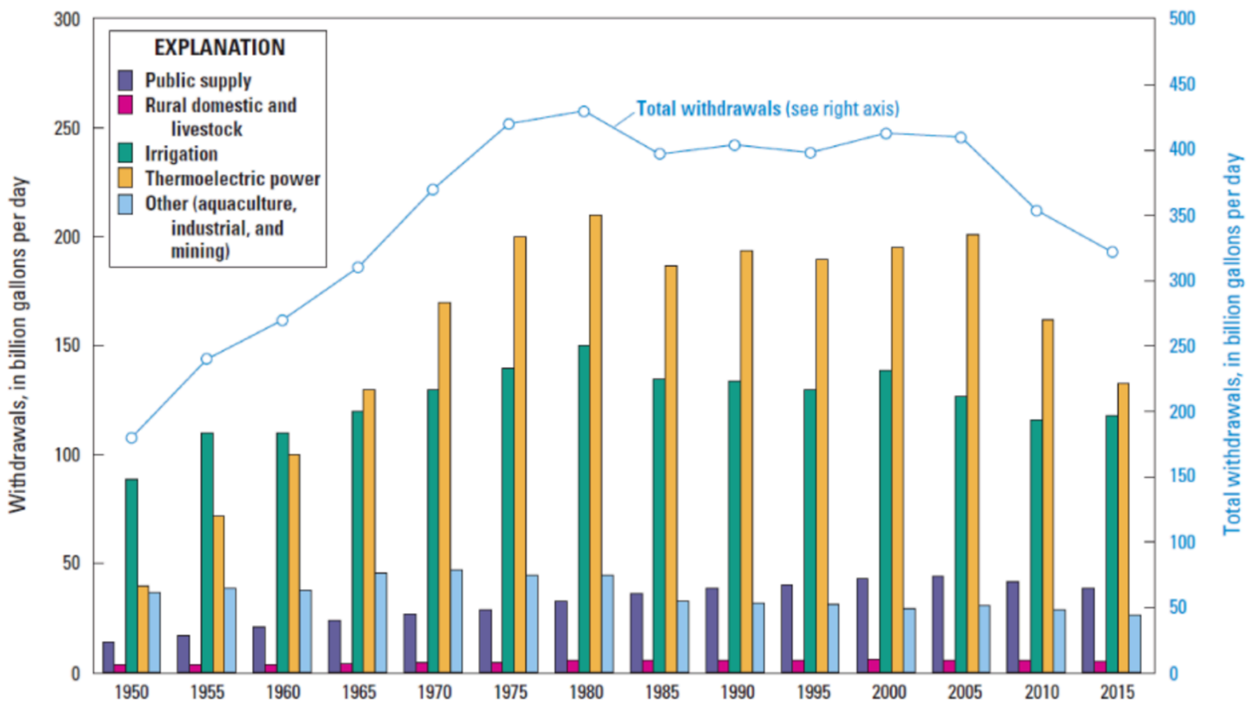
The highly productive Edwards aquifer, the first aquifer to be designated as a sole source aquifer under the Safe Drinking Water Act, is the source of water for more than 1 million people in San Antonio, Texas, some military bases and small towns, and for south-central Texas farmers and ranchers. The aquifer also supplies water to sustain threatened and endangered species habitat associated with natural springs in the region and supplies surface water to users downstream from the major springs. These various uses are in direct competition with ground-water development and have created challenging issues of ground-water management in the region. (Photograph by Robert Morris, U.S. Geological Survey (https://pubs.usgs.gov/circ/circ1186/html/gw_effect.html).

Water Use in the U.S

People need water to produce the food, energy, and mineral resources they use—commonly large amounts of it. Consider, for example, these

approximate water requirements for some things people in the developed world use every day: one tomato = 3 gallons; one kilowatt-hour of electricity (from a thermoelectric power plant) = 21 gallons; one loaf of bread = 150 gallons; one pound of beef = 1,600 gallons; and one ton of steel = 63,000 gallons. Human beings require only about 1 gallon per day to survive, but a typical person in a U.S. household uses approximately 100 gallons per day, which includes cooking, washing dishes and clothes, flushing the toilet, and bathing.

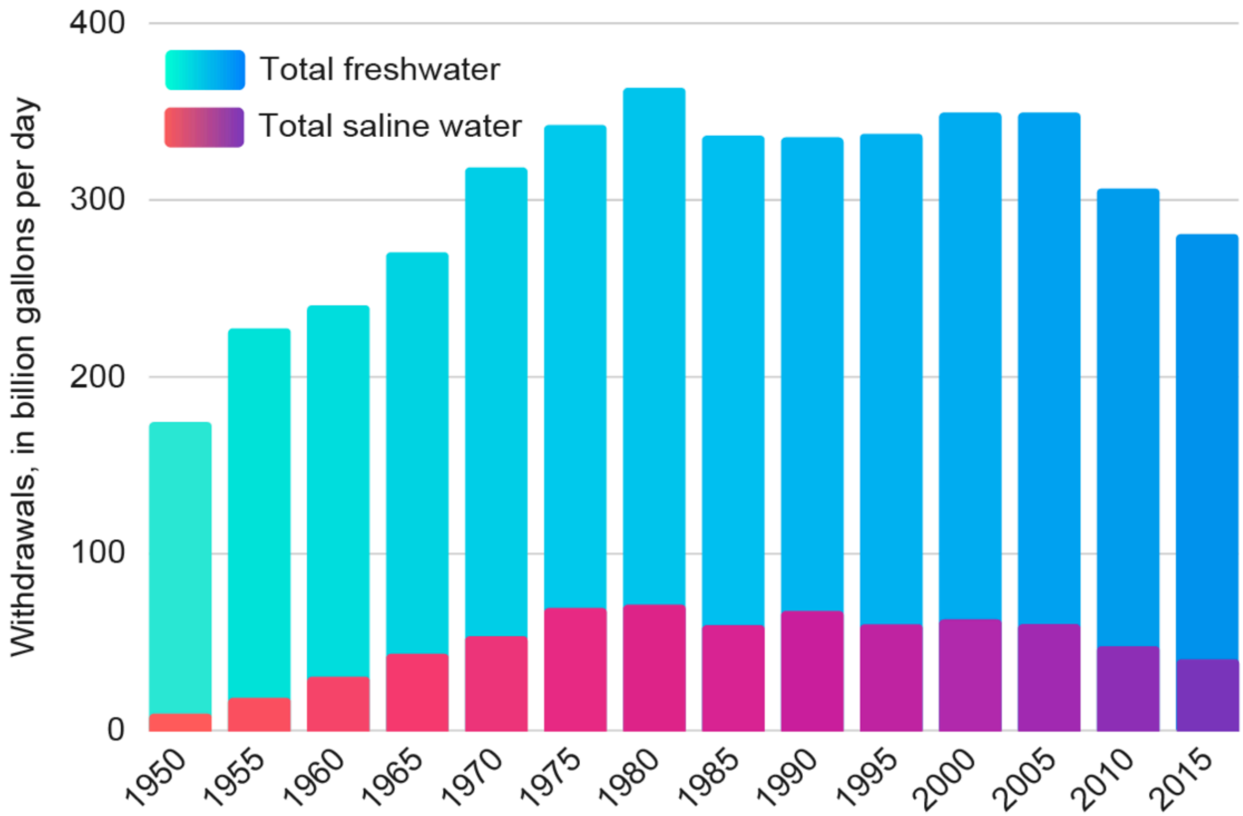
The water demand of an area is a function of the population and other uses of water. There are several general categories of water use, including offstream use, which removes water from its source, e.g., irrigation, thermoelectric power generation (cooling electricity-producing equipment in fossil fuel, nuclear, and geothermal power plants), industry, and public supply; consumptive use, which is a type of offstream use where water does not return to the surface water or groundwater system immediately after use, e.g., irrigation water that evaporates or goes to plant growth; and instream use, which is water used but not removed from a river, mostly for hydroelectric power generation. The relative size of these three categories are instream use >> offstream use > consumptive use. In 2005, the U.S. used approximately 3,300 billion gallons per day for instream use, 410 billion gallons per day for offstream use, and 100 billion gallons per day for consumptive use. The major offstream uses of that water were thermoelectric (49%), irrigation (31%), public supply (11%), and industry (4%, see Figure Trends in Total Water Withdrawals by Water-use Category, 1950-2005). About 15% of the total water withdrawals in the U.S. in 2005 were saline water, which was used almost entirely for thermoelectric power generation. Almost all of the water used for thermoelectric power generation is returned to the river, lake, or ocean from where it came but about half of irrigation water does not return to the original source due to evaporation, plant transpiration, and loss during transport, e.g., leaking pipes. Total withdrawals of water in the U.S. actually decreased slightly from 1980 to 2005, despite a steadily increasing population. This is because the two largest categories of water use (thermoelectric and irrigation) stabilized or decreased over that time period due to better water management and conservation. In contrast, public supply water demand increased steadily from 1950 (when estimates began) through 2005. Approximately 77% of the water for offstream use in the U.S. in 2005 came from surface water and the rest was from groundwater.



Trends in total water withdrawals by water-use category, 1950–2015

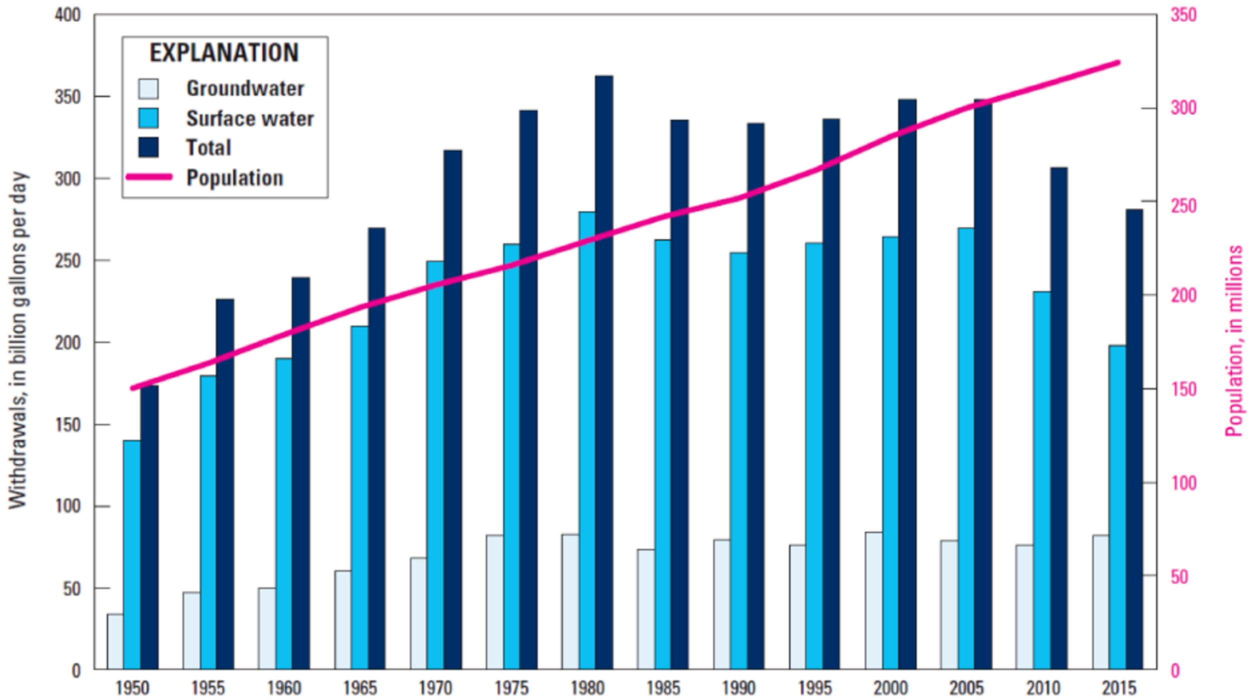
The bars that stand out most are the yellow ones -- freshwater for electricity production. **Electricity water use** increased almost 400 percent from 1950 to 2005, but dropped about 19 percent from 2005 to 2015. **Irrigation water use** increased by about 29 percent since 1950—it takes more water to grow food for our increasing population. Notice how after 1980 water use started to decrease a bit, possibly due to the Nation making more use of water-conservation measures. The purple **public-supply** boxes are important. Notice how they continue on an uptrend. Public-supply water (water withdrawn by the local county and city water departments and delivered to homes and businesses) goes to serve the Nation's normal water uses, such as supplying industries, restaurants, and homes with water. The Nation's ever-increasing population demands ever-increasing supplies of water. Source USGS

Trends in total water withdrawals, 1950-2015



This chart shows the trends in freshwater and saline-water withdrawals for the Nation from 1950 to 2015. What is remarkable about this chart is that it shows that the Nation's water use peaked in 1980 and has been fairly steady since then. Many of the stresses for greater water use have risen since 1980, such as population, the need to grow more food (irrigation), more industry, etc, yet total water use has not risen. This shows that water conservation efforts and greater efficiencies in using water have had a positive effect in the last 35 year

Trends in total freshwater withdrawals by source, 1950-2015



Trends in population and freshwater withdrawals by source, 1950–2015

This chart shows the trends in **surface-water**, **groundwater**, and total-water withdrawals for the Nation from 1950 to 2015. Notice how the relative amounts of surface- and groundwater withdrawals (in percentages) has remained fairly constant. About three-fourths of the water used in America comes from surface water.

Trends in estimated use of water in the United States, 1950-2015

Table 14. Trends in estimated water use in the United States, 1950–2015.

[Data for 1980 and earlier are from Kenny and others (2009). Water-use data are in billion gallons per day (thousand million gallons per day) and are rounded to two significant figures for 1950–80, and to three significant figures for 1985–2015; percent change is calculated from unrounded numbers. Values may not sum to totals because of independent rounding. Geographic extent: 1950, 48 States, District of Columbia, and Hawaii; 1955, 48 States and District of Columbia; 1960 and 1975–2015, 50 States, District of Columbia, Puerto Rico, and U.S. Virgin Islands; 1965–70, 50 States, District of Columbia, and Puerto Rico]

	Year														Percent change, 2010–15
	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015	
Population, in millions	150.7	164.0	179.3	193.8	205.9	216.4	229.6	242.4	252.3	267.1	285.3	300.7	312.6	325.0	4
Total withdrawals	180	240	270	310	370	420	430	397	404	398	413	410[a]	354[a]	322	–9
Public supply	14	17	21	24	27	29	33	36.6	38.7	40.2	43.3	44.4[a]	42.0	39.0	–7
Rural domestic and livestock															
Self-supplied domestic	2.1	2.1	2.0	2.3	2.6	2.8	3.4	3.32	3.39	3.39	3.58	3.73[a]	3.53[a]	3.26	–8
Livestock	1.5	1.5	1.6	1.7	1.9	2.1	2.2	2.23	2.25	2.28	2.37[a]	2.15	2.00	2.00	0
Irrigation	89	110	110	120	130	140	150	135	134	130	139	127	116[a]	118	2
Thermoelectric power	40	72	100	130	170	200	210	187	194	190	195	201	162[a]	133	–18
Other															
Self-supplied industrial	37	39	38	46	47	45	45	25.8	22.4[a]	21.6	19.5[a]	18.1	16.2[a]	14.8	–9
Mining	(b)	(b)	(b)	(b)	(b)	(b)	(b)	3.44	4.93	3.59	4.13[a]	3.83	3.97[a]	4.00	1
Commercial	(b)	(b)	(b)	(b)	(b)	(b)	(b)	1.23	2.39	2.89	(c)	(c)	(c)	(c)	
Aquaculture	(b)	(b)	(b)	(b)	(b)	(b)	(b)	2.24	2.24	3.27[a]	5.79[a]	8.83[a]	8.96[a]	7.55	–16
Source of water															
Groundwater															
Fresh	34	47	50	60	68	82	83	73.4	79.4	76.4[a]	84.3[a]	78.9	75.9[a]	82.3	8
Saline	(c)	0.6	0.4	0.5	1.0	1.0	0.93	0.66	1.30[a]	1.11	2.47[a]	1.51	2.22[a]	2.34	5
Surface water															
Fresh	140	180	190	210	250	260	280	263	255[a]	261	265	270	231[a]	198	–14
Saline	10	18	31	43	53	69	71	59.6	68.7[a]	59.7	61.0	59.8[a]	45.0	38.6	–14

[a]Data revised from Maupin and others (2014) because of revisions to individual State data during interim years.

[b]Included in self-supplied industrial.

[c]Data not available.

Source: Trends in Water use in the U.S. Estimated use of water in the United States in 2015

Circular 1441

Water Availability and Use Science Program

By: Cheryl A. Dieter, Molly A. Maupin, Rodney R. Caldwell, Melissa A. Harris, Tamara I. Ivahnenko, John K. Lovelace, Nancy L. Barber, and Kristin S. Linsey

https://doi.org/10.3133/cir1441

Water Supply Crisis

The water crisis refers to a global situation where people in many areas lack access to sufficient water or clean water or both. This section describes the global situation involving water shortages, also called water stress. The next section covers the water crisis involving water pollution.

4: Countries with water threat in 1995 and predicted water-stress countries in 2025. Reference: [21]. Indeed, Egypt is no exception due to increasing population. by 2025, population -whom

Countries with water threat in 1995 and predicted water-stress countries in 2025. Water stress is defined as having a high percentage of water withdrawal compared to total available water in the area. Source:
Philippe Rekacewicz (Le Monde diplomatique), February 2006.

In many parts of the country, competing demands for water create stress in local and regional watersheds. Map shows a "water supply stress index" for the U.S. based on observations, with widespread stress in much of the Southwest, western Great Plains, and parts of the Northwest. Watersheds are considered stressed when water demand (from power plants, agriculture, and municipalities) exceeds 40% (water supply stress index of 0.4) of available supply. (Figure Source: Averyt et al. 2011) https://www.globalchange.gov/browse/multimedia/water-stress-us#:~:text=Map%20shows%20a%20%E2%80%9Cwater%20supply,and%20parts%20of%20the%20Northwest.

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Pacific Institute Launches Water and Climate Equity Strategy for United States

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=147#oembed-1

Water insecurity realities

More than 2.2 billion people globally lack access to safely managed drinking water (United Nations, 2019), while millions of people in the United States are without clean, reliable water, lack basic plumbing, or rely on water systems with Safe Drinking Water Act violations.

Today, the Human Right to Water is formally recognized by the United Nations, the State of California, and dozens of global businesses. Yet, the United States as a whole has yet to recognize the Human Right to Water or meet the United Nations Sustainable Development Goals for clean water and sanitation (SDG 6), climate action (SDG 13), or reduced inequalities (SDG 10). Source : Pacific Institute https://pacinst.org/our-focus-areas/

Case Study: The Aral Sea

The Aral Sea is a lake located east of the Caspian Sea between Uzbekistan and Kazakhstan in central Asia (see Figure Map of Aral Sea Area). This area is part of the Turkestan desert, which is the fourth largest desert in the world; it is produced from a rain shadow effect by Afghanistan's high mountains to the south. Due to the arid and seasonally hot climate there is extensive evaporation and limited surface waters in general. Summer temperatures can reach 60° C (140° F)! The water supply to the Aral Sea is mainly from two rivers, the Amu Darya and Syr Darya, which carry snowmelt from mountainous areas. In the early 1960s the then-Soviet Union diverted the Amu Darya and Syr Darya Rivers for irrigation of one of the driest parts of Asia to produce rice, melons, cereals, and especially cotton. The Soviets wanted cotton or “white gold” to become a major export. They were successful and today Uzbekistan is one of the world's largest exporters of cotton. Unfortunately this action essentially eliminated any river inflow to the Aral Sea and caused it to disappear almost completely.

Map showing the location of the Aral Sea in Central Asia. Source: World Atlas https://www.worldatlas.com/seas/aral-sea.html

In 1960 Aral Sea was the fourth largest inland water body; only the Caspian Sea, Lake Superior, and Lake Victoria were larger. Since then, it has progressively shrunk due to evaporation and lack of recharge by rivers. Before 1965 the Aral Sea received 20–60 km of fresh water per year from rivers and by the early 1980s it received none. By 2007 the Aral Sea shrank to about 10% of its original size and its salinity increased from about 1% dissolved salt to about 10% dissolved salt, which is 3 times more saline than seawater. These changes caused an enormous environmental impact. A once thriving fishing industry is dead as are the 24 species of fish that used to live there; the fish could not adapt to the more saline waters. The current shoreline is tens of kilometers from former fishing towns and commercial ports. Large fishing boats lie in the dried up lakebed of dust and salt (see adandoned boats above)

The wetlands of the two river deltas and their associated ecosystems have disappeared. The regional climate is drier and has greater temperature extremes due to the absence of moisture and moderating influence from the lake. In 2003 some lake restoration work began on the northern part of the Aral Sea and it provided some relief by raising water levels and reducing salinity somewhat. The southern part of the Aral Sea has seen no relief and remains nearly completely dry. The destruction of the Aral Sea is one of the planet's biggest environmental disasters and it is caused entirely by humans. Lake Chad in Africa is another example of a massive lake that has nearly disappeared for the same reasons as the Aral Sea. Aral Sea and Lake Chad are the most extreme examples of large lakes destroyed by unsustainable diversions of river water. Other lakes that have shrunk significantly due to human diversions of water include the Dead Sea in the Middle East, Lake Manchar in Pakistan, and Owens Lake and Mono Lake, both in California.

Water Pollution:

Water pollution is the contamination of water sources by substances which make the water unusable for drinking, cooking, cleaning, swimming, and other activities. Pollutants include chemicals, trash, bacteria, and parasites. All forms of pollution eventually make their way to water. Air pollution settles onto lakes and oceans. Land pollution can seep into an underground stream, then to a river, and finally to the ocean. Thus, waste dumped in a vacant lot can eventually pollute a water supply.

Water pollutants may cause disease or act as poisons. Bacteria and parasites in poorly treated sewage may enter drinking water supplies and cause digestive problems such as cholera and diarrhea. Hazardous chemicals, pesticides, and herbicides from industries, farms, homes and golf courses can cause acute toxicity and immediate death, or chronic toxicity that can lead to neurological problems or cancers. Many water pollutants enter our bodies when we use water for drinking and food preparation. The pollutants enter the digestive tract. From there, they can reach other organs in the body and cause various illnesses. Chemicals come in contact with the skin from washing clothes, or from swimming in polluted water and may lead to skin irritations. Hazardous chemicals in water systems can also affect the animals and plants which live there. Sometimes these organisms will survive with the chemicals in their systems, only to be eaten by humans who may then become mildly ill or develop stronger toxic symptoms. The animals and plants themselves may die or not reproduce properly.

Nonpoint Source Pollution (NPS)

NPS pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. NPS pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.

Nonpoint source pollution can include:

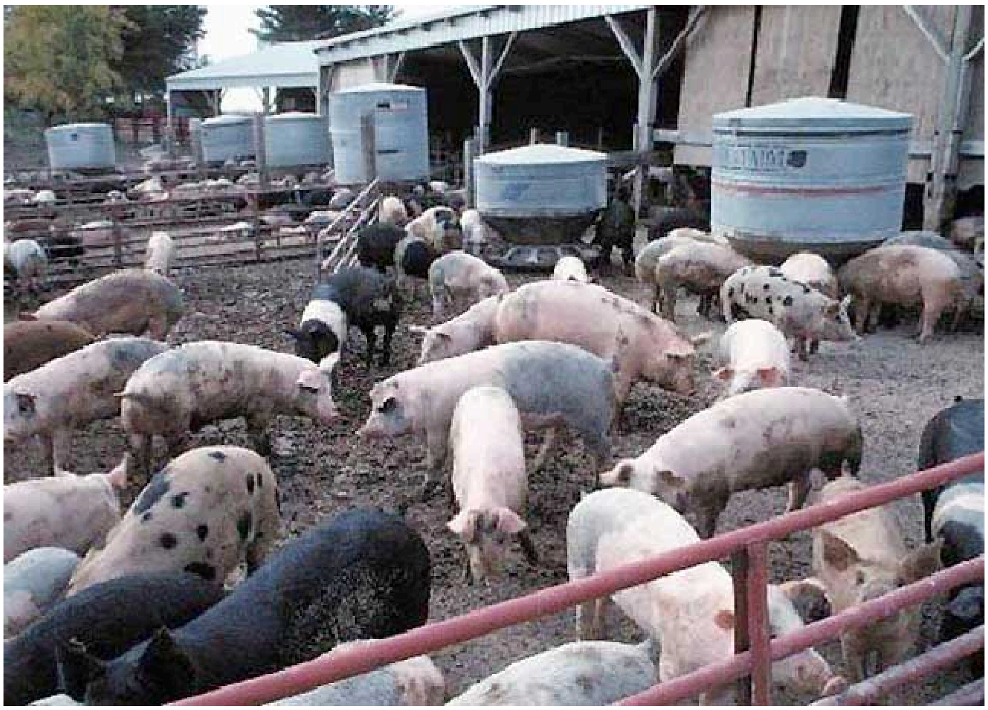
- Excess fertilizers, herbicides and insecticides from agricultural lands and residential areas
- Oil, grease and toxic chemicals from urban runoff and energy production
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks
- Salt from irrigation practices and acid drainage from abandoned mines
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems
- Atmospheric deposition and hydromodification

States report that nonpoint source pollution is the leading remaining cause of water quality problems. The effects of nonpoint source pollutants on specific waters vary and may not always be fully assessed. However, we know that these pollutants have harmful effects on drinking water supplies, recreation, fisheries and wildlife.

Nonpoint Sources vs. Point Sources

The term "**nonpoint source**" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act: **Summary of the Clean Water Act https://www.epa.gov/laws-regulations/summary-clean-water-act**

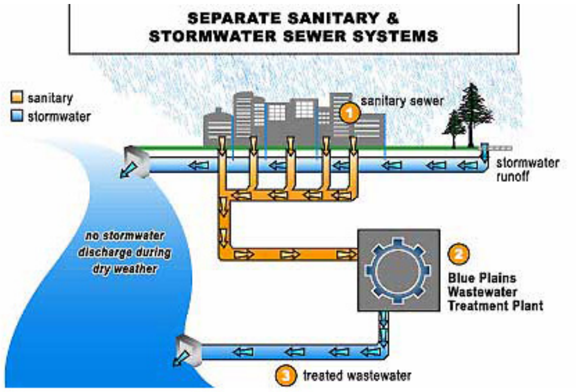
The term **"point source"** means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural storm water discharges and return flows from irrigated agriculture.

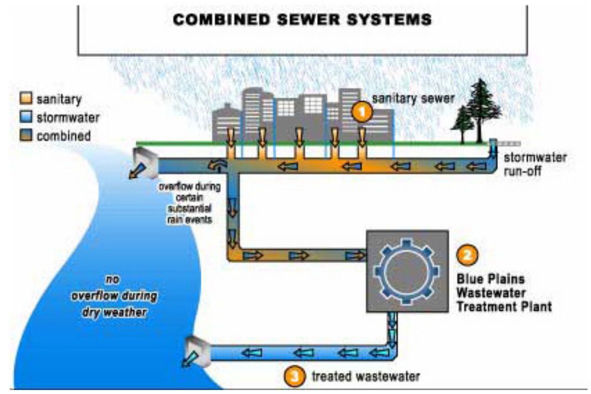


Large farms that raise livestock are often referred to as concentrated feeding operations (CFOs). These farms are considered potential point sources of pollution because untreated animal waste may enter nearby waterbodies as untreated sewage. Source: NOAA https://oceanservice.noaa.gov/education/tutorial_pollution/03pointsource.html#:~:text=The%20U.S.%20Environmental%20Protection%20Agency%20(EPA)%20defines%20point%20source%20pollution,common%20types%20of%20point%20sources

Some factories and sewage treatment plants handle waste material is by mixing it with urban runoff in a combined sewer system. Runoff refers to stormwater that flows over surfaces like driveways and lawns. As the water crosses these surfaces, it picks up chemicals and pollutants. This untreated, polluted water then runs directly into a sewer system.

When it rains excessively, a combined sewer system may not be able handle the volume of water, and some of the combined runoff and raw sewage will overflow from the system, discharging directly into the nearest waterbody without being treated. This combined sewer overflow (CSO) is considered point source pollution, and can cause severe damage to human health and the environment.





These images show the difference between a combined sewer overflow system found in many older cities, and a sewer system where sanitary and stormwater are completely separated. During heavy rains combined sewer overflow systems mix raw sewage with rainwater runoff and discharge it directly into the nearest waterbody without treatment. Photo: Washington DC Water and Sewer Authority.

Unregulated discharges from point sources can result in water pollution and unsafe drinking water, and can restrict activities like fishing and swimming. Some of the chemicals discharged by point sources are harmless, but others are toxic to people and wildlife. Whether a discharged chemical is harmful to the aquatic environment depends on a number of factors, including the type of chemical, its concentration, the timing of its release, weather conditions, and the organisms living in the area.

To control point source discharges, the Clean Water Act established the National Pollutant Discharge Elimination System (NPDES). Under the NPDES program, factories, sewage treatment plants, and other point sources must obtain a permit from the state and EPA before they can discharge their waste or effluents into any body of water. Prior to discharge, the point source must use the latest technologies available to treat its effluents and reduce the level of pollutants. If necessary, a second, more stringent set of controls can be placed on a point source to protect a specific waterbody.

What is the National Environmental Policy Act?

The National Environmental Policy Act (NEPA) was signed into law on January 1, 1970. NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions. The range of actions covered by NEPA is broad and includes:

- making decisions on permit applications,
- adopting federal land management actions, and
- constructing highways and other publicly-owned facilities.

Using the NEPA process, agencies evaluate the environmental and related social and economic effects of their proposed actions. Agencies also provide opportunities for public review and comment on those evaluations.

The National Environmental Policy Act (NEPA) was one of the first laws ever written that establishes the broad national framework for protecting our environment. NEPA's basic policy is to assure that all branches of government give proper consideration to the environment prior to undertaking any major federal action that significantly affects the environment.

NEPA requirements are invoked when airports, buildings, military complexes, highways, parkland purchases, and other federal activities are proposed. Environmental Assessments (EAs) and Environmental Impact Statements (EISs), which are assessments of the likelihood of impacts from alternative courses of action, are required from all Federal agencies and are the most visible NEPA requirements. Source: EPA https://www.epa.gov/nepa/what-national-environmental-policy-act

The Clean Water Act: The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972. Under the Clean Water Act, EPA has implemented pollution control programs such as setting wastewater standards for industry. Furthermore, the EPA has also developed national water quality criteria recommendations for pollutants in surface waters.

Drinking Water:

According to the World Health Organization safe and readily available water is important for public health, whether it is used for drinking, domestic use, food production or recreational purposes. Improved water supply and sanitation, and better management of water resources, can boost countries' economic growth and can contribute greatly to poverty reduction.

In 2010, the UN General Assembly explicitly recognized the human right to water and sanitation. Everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use.

Sustainable Development Goal target 6.1 calls for universal and equitable access to safe and affordable drinking water. The target is tracked with the indicator of "safely managed drinking water services" – drinking water from an improved water source that is located on premises, available when needed, and free from fecal and priority chemical contamination.

In 2020, 5.8 billion people used safely managed drinking-water services – that is, they used improved water sources located on premises, available when needed, and free from contamination. The remaining 2 billion people without safely managed services in 2020 included:

- 1.2 billion people with *basic* services, meaning an improved water source located within a round trip of 30 minutes;
- 282 million people with *limited* services, or an improved water source requiring more than 30 minutes to collect water;
- 368 million people taking water from unprotected wells and springs; and
- 122 million people collecting untreated surface water from lakes, ponds, rivers and streams.

Contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio. Absent, inadequate, or inappropriately managed water and sanitation services expose individuals to preventable health risks. This is particularly the case in health care facilities where both patients and staff are placed at additional risk of infection and disease when water, sanitation and hygiene services are lacking. Globally, 15% of patients develop an infection during a hospital stay, with the proportion much greater in low-income countries.

Inadequate management of urban, industrial and agricultural wastewater means the drinking-water of hundreds of millions of people is dangerously contaminated or chemically polluted. Natural presence of chemicals, particularly in groundwater, can also be of health significance, including arsenic and fluoride, while other chemicals, such as lead, may be elevated in drinking-water as a result of leaching from water supply components in contact with drinking-water.

Some 829 000 people are estimated to die each year from diarrhoea as a result of unsafe drinking-water, sanitation and hand hygiene. Yet diarrhoea is largely preventable, and the deaths of 297 000 children aged under 5 years could be avoided each year if these risk factors were addressed. Where water is not readily available, people may decide handwashing is not a priority, thereby adding to the likelihood of diarrhoea and other diseases.

Diarrhoea is the most widely known disease linked to contaminated food and water but there are other hazards. In 2017, over 220 million people required preventative treatment for schistosomiasis – an acute and chronic disease caused by parasitic worms contracted through exposure to infested water.

In many parts of the world, insects that live or breed in water carry and transmit diseases such as dengue fever. Some of these insects, known as vectors, breed in clean, rather than dirty water, and household drinking water containers can serve as breeding grounds. The simple intervention of covering water storage containers can reduce vector breeding and may also reduce fecal contamination of water at the household level (WHO https://www.who.int/news-room/fact-sheets/detail/drinking-water)

In October of 2022 was the 50th anniversary of the Clean Water Act, which was passed by Congress on October 18, 1972—establishing a nationwide approach to improving the quality of our nation's lakes, rivers, streams, and other water bodies. Over the last 50 years, the health of our waters has improved, but threats to water safety remain.

The CWA requires the Environmental Protection Agency (EPA)—along with states, tribes, and territories—to monitor the quality of U.S. lakes, rivers, streams, estuaries, and other water bodies. EPA and states are also required to list water bodies that are impaired by pollutants and to plan for cleaning them up. Yet, EPA's most recent report (from 2017) says that only about half of U.S. waters have been assessed to date, meaning that quality of the other half has not been assessed and their status is unknown.

Ensuring safe drinking water

Under the Safe Drinking Water Act (SDWA), EPA establishes legally enforceable standards that limit the levels of specific contaminants in drinking water. EPA identifies unregulated contaminants, monitors them, and determines whether to regulate them based on things like how dangerous they are to public health, and how often they occur. The agency has issued standards for around 90 contaminants to date.

However, EPA could more efficiently collect data on unregulated contaminants in order to determine whether they need to be regulated. Additionally, public water systems must comply with monitoring, reporting, and other requirements established by EPA and responsible states. But the data that states reported to EPA did not always reflect the frequency of health-based and monitoring violations by community water systems or the status of enforcement actions.

Most Recent Map of Impaired Waters (As of 2015)

Map showing impaired water bodies in the U.S. as of 2015

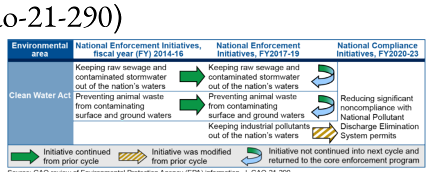
Contaminated water: Both the Clean Water Act and the Safe Drinking Water Act defines the term "contaminant" as meaning any physical, chemical, biological, or radiological substance or matter in water. Therefore, the law defines "contaminant" very broadly as being anything other than water molecules. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. Some drinking water contaminants may be harmful if consumed at certain levels in drinking water while others may be harmless. The presence of contaminants does not necessarily indicate that the water poses a health risk.

Limited monitoring makes it difficult to detect and warn of harmful substances in water bodies. For example, we recently reported that limited monitoring for harmful algal blooms (HABs) in fresh water, may hamper efforts to identify the risks blooms could pose to human health and aquatic life. Harmful algal blooms, or HABs, occur when colonies of algae — simple plants that live in the sea and freshwater — grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. The human illnesses caused by HABs, though rare, can be debilitating or even fatal. All 50 states have experienced harmful algal blooms and, according to federal agencies, may experience more blooms in the future with climate change and warming waters.

Imagery of the Western Lake Erie harmful algal bloom from September 26, 2017. The scum shown here near downtown Toledo stretched all the way to Lake Ontario. This photo is from Landsat-8 (a NASA/USGS satellite Source: https://oceanservice.noaa.gov/facts/hab-solutions.html

Since 2015, the Environmental Protection Agency (EPA) has modified one of its three national initiatives emphasizing compliance with the Clean Water Act and has discontinued two others (see fig below). The goal of the modified initiative is to reduce significant noncompliance with National Pollutant Discharge Elimination System (NPDES) permits by half by the end of fiscal year 2022. Such permits set limits on discharges of wastewater from point sources, such as a pipe from an industrial facility. This goal supports EPA's strategic objective to increase compliance with environmental laws in its strategic plan for fiscal years 2018-2022. EPA discontinued its initiatives focused on animal waste pollution and raw sewage and stormwater runoff, returning these areas to the core enforcement program in 2018 and 2019, respectively. As a result, these areas no longer receive the heightened attention and focused resources of the national initiatives, but the agency still pursues enforcement actions when needed.

Changes in EPA's Clean Water Act National Initiatives(Source: https://www.gao.gov/products/gao-21-290)



One key program under the CWA established requirements for regulating and limiting point sources of pollution—pollution that is discharged into waters from sources such as pipes from industrial facilities and wastewater treatment plants.

This type of pollution is allowed, but requires permits. Permit holders must self-report discharges and noncompliance with water quality requirements. In 2021, the U.S. Government Accountability Office (GAO) found that EPA lacks reliable information needed to ensure polluters are complying with their permits. We also recommended steps to improve that will help EPA identify and reduce illegal discharges.

While point source pollution is an important issue, the leading cause of water pollution is nonpoint sources. These sources come from runoff that carries sediment, oil, bacteria, toxins, and other pollutants from farms, yards, and paved areas (e.g., streets and parking lots) into nearby waters. Such pollution can harm fish and other aquatic life, lead to the development of harmful algal blooms, and contribute to ocean acidification in coastal waters, an emerging threat to marine life on which was previously by the GAO.

Illustration showing the types of water pollution from run off.

The graphic above shows examples of how pollutants from both point sources and nonpoint sources enter our waters

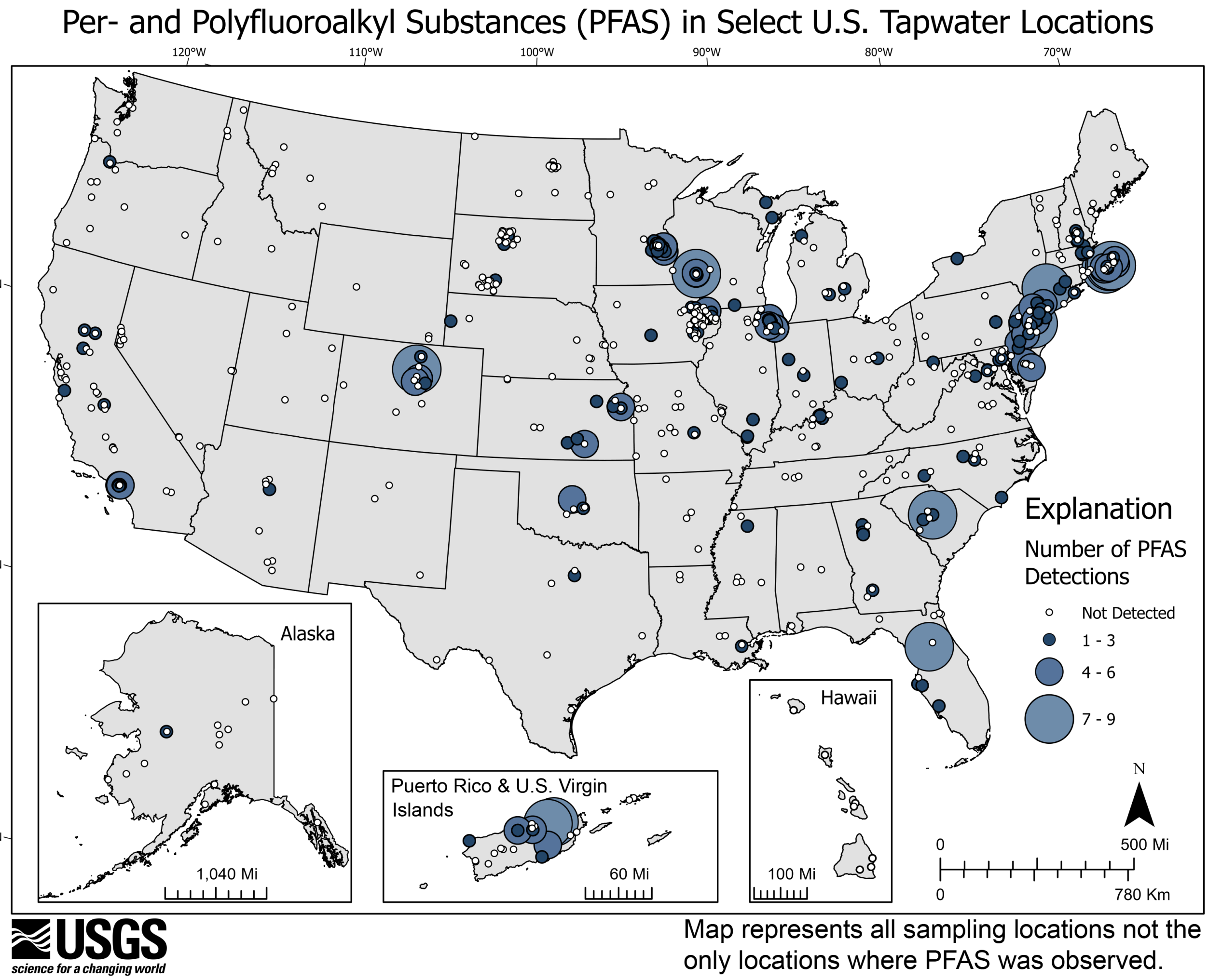
What are the emerging threats to our waters?

Recently, the discovery of widespread pollution of rivers, lakes, and groundwater by persistent chemicals called PFAS, has raised concerns about the risks to human health. PFAS are commonly used in consumer goods, such as nonstick pans, food packaging, and carpeting. They are considered "forever" chemicals because they don't break down in the environment and can accumulate in our bodies. In 2021, the GAO reported on EPA's attention to PFAS, including its efforts to identify and control industrial sources of them. In April 2022, EPA announced actions to protect communities and the environment from PFAS. These measures include using the Act's permitting authorities to reduce PFAS discharges, obtaining monitoring information on PFAS sources and quantities, and using the data for EPA decisions about restricting releases of PFAS by industrial facilities and others.

At least 45% of the nation's tap water is estimated to have one or more types of the chemicals known as per- and polyfluorinated alkyl substances, or PFAS, according to a new study by the U.S. Geological Survey. There are more than 12,000 types of PFAS, not all of which can be detected with current tests; the USGS study tested for the presence of 32 types.

PFAS are a group of synthetic chemicals used in a wide variety of common applications, from the linings of fast-food boxes and non-stick cookware to fire-fighting foams and other purposes. High concentrations of some PFAS may lead to adverse health risks in people, according to the U.S. Environmental Protection Agency. Research is still ongoing to better understand the potential health effects of PFAS exposure over long periods of time. Because they break down very slowly, PFAS are commonly called "forever chemicals." Their persistence in the environment and prevalence across the country make them a unique water-quality concern. The study tested for 32 individual PFAS compounds using a method developed by the USGS National Water Quality Laboratory. The most frequently detected compounds in this study were PFBS, PFHxS and PFOA.

The interim health advisories released by the EPA in 2022 for PFOS and PFOA were exceeded in every sample in which they were detected in this study.



This USGS map shows the number of PFAS detected in tap water samples from select sites across the nation. The findings are based on a USGS study of samples taken between 2016 and 2021 from private and public supplies at 716 locations. The map does not represent the only locations in the U.S. with PFAS. Sources/Usage Public Domain. USGS Image. https://www.usgs.gov/media/images/pfas-select-us-tapwater-locations. https://www.usgs.gov/news/national-news-release/tap-water-study-detects-pfas-forever-chemicals-across-us

Where do we go from here?

Before the passage of the Clean Water Act, large numbers of our nation's lakes, rivers, and streams, were polluted with raw sewage, industrial chemicals, and dangerous metals. For example, in Washington, D.C., the Potomac River was so polluted with sewage that the smell across parts of the National Mall was nearly unbearable. The Cuyahoga River in Ohio was so polluted with oil and debris that it used to catch on fire!

Cuyahoga River Fire

Original Caption: Firemen stand on a bridge over the Cuyahoga River to spray water on the tug Arizona, as a fire, started in an oil slick on the river, sweeps the docks at the Great Lakes Towing Company site in Cleveland Nov., 1st. The blaze destroyed three tugs, three buildings, and the ship repair yards. Bettmann / Contributor via Getty Images (https://www.smithsonianmag.com/history/cuyahoga-river-caught-fire-least-dozen-times-no-one-cared-until-1969-180972444/)

The Cuyahoga's Comeback Source; https://www.americanrivers.org/cuyahoga50/index.html

While the sources of pollution that created such situations have largely been addressed, threats from more dispersed sources—such as stormwater runoff that carries pollutants into our waters—will require further actions. Emerging threats resulting from a changing climate also need to be addressed. The key to tackling these threats will require using the tools provided by the Clean Water Act. But more action may be needed to strengthen the Act and help it meet the goals established half a century ago.

Lead in Drinking Water U.S. Government Accountability Office (GAO) https://www.gao.gov/water-quality-and-protection

Additionally, the Lead and Copper Rule requires water systems to test for lead and treat water to help prevent corroded pipes from leaching lead. The 68,000 water systems serving the majority of U.S. residents are subject to this rule, and must test in high-risk areas near lead pipes. However, many lead pipe locations are unknown. EPA should collect data on lead pipes to improve its oversight of the rule. Lead in school drinking water is also of concern because it is a daily source of water for over 50 million children. EPA and the Department of Education should promote lead testing and improve guidance for school districts and in child care settings.

Under the SDWA, EPA is also charged with protecting underground sources of drinking water from contamination. It does so through the Underground Injection Control (UIC) program, which regulates the injection of wastewater into underground wells. However, EPA has not collected specific inspection or complete and consistent enforcement information or consistently conducted oversight activities to assess whether state and EPA-managed UIC programs for oil and gas wastewater disposal wells are protecting underground sources of drinking water.

How Oil and Gas Wells Can Contaminate Underground Drinking Water

How Oil and Gas Wells Can Contaminate Underground Drinking Water. Source: https://www.gao.gov/water-quality-and-protection

Figure 3: Typical Responsibilities of Key Stakeholders in Implementing the Lead and Copper Rule

	Entity responsible:			
	EPA	State	Water system	Homeowner
Standards and guidance:				
Set and revise Lead and Copper Rule (LCR) standards	✓	–	–	–
Provide guidance, training, and technical assistance to water sytems	✓	✓	–	–
Provide infrastructure funding	✓	✓	–	–
LCR requirements:				
(1) Identify lead service lines and other materials and (2) develop sample site plan	–	–	✓	–
Collect drinking water samples at the tap	–	–	✓ [a]	✓ [a]
Report drinking water sample data to state	–	–	✓	–
Report drinking water sample data to Environmental Protection Agency (EPA)	–	✓	–	–
Notify homeowners of sample results	–	–	✓	–
Install or maintain corrosion control treatment	–	–	✓	–
Sample and treat source water	–	–	✓	–
Conduct water quality parameter samples	–	–	✓	–
Review and approve water systems' activities as provided in the LCR	–	✓	–	–
Provide public education materials to consumers	–	–	✓	–
Replace lead service lines	–	–	✓ [b]	✓ [b]
Enforcement:				
Initiate enforcement actions for noncompliance	✓	✓	–	–
Take enforcement action	✓	✓	–	–

Source: GAO analysis of the Lead and Copper Rule and Environmental Protection Agency documents. | GAO-17-424

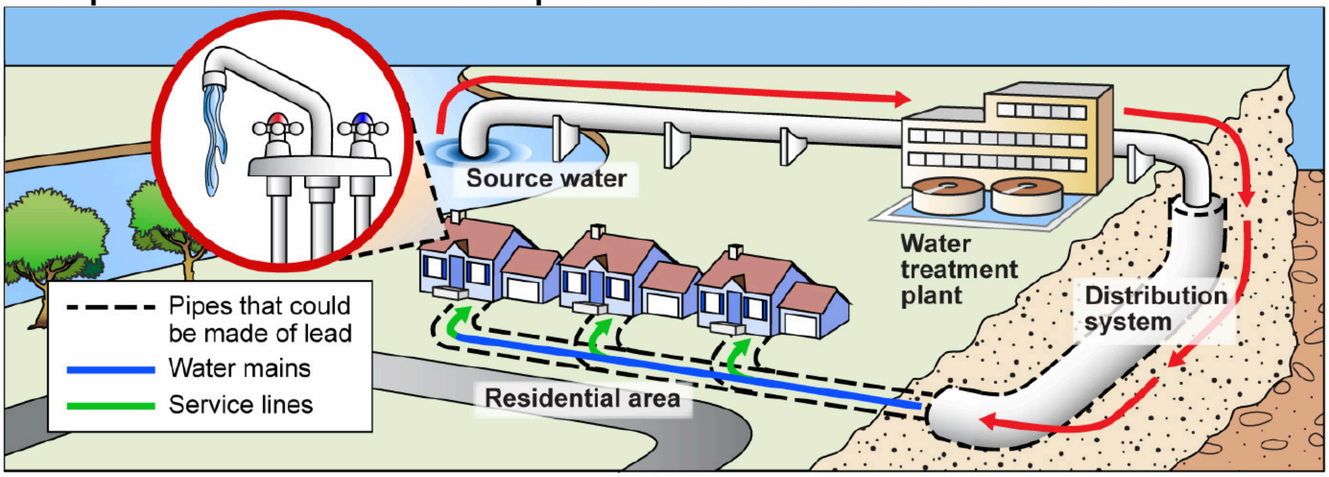
[a] The water system may collect the samples or may allow residents to collect the samples after instructing the residents of the procedures for collecting samples.

[b] The LCR only requires water systems to replace lead service lines that they own. The LCR does not require homeowners to replace their portion of lead service lines, but if they choose to do so they are generally responsible for the associated costs.

Source: U.S. Government Accountability Office https://www.gao.gov/blog/2018/03/22/bottoms-up-to-clean-drinking-water

Although the rule requires water systems to test in high-risk homes and buildings with lead pipes, the locations of many lead pipes are unknown.

Example of Potential Lead in the Pipe Infrastructure from Source to Homes



Source: GAO. | GAO-17-424

Lead in public schools drinking water

Children attending K-12 public schools may also be at risk of lead exposure from drinking water. Lead in school drinking water is a concern because it is a daily source of water for more than 50 million children enrolled in public schools. Similar to child care centers, the pattern of schools' schedules—including time off during weekends, holidays, and extended breaks—can contribute to standing water in the schools' plumbing systems, possibly allowing lead to leach into the water.

The GAO found that an estimated 41% of school districts—serving 12 million students—had not tested school water for lead in 2016 or 2017. Similarly, another 16% of school districts didn't know whether they had tested for lead at all. Of the school districts that did test for lead (43% of those we surveyed—representing some 35 million students), about 37% found elevated lead levels in their water. The figure below shows the estimated percent of school districts testing and those that found elevated lead levels.

Estimated Percentage of Public School Districts Reporting Lead Testing and Results for Drinking Water

There are no federal laws requiring lead testing of drinking water in schools that receive water from public water systems, even though these systems are regulated by the EPA. According to the EPA, at least 8 states had requirements for schools to test for lead in water, and an additional 13 states supported school districts' voluntary efforts with funding or in-kind support for tests and remediation.

As of the GAO report in 2018, the EPA has taken a variety of actions, such as communicating the importance of testing for lead in school drinking water and collaborating with the Department of Education. In 2019 and 2020, EPA awarded grants authorized by the Water Infrastructure Improvements for the Nation Act to states and the District of Columbia to help with voluntary testing in schools and child care facilities (Source; https://www.gao.gov/blog/protecting-children-lead-exposure-schools-and-child-care-facilities)

Summary:

Water, air, and food are the most important natural resources to people. Humans can live only a few minutes without oxygen, about a week without water, and about a month without food. Water also is essential for our oxygen and food supply. Plants, which require water to survive, provide oxygen through photosynthesis and form the base of our food supply. Plants grow in soil, which forms by weathering reactions between water and rock.

Water is the only substance that occurs naturally on Earth in three forms: solid, liquid and gas. Shallow groundwater is the largest reservoirs of fresh water however, it is not easily located. Although rivers and lakes are the most heavily used water resources, they represent only a tiny amount of the world's water. The water cycle shows the movement of water through different reservoirs, which include oceans, atmosphere, glaciers, groundwater, lakes, rivers, and biosphere. Solar energy and gravity drive the motion of water in the water cycle. Precipitation is a major control of fresh water availability, and it is unevenly distributed around the globe. Flowing water from rain and melted snow on land enters river channels by surface runoff and groundwater seepage.

Lakes can also be an excellent source of fresh water for human use. They usually receive water from surface runoff and groundwater discharge. The Great Lakes hold 21% of the world's surface fresh water. Although glaciers represent the largest reservoir of fresh water, they generally are not used as a water source because they are located too far from most people. If Earth's climate continues to warm, the melting glaciers will cause an additional rise in sea level.

An Earth material that is capable of supplying groundwater from a well at a useful rate—i.e., it has relatively high permeability and medium to high porosity—is called an aquifer. A spring is a water resource formed when the side of a hill, a valley bottom or other excavation intersects groundwater at or below the local water table, below which the subsurface material is saturated with water. Groundwater and surface water (rivers, lakes, swamps, and reservoirs) are strongly interrelated because both are part of the same overall resource. Major groundwater removal (from pumping or drought) can lower the levels of surface water and vice versa. People need water to produce the food, energy, and mineral resources they use—commonly large amounts of it.

The water demand of an area is a function of the population and other uses of water. The water crisis refers to a global situation where people in many areas lack access to sufficient water or clean water or both. More than 2.2 billion people globally lack access to safely managed drinking water (United Nations, 2019), while millions of people in the United States are without clean, reliable water, lack basic plumbing, or rely on water systems with Safe Drinking Water Act violations. Today, the Human Right to Water is formally recognized by the United Nations, the State of California, and dozens of global businesses. Yet, the United States as a whole has yet to recognize the Human Right to Water or meet the United Nations Sustainable Development Goals for clean water and sanitation (SDG 6), climate action (SDG 13), or reduced inequalities (SDG 10)

Water pollution is the contamination of water sources by substances which make the water unusable for drinking, cooking, cleaning, swimming, and other activities. Pollutants include chemicals, trash, bacteria, and parasites. Non-point pollution (NPS) generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. The term "point source" means any discernible, confined and discrete conveyance. When it rains excessively, a combined sewer system may not be able handle the volume of water, and some of the combined runoff and raw sewage will overflow from the system, discharging directly into the nearest waterbody without being treated. Under the Safe Drinking Water Act (SDWA), EPA establishes legally enforceable standards that limit the levels of specific contaminants in drinking water. At least 45% of the nation's tap water is estimated to have one or more types of the chemicals known as per- and polyfluorinated alkyl substances, or PFAS. Before the passage of the Clean Water Act, large numbers of our nation's lakes, rivers, and streams, were polluted with raw sewage, industrial chemicals, and dangerous metals.

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Water Availability and Use Science Program

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5.

SOLID AND HAZARDOUS WASTE

Managing Growing Waste Generation

An enormous quantity of waste is generated and disposed of annually. Alarmingly, this quantity continues to increase on an annual basis. Industries generate and dispose of over 7.6 billion tons of industrial solid wastes each year, and it is estimated that over 40 million tons of this waste is hazardous. Nuclear wastes, as well as medical wastes, are also increasing in quantity every year.

Generally speaking, developed nations generate more waste than developing nations due to higher consumption rates. Not surprisingly, the United States generates more waste per capita than any other country.

High waste per capita rates are also very common throughout Europe and developed nations in Asia and Oceania. In the United States, about 243 million tons (243 trillion kg) of MSW is generated annually, equal to about 4.3 pounds (1.95 kg) of waste per person per day. Nearly 34 percent of MSW is recovered and recycled or composted, approximately 12 percent is burned in combustion facilities, and the remaining 54 percent is disposed of in landfills. Waste stream percentages also vary widely by region. For example, San Francisco, California, captures and recycles nearly 75 percent of its waste material, whereas Houston, Texas, recycles less than three percent.

Concerning waste mitigation options, landfilling is quickly evolving into a less desirable or feasible option. Landfill capacity in the United States has been declining primarily due to (a) older existing landfills that are increasingly reaching their authorized capacity, (b) the promulgation of stricter environmental regulations has made the permitting and siting of new landfills increasingly difficult, (c) public opposition (e.g., "Not In My Backyard" or **NIMBY**ism) delays or, in many cases, prevent the approval of new landfills or expansion of existing facilities.

Effects of Improper Waste Disposal and Unauthorized Releases

Before the passage of environmental regulations, wastes were disposed of improperly without considering the potential effects on public health and the environment. This practice has led to numerous contaminated sites where soils and groundwater have been contaminated and pose a risk to public safety. Of more than 36,000 environmentally impacted candidate sites, more than 1,400 sites are listed under the Superfund program National Priority List (NPL) that require immediate cleanup resulting from acute, imminent threats to environmental and human health. The USEPA identified about 2,500 additional contaminated sites that eventually require remediation. The United States Department of Defense maintains 19,000 sites, many of which have been extensively contaminated from various uses and disposal practices. Further, approximately 400,000 underground storage tanks have been confirmed or are suspected of leaking, contaminating underlying soils and groundwater. Over $10 billion (more than $25 billion in current dollars) were specifically allocated by CERCLA and subsequent amendments to mitigate impacted sites. However, the USEPA has estimated that the value of environmental remediation exceeds $100 billion. Alarmingly, if past expenditures on NPL sites are extrapolated across remaining and proposed NPL sites, this total may be significantly higher – well into the trillions of dollars.

It is estimated that more than 4,700 facilities in the United States currently treat, store, or dispose of hazardous wastes. About 3,700 facilities that house approximately 64,000 solid waste management units (SWMUs) may require corrective action. Accidental spillage of hazardous wastes and nuclear materials due to anthropogenic operations or natural disasters has also caused enormous environmental damage, as evidenced by the events such as the facility failure in Chornobyl, Ukraine (formerly USSR) in 1986, the effects of Hurricane Katrina that devastated New Orleans, Louisiana in 2005, and the 2011 Tōhoku earthquake and tsunami in Fukushima, Japan.

Adverse Impacts on Public Health

Various chemicals are present within waste materials, many of which pose a significant environmental concern. Though the **leachate** generated from the wastes may contain toxic chemicals, the concentrations and variety of toxic chemicals are quite small compared to hazardous waste sites. For example, explosives and radioactive wastes are primarily located at Department of Energy (DOE) sites because many facilities have historically been used for weapons research, fabrication, testing, and training. Organic contaminants are largely found at oil refineries or petroleum storage sites, and inorganic and pesticide contamination usually results from various industrial and agricultural activities. Yet, soil and groundwater contamination is not the only direct adverse effect of improper waste management activities – recent studies have also shown that greenhouse gas emissions from the wastes are significant, exacerbating global climate change.

A wide range of toxic chemicals, with an equally wide distribution of respective concentrations, is found in waste streams. These compounds may be present in concentrations that alone may threaten human health or have a synergistic/cumulative effect due to the presence of other compounds. Exposure to hazardous wastes has been linked to many types of cancer, chronic illnesses, and abnormal reproductive outcomes such as birth defects, low birth weights, and spontaneous abortions. Many studies have been performed on major toxic chemicals found at hazardous waste sites incorporating epidemiological or animal tests to determine their toxic effects.

As an example, the effects of radioactive materials are classified as **somatic** or **genetic**. The somatic effects may be immediate or occur over a long period of time. Immediate effects from large radiation doses often produce nausea and vomiting and may be followed by severe blood changes, hemorrhage, infection, and death. Delayed effects include leukemia and many types of cancer, including bone, lung, and breast. Genetic effects have been observed in which gene mutations or chromosome abnormalities result in measurable harmful effects, such as decreased life expectancy, increased susceptibility to sickness or disease, infertility, or even death during embryonic stages. Because of these studies, occupational dosage limits have been recommended by the National Council on Radiation Protection. Similar studies have been completed for a wide range of potentially hazardous materials. These studies have, in turn, been used to determine safe exposure levels for numerous exposure scenarios, including those that consider occupational safety and remediation standards for various land use scenarios, including residential, commercial, and industrial land uses.

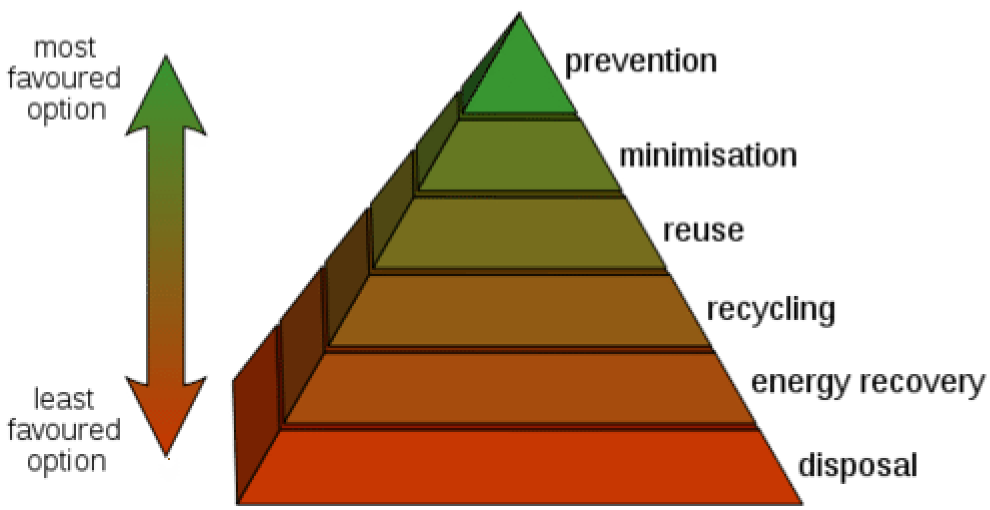
Adverse Impacts on the Environment

The chemicals found in waste pose a threat to human health and have profound effects on entire ecosystems.

Contaminants may change the chemistry of waters and destroy aquatic life and underwater ecosystems dependent upon more complex species. Contaminants may also enter the food chain through plants or microbiological organisms, and higher, more evolved organisms bioaccumulate the wastes through subsequent ingestion. The continued bioaccumulation results in increased contaminant mass and concentration as the contaminants move farther up the food chain. In many cases, toxic concentrations are reached, resulting in increased mortality of one or more species. As the populations of these species decrease, the natural inter-species balance is affected. With decreased numbers of predators or food sources, other species may be drastically affected, leading to a chain reaction that can affect a wide range of flora and fauna within a specific ecosystem. As the ecosystem continues to deviate from equilibrium, disastrous consequences may occur. Examples include the near extinction of the bald eagle due to persistent ingestion of DDT-impacted fish and the depletion of oysters, crabs, and fish in the Chesapeake Bay due to excessive quantities of fertilizers, toxic chemicals, farm manure wastes, and power plant emissions.

Waste Management

The long-recognized hierarchy of management of wastes, in order of preference, consists of prevention, minimization, recycling and **reuse, biological treatment**, incineration, and landfill disposal (see Figure 1 below).



Hierarchy of Waste Management figure shows the hierarchy of management of wastes in order or preference, starting with prevention as the most favorable to disposal as the least favorable option. Source: Drstuey via Wikimedia Commons

Waste Prevention

The ideal waste management alternative is to prevent waste generation in the first place. Hence, **waste prevention** is a basic goal of all waste management strategies. Numerous technologies can be employed throughout the manufacturing, use, or post-use portions of product life cycles to eliminate waste and, in turn, reduce or **prevent pollution**. Some representative strategies include environmentally conscious manufacturing methods that incorporate less hazardous or harmful materials, the use of modern leakage detection systems for material storage, innovative chemical neutralization techniques to reduce reactivity or water-saving technologies that reduce the need for freshwater inputs.

Waste Minimization

In many cases, wastes cannot be outright eliminated from a variety of processes. However, numerous strategies can be implemented to reduce or minimize waste generation. **Waste minimization**, or source reduction, refers to the collective strategies of design and fabrication of products or services that minimize the amount of generated waste and/or reduce the toxicity of the resultant waste. Often these efforts come about from identified trends or specific products that may be causing problems in the waste stream and the subsequent steps taken to halt these problems. In industry, waste can be reduced by reusing materials, using less hazardous substitute materials, or modifying components of design and processing. Many benefits can be realized by waste minimization or source reduction, including reduced use of natural resources and the reduction of toxicity of wastes.

Waste minimization strategies are extremely common in manufacturing applications; the savings of material use preserves resources but also saves significant manufacturing-related costs. Advancements in streamlined packaging reduce material use, and increased distribution efficiency reduces fuel consumption and resulting air emissions. Further, engineered building materials can often be designed with specific favorable properties that, when accounted for in an overall structural design, can greatly reduce the overall mass and weight of material needed for a given structure. This reduces the need for excess material and reduces the waste associated with component fabrication.

The dry cleaning industry provides an excellent example of product substitution to reduce toxic waste generation. For decades, dry cleaners used tetrachloroethylene, or “perc” as a dry cleaning solvent. Although effective, tetrachloroethylene is a relatively toxic compound. Additionally, it is easily introduced into the environment, where it is highly recalcitrant due to its physical properties. Further, when its degradation occurs, the intermediate daughter products generated are more toxic to human health and the environment.

Because of its toxicity and impact on the environment, the dry cleaning industry has adopted new practices and increasingly utilizes less toxic replacement products, including petroleum-based compounds. Further, new emerging technologies are incorporating carbon dioxide and other relatively harmless compounds. While these substitute products have in many cases been mandated by government regulation, they have also been adopted in response to consumer demands and other market-based forces.

Recycling and Reuse

Recycling refers to the recovery of useful materials such as glass, paper, plastics, wood, and metals from the waste stream so they may be incorporated into the fabrication of new products. With the greater incorporation of recycled materials, the required use of raw materials for identical applications is reduced. Recycling reduces the need for natural resource exploitation for raw materials, but it also allows waste materials to be recovered and utilized as valuable resource materials. Recycling of wastes directly conserves natural resources, reduces energy consumption and emissions generated by the extraction of virgin materials and their subsequent manufacture into finished products, reduces overall energy consumption and greenhouse gas emissions that contribute to global climate change, and reduces the incineration or landfilling of the materials that have been recycled. Moreover, recycling creates several economic benefits, including the potential to create job markets and drive growth.

Commonly recycled materials include paper, plastics, glass, aluminum, steel, and wood. Additionally, many construction materials can be reused, including concrete, asphalt materials, masonry, and reinforcing steel. "Green" plant-based wastes are often recovered and immediately reused for mulch or fertilizer applications. Many industries also recover various by-products and/or refine and "re-generate" solvents for reuse. Examples include copper and nickel recovery from metal finishing processes; the recovery of oils, fats, and plasticizers by solvent extraction from filter media such as activated carbon and clays; and acid recovery by spray roasting, ion exchange, or crystallization. Further, a range of used food-based oils are being recovered and utilized in "biodiesel" applications.

Numerous examples of successful recycling and reuse efforts are encountered every day. In some cases, recycled materials are used as input materials and are heavily processed into end products. Common examples include the use of scrap paper for new paper manufacturing or the processing of old aluminum cans into new aluminum products. In other cases, reclaimed materials undergo little or no processing prior to their re-use.

Some common examples include the use of tree waste as wood chips or the use of brick and other fixtures in new structural construction. In any case, the success of recycling depends on the effective collection and processing of recyclables, markets for reuse (e.g. manufacturing and/or applications that utilize recycled materials), and public acceptance and promotion of recycled products and applications utilizing recycled materials.

Biological Treatment

Landfill disposal of wastes containing significant organic fractions is increasingly discouraged in many countries, including the United States. Such disposal practices are even prohibited in several European countries. Since landfilling does not provide an attractive management option, other techniques have been identified. One option is to treat waste so that biodegradable materials are degraded and the remaining inorganic waste fraction (known as residuals) can be subsequently disposed of or used for a beneficial purpose.

Biodegradation of wastes can be accomplished by using **aerobic** composting, a**naerobic digestion**, or **mechanical biological treatment** (MBT) methods. If the organic fraction can be separated from inorganic material, aerobic composting or anaerobic digestion can be used to degrade the waste and convert it into usable **compost**. For example, organic wastes such as food waste, yard waste, and animal manure that consist of naturally degrading bacteria can be converted under controlled conditions into compost, which can then be utilized as a natural fertilizer. Aerobic composting is accomplished by placing selected proportions of organic waste into piles, rows, or vessels, either in open conditions or within closed buildings fitted with gas collection and treatment systems. During the process, bulking agents such as wood chips are added to the waste material to enhance the aerobic degradation of organic materials. Finally, the material is allowed to stabilize and mature during a curing process where pathogens are concurrently destroyed. The end products of the composting process include carbon dioxide, water, and usable compost material.

Compost material may be used in a variety of applications. In addition to its use as a soil amendment for plant cultivation, compost can be used remediate soils, groundwater, and storm water. Composting can be labor-intensive, and the quality of the compost is heavily dependent on proper control of the composting process. Inadequate control of the operating conditions can result in compost that is unsuitable for beneficial applications. Nevertheless, composting is becoming increasingly popular; composting diverted 82 million tons of waste material away from the landfill waste stream in 2009, increasing from 15 million tons in 1980. This diversion also prevented the release of approximately 178 million metric tons of carbon dioxide in 2009 – an amount equivalent to the yearly carbon dioxide emissions of 33 million automobiles.

In some cases, aerobic processes are not feasible. As an alternative, anaerobic processes may be utilized. Anaerobic digestion consists of degrading mixed or sorted organic wastes in vessels under anaerobic conditions. The anaerobic degradation process produces a combination of methane and carbon dioxide (biogas) and residuals (biosolids). Biogas can be used for heating and electricity production, while residuals can be used as fertilizers and soil amendments. Anaerobic digestion is a preferred degradation for wet wastes as compared to the preference of composting for dry wastes. The advantage of anaerobic digestion is biogas collection; this collection and subsequent beneficial utilization make it a preferred alternative to landfill disposal of wastes. Also, waste is degraded faster through anaerobic digestion as compared to landfill disposal.

Another waste treatment alternative, mechanical biological treatment (MBT), is not common in the United States. However, this alternative is widely used in Europe. During the implementation of this method, waste material is subjected to a combination of mechanical and biological operations that reduce volume through the degradation of organic fractions in the waste. Mechanical operations such as sorting, shredding, and crushing prepare the waste for subsequent biological treatment, consisting of either aerobic composting or anaerobic digestion. Following the biological processes, the reduced waste mass may be subjected to incineration.

Incineration

Waste degradation not only produces useful solid end-products (such as compost), but degradation by-products can also be used as a beneficial energy source. As discussed above, anaerobic digestion of waste can generate biogas, which can be captured and incorporated into electricity generation. Alternatively, waste can be directly incinerated to produce energy. Incineration consists of waste combustion at very high temperatures to produce electrical energy. The byproduct of incineration is ash, which requires proper characterization prior to disposal, or in some cases, beneficial re-use. It is widely used in developed countries due to landfill space limitations. It is estimated that about 130 million tons of waste are annually combusted in more than 600 plants in 35 countries. Further, incineration is often used to effectively mitigate hazardous wastes such as chlorinated hydrocarbons, oils, solvents, medical wastes, and pesticides.

Pros of Incinerators	**Cons of Incinerators**
The incinerated waste is turned into energy	The fly ash (airborne particles) has high levels of toxic chemicals, including dioxin, cadmium, and lead.
The volume of waste is reduced.	The initial construction costs are high.

Despite the advantages, incineration is often viewed negatively because of high initial construction costs, and emissions of ash, which is toxic (see Table above). Currently, many 'next generation" systems are being researched and developed, and the USEPA is developing new regulations to carefully monitor incinerator air emissions under the Clean Air Act.

Landfill Disposal

Despite advances in reuse and recycling, landfill disposal remains the primary waste disposal method in the United States. As previously mentioned, the rate of MSW generation continues to increase, but overall landfill capacity is decreasing. New regulations concerning proper waste disposal and the use of innovative liner systems to minimize the potential of groundwater contamination from leachate infiltration and migration have resulted in a substantial increase in the costs of landfill disposal. Also, public opposition to landfills continues to grow, partially inspired by memories of historic uncontrolled dumping practices and the resulting undesirable side effects of uncontrolled vectors, contaminated groundwater, unmitigated odors, and subsequent diminished property values.

Landfills can be designed and permitted to accept hazardous wastes in accordance with RCRA Subtitle C regulations, or they may be designed and permitted to accept municipal solid waste in accordance with RCRA Subtitle D regulations. Regardless of their waste designation, landfills are engineered structures consisting of bottom and side liner systems, leachate collection and removal systems, final cover systems, gas collection and removal systems, and groundwater monitoring systems. An extensive permitting process is required for siting, designing, and operating landfills. Post-closure monitoring of landfills is also typically required for at least 30 years. Because of their design, wastes within landfills are degraded anaerobically. During degradation, biogas is produced and collected. The collection systems prevent uncontrolled subsurface gas migration and reduce the potential for explosive conditions. The captured gas is often used in cogeneration facilities for heating or electricity generation. Further, upon closure, many landfills undergo "land recycling" and are redeveloped as golf courses, recreational parks, and other beneficial uses. Wastes commonly exist in dry conditions within landfills, and as a result, the rate of waste degradation is commonly very slow. These slow degradation rates are coupled with slow rates of degradation-induced settlement, which can in turn complicate or reduce the potential for beneficial land re-use at the surface. Recently, the concept of bioreactor landfills has emerged, which involves the recirculation of leachate and/or injection of selected liquids to increase the moisture in the waste, which in turn induces rapid degradation. The increased rates of degradation increase the rate of biogas production, which increases the potential of beneficial energy production from biogas capture and utilization.

Regulatory Framework in the United States

During the course of the 20th century, especially following World War II, the United States experienced unprecedented economic growth. Much of the growth was fueled by rapid and increasingly complex industrialization. With advances in manufacturing and chemical applications also came increases in the volume and, in many cases, the toxicity of generated wastes. Furthermore, few, if any, controls or regulations were in place concerning the handling of toxic materials or the disposal of waste products. The continued industrial activity led to several high-profile examples of detrimental environmental consequences resulting from these uncontrolled activities. Finally, several forms of intervention, both in the form of government regulation and citizen action, occurred in the early 1970s. Ultimately, several regulations were promulgated on the state and federal levels to ensure the safety of public health and the environment. For waste materials, the Resource Conservation and Recovery Act (RCRA), enacted by the United States Congress in 1976 and amended in 1984, provides a comprehensive framework for properly managing hazardous and non-hazardous solid wastes in the United States. RCRA stipulates broad and general legal objectives while mandating the United States Environmental Protection Agency (USEPA)to develop specific regulations to implement and enforce the law. States and local governments can either adopt the federal regulations or they may develop and enforce more stringent regulations than those specified in RCRA. Similar regulations have been developed or are being developed worldwide to manage waste similarly in other countries.

The broad goals of RCRA include (1) the protection of public health and the environment from the hazards of waste disposal; (2) the conservation of energy and natural resources; (3) the reduction or elimination of waste; and (4) the assurance that wastes are managed in an environmentally-sound manner (e.g., the remediation of waste which may have spilled, leaked, or been improperly disposed of). It should be noted here that the RCRA focuses only on active and future facilities and does not address abandoned or historical sites.

These types of environmentally impacted sites are managed under a different regulatory framework, known as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, more commonly known as "Superfund."

Solid Waste Regulations

RCRA defines solid waste as any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities. In general, solid waste can be categorized as either **non-hazardous waste** or **hazardous waste**.

Non-hazardous solid waste can be trash or garbage generated from residential households, offices, and other sources. Generally, these materials are classified as **municipal solid waste**(MSW). Alternatively, industrial solid waste is collectively known as non-hazardous materials that result from producing goods and products by various industries (e.g., coal combustion residues, mining wastes, cement kiln dust). Because they are classified as non-hazardous materials, many municipal solid and industrial waste components have potential for recycling and reuse. Significant efforts are underway by both government agencies and industry to advance these objectives.

Hazardous waste generated by many industries and businesses (e.g., dry cleaners and auto repair shops) is constituted of materials that are dangerous or potentially harmful to human health and the environment. The EPA classifies waste as hazardous if it exhibits at least one of these four characteristics:

- **Ignitability** refers to the creation of fires under certain conditions, including spontaneously combustible materials or those with a flash point less than 140 F.
- **Corrosivity** refers to the capability to corrode metal containers, including materials with a pH less than or equal to 2 or greater than or equal to 12.5.
- **Reactivity** refers to materials susceptible to unstable conditions such as explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water under normal conditions.
- **Toxicity** is substances that can induce harmful or fatal effects when ingested, absorbed, or inhaled.

As required by RCRA, the EPA established a cradle-to-grave hazardous material management system in an attempt to track hazardous material or waste from its point of generation to its ultimate point of disposal, where the generators of hazardous materials have to attach a "manifest" form to their hazardous materials shipments. The management of hazardous wastes including the transport, treatment, storage and disposal of hazardous wastes is regulated under the RCRA. For hazardous wastes disposal, this procedure will result in the shipment and arrival of those wastes at a permitted disposal site. The RCRA also promotes the concept of resource recovery to decrease the generation of waste materials.

Hazardous waste management facilities receiving hazardous wastes for treatment, storage or disposal are referred to as treatment, storage and disposal facilities (TSDFs). The EPA closely regulates the TSDFs so that they operate properly for protection of human health and the environment. TSDFs may be owned and operated by independent companies that receive wastes from a number of waste generators, or by the generators of waste themselves. TSDFs include landfills, incinerators, impoundments, holding tanks, and many other treatment units designed for safe and efficient management of hazardous waste. The EPA closely regulates the construction and operation of these TSDFs, where the operators of TSDFs must obtain a permit from the EPA delineating the procedures for the operation of these facilities. The operators must also provide insurance and adequate financial backing. The shipping of wastes to a TSDF or recycler is frequently less expensive than obtaining and meeting all the requirements for a storage permit.

The major amendment to Resource Conservation and Recovery Act was instituted in 1984 as the Hazardous and Solid Waste Amendments (HSWA). The HSWA provides regulation for leaking underground storage tanks (leaking USTs) affecting groundwater pollution. The RCRA regulates USTs containing hazardous wastes. In addition, the HSWA provides for regulation to prevent the contamination of groundwater by hazardous wastes, where the EPA restricts the disposal of hazardous wastes in landfills due to the migration of hazardous constituents from the waste placed in landfills.

Radioactive Hazardous Wastes

Although non-hazardous waste and hazardous waste are regulated by RCRA, nuclear or radioactive waste is regulated under the Atomic Energy Act of 1954 by the Nuclear Regulatory Commission (NRC) in the United States.

Radioactive wastes are characterized according to four categories: (1) **High-level waste** (HLW), (2) **Transuranic waste** (TRU), (3) **Low-level waste** (LLW), and (4) **Mill tailings**. Various radioactive wastes decay at different rates, but health and environmental dangers due to radiation may persist for hundreds or thousands of years.

High-level waste is typically liquid or solid waste resulting from government defense-related activities, nuclear power plants, and spent fuel assemblies. These wastes are extremely dangerous due to their heavy concentrations of radionuclides, and humans must not come into contact with them.

Transuranic waste mainly results from reprocessing spent nuclear fuels and the fabrication of nuclear weapons for defense projects. They are characterized by moderately penetrating radiation and a decay time of approximately twenty years until safe radionuclide levels are achieved. Following the passage of a reprocessing ban in 1977, most of this waste generation ended. Even though the ban was lifted in 1981, Transuranic waste remains rare because reprocessing nuclear fuel is expensive. Further, political and social pressures minimize these activities because the extracted plutonium may be used to manufacture nuclear weapons.

Low-level wastes include much of the remainder of radioactive waste materials. They constitute over 80 percent of the volume of all nuclear wastes but only about two percent of total radioactivity. Low-level waste includes all of the previously cited sources of High-level waste and Transuranic waste, plus wastes generated by hospitals, industrial plants, universities, and commercial laboratories. Low-level waste is much less dangerous than High-level waste, and NRC regulations allow some very low-level wastes to be released into the environment. Low-level wastes may also be stored or buried until the isotopes decay to low enough so they may be disposed of as non-hazardous waste. Low-level waste disposal is managed at the state level, but the USEPA and NRC establish requirements for operation and disposal. The Occupational Health and Safety Administration (OSHA) is responsible for setting the standards for workers exposed to radioactive materials.

International Regulatory Framework

The 1992 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal first came into force in 1992. The Convention puts an onus on exporting countries to ensure that hazardous wastes are managed in an environmentally sound manner in the country of import. The Basel Convention places obligations on countries that are party to the Convention. 151 Countries have ratified the Basel Convention as of December 2002. These have obligations to:

- Minimize generations of hazardous waste;
- Ensure adequate disposal facilities are available;
- Control and reduce international movements of hazardous waste;
- Ensure environmentally sound management of waste; and
- Prevent and punish illegal traffic.

The 1995 Waigani Convention

The Basel Convention establishes a global control system for shipping hazardous waste from one country to another. States that are Parties to the Convention must not trade hazardous wastes with non-Parties. Still, an exception to this is provided for in Article 11 of the Convention, whereby Parties may enter into agreements or arrangements with other Parties or non-Parties.

These agreements or arrangements can also set out controls different from those prescribed by the Convention itself, provided such controls do not reduce the level of environmental protection intended by the Convention.

The **Waigani Conventio**n is to ban the importation of hazardous and radioactive wastes into Forum Island Countries and to control the transboundary movement and management of hazardous wastes within the South Pacific Region. This agreement was enforced in October 2001. The Convention also enables Australia to receive hazardous wastes exported from South Pacific Forum Island countries that are not Parties to the Basel Convention. There are 24 countries within the coverage area of the Waigani Convention. As of December 2002, ten parties had ratified the Waigani Convention. These were Australia, the Cook Islands, the Federated States of Micronesia, Kiribati, New Zealand, Papua New Guinea, Samoa, Solomon Islands, Tuvalu, and Vanuatu.

Electronic Waste

Electronic waste, commonly known as e-waste, refers to discarded electronic products such as televisions, computers and computer peripherals (e.g., monitors, keyboards, disk drives, and printers), telephones and cellular phones, audio and video equipment, video cameras, fax and copy machines, video game consoles, and others (see Figure 1 below).

Electronic Waste Photograph shows many computers piled up in a parking lot as waste. Source: Bluedisk via Wikimedia Commons

In the United States, it is estimated that about 3 million tons of e-waste are generated each year. This waste quantity includes approximately 27 million units of televisions, 205 million units of computer products, and

140 million units of cell phones. Less than 15 to 20 percent of the e-waste is recycled or refurbished; the remaining percentage is commonly disposed of in landfills and/or incinerated. It should be noted that e-waste constitutes less than 4 percent of total solid waste generated in the United States. However, with tremendous growth in technological advancements in the electronics industry, many electronic products are becoming obsolete quickly, thus increasing the production of e-waste very rapidly. The quantities of e-waste generated are also increasing rapidly in other countries, such as India and China, due to the high demand for computers and cell phones.

In addition to the growing quantity of e-waste, the hazardous content of e-waste is a major environmental concern. It poses risks to the environment if these wastes are improperly managed once they have reached the end of their useful life. Many e-waste components contain toxic substances, including heavy metals such as lead, copper, zinc, cadmium, and mercury, and organic contaminants, such as flame retardants (polybrominated biphenyls and polybrominated diphenyl ethers). Releasing these substances into the environment and subsequent human exposure can lead to serious health and pollution issues. Concerns have also been raised regarding releasing toxic constituents of e-waste into the environment if landfilling and/or incineration options are used to manage the e-waste.

Various regulatory and voluntary programs have been instituted to promote the reuse, recycling, and safe disposal of bulk e-waste. Reuse and refurbishing has been promoted to reduce raw material use, energy consumption, and water consumption associated with manufacturing new products. Recycling and recovering elements such as lead, copper, gold, silver, and platinum can yield valuable resources that may cause pollution if improperly released into the environment. The recycling and recovery operations have to be conducted with extreme care, as the exposure of e-waste components can result in adverse health impacts on the workers performing these operations. For economic reasons, recycled e-waste is often exported to other countries for recovery operations. However, lax regulatory environments in many of these countries can lead to unsafe practices or improper disposal of bulk residual e-waste, adversely affecting vulnerable populations.

There are no specific federal laws dealing with e-waste in the United States, but many states have recently developed e-waste regulations that promote environmentally sound management. For example, California passed the Electronic Waste Recycling Act in 2003 to foster recycling, reuse, and environmentally sound disposal of residual bulk e-waste. Yet, despite recent regulations and advances in reuse, recycling, and proper disposal practices, additional sustainable strategies to manage e-waste are urgently needed.

One sustainable strategy used to manage e-waste is extended producer responsibility (EPR), also known as product stewardship. This concept holds manufacturers liable for the entire life-cycle costs associated with the electronic products, including disposal costs, and encourages the use of environmental-friendly manufacturing processes and products. Manufacturers can pursue EPR in multiple ways, including reuse/refurbishing, buy-back recycling, and energy production or beneficial reuse applications. Life-cycle assessment and cost methodologies may be used to compare the environmental impacts of these different waste management options. Incentives or financial support are also provided by some government and/or regulatory agencies to promote EPR. Using non-toxic and easily recyclable materials in product fabrication is a major component of any EPR strategy. A growing number of companies (e.g., Dell, Sony, HP) are embracing EPR with various initiatives toward achieving sustainable e-waste management.

EPR is a preferred strategy because the manufacturer bears financial and legal responsibility for their products; hence, they are incentivized to incorporate green design and manufacturing practices that incorporate easily recyclable and less toxic material components while producing electronics with longer product lives. One obvious disadvantage of EPR is the higher manufacturing cost, which leads to increased costs of electronics to consumers.

There is no specific federal law requiring EPR for electronics. Still, the United States Environmental Protection Agency (USEPA) undertook several initiatives to promote EPR to achieve the following goals: (1) foster environmentally conscious design and manufacturing, (2) increase purchasing and use of more environmentally sustainable electronics, and (3) increase safe, environmentally sound reuse and recycling of used electronics. To achieve these goals, USEPA has been engaged in various activities, including the promotion of environmental considerations in product design, the development of evaluation tools for environmental attributes of electronic products, the encouragement of recycling (or ecycling), and the support of programs to reduce e-waste, among others. More than 20 states in the United States and various organizations worldwide have already developed laws and/or policies requiring EPR in some form when dealing with electronic products. For instance, the New York State Wireless Recycling Act emphasizes that authorized retailers and service providers should be compelled to participate in take-back programs, thus allowing increased recycling and reuse of e-waste. Similarly, Maine is the first U.S. state to adopt a household e-waste law with EPR.

In Illinois, Electronic Products Recycling & Reuse Act requires electronic manufacturers to participate in managing discarded and unwanted electronic products from residences. The Illinois EPA has also compiled e-waste collection site locations where the residents can give away their discarded electronic products at no charge. Furthermore, USEPA compiled a list of local programs and manufacturers/retailers that can help consumers properly donate or recycle e-waste.

On January 9, 2017, Governor Christie of New Jersey signed legislation that revised certain requirements of the State's electronic waste management program under the "Electronic Waste Management Act " (https://www.nj.gov/dep/dshw/ewaste/legislation.html). New Jersey consumers and small businesses with fewer than 50 full-time employees, can recycle for free at the approved manufacturers collection sites. All computers, monitors, laptops, portable computers, desktop printers, desktop fax machines and televisions are accepted for free recycling. Each manufacturer must ensure to the New Jersey Department of Environmental Protection (NJDEP) that electronic devices are recycled in a manner that is in compliance with all applicable federal, state and local laws, regulations and ordinances. Manufacturers must also ensure that these devices are not exported for disposal in a manner that poses a risk to the public health or the environment.

Overall, the growing quantities and environmental hazards associated with electronic waste are of major concern to waste management professionals worldwide. Current management strategies, including recycling and refurbishing, have not been successful. As a result, EPR regulations are rapidly evolving worldwide to promote sustainable e-waste management. However, neither a consistent framework nor assessment tools to evaluate EPR have been fully developed.

Marine Debris

What is Marine Debris?

Our oceans are filled with items that do not belong there. Huge amounts of plastics, metals, rubber, paper, textiles, derelict fishing gear, derelict vessels, and other lost or discarded items enter the marine environment every day. This makes marine debris one of the most widespread pollution problems facing the world's ocean and waterways.

Marine debris is defined as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes. Anything human-made and solid can become marine debris once lost or littered in these aquatic environments. Our trash has been found in every corner of our ocean, from the most remote shorelines, to ice in the Arctic, and even the deepest parts of the sea floor.

Some of the most common and harmful types of marine debris include plastic, such as cigarette butts, plastic bags, and food wrappers, and derelict fishing gear. Marine debris can also range greatly in size from the smallest plastic pieces, called microplastics, that can be too small to be seen with the human eye, to huge abandoned and derelict vessels, construction debris, and household appliances that can damage sensitive habitats. Although some of these items may eventually break down, others are made to last a long time. Once they are in the environment, these items may never fully go away.

It's most important to remember that marine debris is preventable. This global problem is caused by people, and we can also be the solution. The NOAA Marine Debris Program funds projects across the United States and territories that remove marine debris from shorelines, research the issue to better understand the problem, and prevent it from entering the ocean in the first place.

You can make a difference too! Learn how you can help take on marine debris, no matter where you are.

How much marine debris is in the ocean and Great Lakes?

Marine debris is a large and global problem, and it can be very difficult to say how much enters the ocean and Great Lakes. Once marine debris is in the ocean, it can be challenging to understand where it came from, where it goes, or how much is there.

A study by Borrelle et al.(link is external) estimated that in 2016, as much as 23 million metric tons of plastic waste entered aquatic ecosystems from land around the world. This number may feel huge, but it's not the whole picture. It doesn't include marine debris items not made of plastic, or ocean-based marine debris, such as lost fishing gear and vessels.

If you think about an overflowing sink, the first step before cleaning up the water is to turn the faucet off. By preventing plastic marine debris, we can turn the faucet off and keep this problem from growing. The NOAA Marine Debris Program supports projects that prevent marine debris from ever entering our ocean and waterways through outreach and education efforts that raise awareness of the issue and change behaviors related to common marine debris items.

There is not a 'one-size fits all' solution to the problem, and cleaning up marine debris is also important. The NOAA Marine Debris Program also supports community-based marine debris removal projects across the United States. From local shoreline cleanups to vessel removals, these projects benefit coastal habitats, waterways, and wildlife. Since 2006, the NOAA Marine Debris Program has supported over 160 marine debris removal projects and removed more than 22,500 metric tons of marine debris from our coasts and ocean.

Plastic

Bottle caps removed from the shorelines of Midway Atoll (Kuaihelani, Pihemanu) in the largely uninhabited Papahānaumokuākea Marine National Monument (Photo: NOAA).

Plastic items are the most common type of marine debris in our ocean, waterways, and Great Lakes. Plastic is used to create items that are part of our everyday lives, including toys, food storage, and even medical supplies. Plastic marine debris can also include larger items, such as lost or discarded fishing gear or large sheets of plastic used in agriculture.

Plastic can enter the marine environment in a variety of ways, including limited resources for disposing of trash, improper trash collection, littering, or through stormwater runoff. Once in the environment, plastics don't break down the way natural materials do and may never fully go away, which is why preventing these items from entering our waters in the first place is especially important.

Why is plastic marine debris a problem?

Plastic is durable and designed to last for a long time. This can be really useful and serve important purposes, such as for medical devices that keep many people safe and healthy. However, the durability of plastic is also one of the traits that makes it so damaging as marine debris.

Plastic doesn't degrade or break down like other materials do. Instead, as plastic is exposed to the sun, salt water, and movement from waves, it can fragment and break up into smaller and smaller pieces, called microplastics. Because of their small size, these tiny plastic pieces are extremely difficult to remove, and may never fully go away.

Plastic marine debris is also a problem because of how common this material is in our lives. If you look around you, chances are you'll notice plastic in the items around you, from your clothing or jewelry, to the glasses you're reading with, the pen you're writing with, or the materials keeping your lunch fresh. Unfortunately, many plastics are single-use items and are specifically designed to be used only once before being thrown away or recycled. During the Ocean Conservancy's(link is external) 2018 International Coastal Cleanup, all ten of the top items found around the world were single-use plastic items, including cigarette butts, food wrappers, straws, single-use cutlery, beverage bottles, bottle caps, grocery bags and other plastic bags, lids, and cups and plates.

Summary

Many wastes, such as high-level radioactive wastes, will remain dangerous for thousands of years, and even MSW can produce dangerous leachate that could devastate an entire ecosystem if allowed to infiltrate into and migrate within groundwater. Environmental professionals must deal with problems associated with increased generation of waste materials to protect human health and the environment. The solution must focus on reducing the sources of waste and the safe disposal of waste. It is, therefore, extremely important to know the waste's sources, classifications, chemical compositions, and physical characteristics and understand the strategies for managing them. Waste management practices vary not only from country to country but also based on the type and composition of waste. Regardless of the geographical setting of the type of waste that needs to be managed, resource conservation is the governing principle in developing any waste management plan. Natural resource and energy conservation are achieved by managing materials more efficiently. Reduction, reuse, and recycling are primary strategies for effectively reducing waste quantities. Further, proper waste management decisions have increasing importance, as the consequences of these decisions have broader implications concerning greenhouse gas emissions and global climate change. As a result, several public and private partnership programs are under development with the goal of reducing waste by adopting new and innovative waste management technologies. Because waste is an inevitable by-product of civilization, successfully implementing these initiatives will directly affect societies' enhanced quality of life worldwide.

Resources – Links

Plastic Marine Debris Fact Sheet
Plastics in the Ocean Infographic
Report: Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean
Fighting for Trash Free Seas
Clean Ocean Action Reducing Sources of Litter in the Ocean

Attributes

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Sustainability – A Comprehensive Foundation (Cabezas) is shared under a CC BY license and was authored, remixed, and/or curated by Heriberto Cabezas (GALILEO Open Learning Materials) .

Plastic Waste Legislation. NJ S2776 https://www.billtrack50.com/BillDetail/988016

NOAA Marine Debris Program. Plastic. https://marinedebris.noaa.gov/what-marine-debris/plastic

NOAA What are microplastics. https://oceanservice.noaa.gov/facts/microplastics.html.

e-Waste Regulations in NJ. https://www.nj.gov/dep/dshw/ewaste/index

6. ENVIRONMENTAL TOXINS: WHAT ARE YOU EXPOSED TO!

Types of environmental hazards:

Environmental health is defined as the assessment of environmental factors that influence human health and quality of life, and steps taken to avoid environmental hazards or minimize its effects. There are 4 major types of environmental hazards:

1. Physical e.g. Earthquakes, volcanoes, fires, floods, droughts, lightning, hurricanes, landslides,
2. Chemical synthetic (man-made) (e.g. pesticides, disinfectants, pharmaceuticals) or natural chemicals (e.g. venom from cobras, urushiol in poison ivy)
3. Biological e.g. bacterial infections from E. coli, parasites like malaria, viruses like the flu
4. Cultural lifestyle based e.g. smoking, diet and nutrition, activity level

Environmental Toxicology

Environmental toxicology is the scientific study of the health effects associated with exposure to **toxic chemicals** and systems occurring in the natural, work, and living environments; the management of environmental toxins and toxicity; and the development of protections for humans, animals, and plants (Table below).

The table below lists top 20 substances, in order of priority, which are determined to pose the most significant potential threat to human health.This priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at various sites.

Table 8.3.1″>8.3.1 8.3.1 **: The ATSDR 2013 Substance Priority List**

2013 RANK	NAME
1	ARSENIC
2	LEAD
3	MERCURY
4	VINYL CHLORIDE
5	POLYCHLORINATED BIPHENYLS
6	BENZENE
7	CADMIUM
8	BENZO(A)PYRENE
9	POLYCYCLIC AROMATIC HYDROCARBONS
10	BENZO(B)FLUORANTHENE
11	CHLOROFORM
12	AROCLOR 1260
13	DDT, P,P'-
14	AROCLOR 1254
15	DIBENZO(A,H)ANTHRACENE
16	TRICHLOROETHYLENE
17	CHROMIUM, HEXAVALENT
18	DIELDRIN
19	PHOSPHORUS, WHITE
20	HEXACHLOROBUTADIENE

Routes of Exposure to Chemicals

In order to cause health problems, chemicals must enter your body. There are three main "routes of exposure," or ways a chemical can get into your body.

- Breathing (inhalation): Breathing in chemical gases, mists, or dusts that are in the air.
- Skin or eye contact: Getting chemicals on the skin, or in the eyes. They can damage the skin, or be absorbed through the skin into the bloodstream.
- Swallowing (ingestion): This can happen when chemicals have spilled or settled onto food, beverages, cigarettes, beards, or hands.

Once chemicals have entered your body, some can move into your bloodstream and reach internal "target" organs, such as the lungs, liver, kidneys, or nervous system.

What Forms do Chemicals Take?

Chemical substances can take a variety of forms. They can be in the form of solids, liquids, dusts, vapors, gases, fibers, mists and fumes. The form a substance is in has a lot to do with how it gets into your body and what harm it can cause. A chemical can also change forms. For example, liquid solvents can evaporate and give off vapors that you can inhale. Sometimes chemicals are in a form that can't be seen or smelled, so they can't be detected.

Detecting some forms of chemicals can be difficult. Solids and liquids are easier to recognize since they can be seen. Dusts and mists may or may not be visible, depending upon their size and concentration. Fumes, vapors, and gases are usually invisible.

What Health Effects Can Chemicals Cause?

An **acute effect** of a contaminant (The term "contaminant" means hazardous substances, pollutants, pollution, and chemicals) is one that occurs rapidly after exposure to a large amount of that substance. A chronic effect of a contaminant results from exposure to small amounts of a substance over a long period of time. In such a case, the effect may not be immediately obvious. **Chronic effect** are difficult to measure, as the effects may not be seen for years. Long-term exposure to cigarette smoking, low level radiation exposure, and moderate alcohol use are all thought to produce chronic effects.

For centuries, scientists have known that just about any substance is toxic in sufficient quantities. For example, small amounts of selenium are required by living organisms for proper functioning, but large amounts may cause cancer. The effect of a certain chemical on an individual depends on the dose (amount) of the chemical. This relationship is often illustrated by a dose-response curve which shows the relationship between dose and the response of the individual. **Lethal doses** in humans have been determined for many substances from information gathered from records of homicides and accidental poisonings.

Much of the dose-response information also comes from animal testing. Mice, rats, monkeys, hamsters, pigeons, and guinea pigs are commonly used for dose-response testing. A population of laboratory animals is exposed to measured doses under controlled conditions and the effects noted and analyzed. Animal testing poses numerous problems, however. For instance, the tests may be painful to animals, and unrelated species can react differently to the same toxin. In addition, the many differences between test animals and humans makes extrapolating test results to humans very difficult. A dose that is lethal to 50 percent of a population of test animals is called the **lethal dose-50 percent** or **LD-50**. Determination of the LD-50 is required for new synthetic chemicals in order to give a measure of their toxicity. A dose that causes 50 percent of a population to exhibit any significant response (e.g., hair loss, stunted development) is referred to as the effective dose-50 percent or ED-50. Some toxins have a threshold amount below which there is no apparent effect on the exposed population.

Some scientists believe that all toxins should be kept at a zero-level threshold because their effects at low levels are not well known. That is because of the synergy effect in which one substance exacerbates the effects of another. For example, if cigarette smoking increases lung cancer rates 20 times and occupational asbestos exposure also increases lung cancer rates 20 times, then smoking and working in an asbestos plant may increase lung cancer rates up to 400 times.

Environmental Contaminants

The contamination of the air, water, or soil with potentially harmful substances can affect any person or community. Contaminants (Table below) are often chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources. Sometimes harmful environmental contaminants occur biologically, such as mold or a toxic algae bloom.

Table 8.3.2″>8.3.2 8.3.2 **: Classification of Environmental Contaminants**

Contaminant	Definition
Carcinogen	An agent which may produce cancer (uncontrolled cell growth), either by itself or in conjunction with another substance. Examples include formaldehyde, asbestos, radon, vinyl chloride, and tobacco.
Suspect Carcinogen	An agent which is suspected of being a carcinogen based on chemical structure, animal research studies, or mutagenicity studies.
Confirmed Animal Carcinogen with Unknown Relevance to Humans	An agent that is carcinogenic in experimental animals at a relatively high dose, by routes of administration, at sites, or histologic types, or by mechanisms that may not be relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.
Teratogen	A substance which can cause physical defects in a developing embryo. Examples include alcohol and cigarette smoke.
Mutagen	A material that induces genetic changes (mutations) in the DNA. Examples include radioactive substances, x-rays and ultraviolet radiation.
Neurotoxicant	A substance that can cause an adverse effect on the chemistry, structure or function of the nervous system. Examples include lead and mercury.
Endocrine disruptor	A chemical that may interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological, and immune effects in both humans and wildlife. A wide range of substances, both natural and man-made, are thought to cause endocrine disruption, including pharmaceuticals, dioxin and dioxin-like compounds, arsenic, polychlorinated biphenyls (PCBs), DDT and other pesticides, and plasticizers such as bisphenol A (BPA). Endocrine disruptors may be found in many everyday products– including plastic bottles, metal food cans, detergents, flame retardants, food, toys, cosmetics, and pesticides. Research shows that endocrine disruptors may pose the greatest risk during prenatal and early postnatal development when organ and neural systems are forming.

The following are some environmental contaminants that can affect a community or an individual's health.

Arsenic is a naturally occurring element that is normally present throughout our environment in water, soil, dust, air, and food. Levels of arsenic can vary from place to place due to farming and industrial activity as well as natural geological processes. The arsenic from farming and smelting tends to bind strongly to soil and is expected to remain near the surface of the land for hundreds of years as a long-term source of exposure. Wood that has been treated with chromated copper arsenate (CCA) is commonly found in decks and railing in existing homes and outdoor structures such as playground equipment. Some underground aquifers are located in rock or soil that has naturally high arsenic content.

Most arsenic gets into the body through ingestion of food or water. Arsenic in drinking water is a problem in many countries around the world, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the

United States. Arsenic may also be found in foods, including rice and some fish, where it is present due to uptake from soil and water. It can also enter the body by breathing dust containing arsenic, or through the skin, though this is not a major route of exposure. Researchers are finding that arsenic, even at low levels, can interfere with the body's endocrine system. In several cell culture and animal models, arsenic has been found to act as an endocrine disruptor, which may underlie many of its health effects. Arsenic is also a known human carcinogen associated with skin, lung, bladder, kidney, and liver cancer.

Polychlorinated biphenyls, commonly called PCBs, are mixtures of up to 209 chlorinated compounds that do not occur naturally. They have no taste or smell. *PCBs are persistent organic pollutants (POPs) and endocrine disruptors*. The manufacture of PCBs was stopped in the U.S. in 1977 because of evidence they build up in the environment and can cause harmful health effects. But, before 1977, PCBs were used as insulation, as plasticizers, and in surface coatings, sealants, fire retardants, glues, inks, pesticides, and carbonless copy paper. *PCBs don't break down easily in the environment and may remain there for very long periods of time*. Studies indicate that PCBs are associated with certain kinds of cancer in humans. Women who were exposed to relatively high levels of PCBs in the workplace or ate large amounts of fish contaminated with PCBs had babies that weighed slightly less than babies from women who did not have these exposures.

Per- and Polyfluoroalkyl Substances (PFAS)

Per- and polyfluoroalkyl substances (PFAS) are a diverse group of thousands of chemicals used in hundreds of types of products. PFAS in the environment can enter the food supply through plants and animals grown, raised, or processed in contaminated areas. It is also possible for very small amounts of PFAS to enter foods through food packaging, processing, and cookware. And most recently, PFAS have been detected in most of the U.S. water supply (see chapter Water: Necessary for Life).

However, A recent investigation by the Food and Drug Administration found toxic per- and poly-fluoroalkyl substances, or PFAS, in food, including meat, seafood and dairy products; sweet potatoes; pineapples; leafy greens, and chocolate cake with icing. Exposure to PFAS chemicals is associated with serious health risks, including cancer, reproductive harm, developmental harm, high cholesterol, damage to the immune system, hormone disruption, and liver and kidney damage. (ewg)

Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS), for example, are two of the most widely used and studied chemicals in the PFAS group. PFOA and PFOS have been replaced in the United States with other PFAS in recent years. One common characteristic of concern of PFAS is that many break down very slowly and can build up in people, animals, and the environment over time.

PFAS can be present in our water, soil, air, and food as well as in materials found in our homes or workplaces, including:

- **Drinking water** – in public drinking water systems and private drinking water wells.
- **Soil and water at or near waste sites** – at landfills, disposal sites, and hazardous waste sites such as those that fall under the federal Superfund and Resource Conservation and Recovery Act programs.

- **Fire extinguishing foam** – in aqueous film-forming foams (or AFFFs) used to extinguish flammable liquid-based fires. Such foams are used in training and emergency response events at airports, shipyards, military bases, firefighting training facilities, chemical plants, and refineries.
- **Manufacturing or chemical production facilities that produce or use PFAS** – for example at chrome plating, electronics, and certain textile and paper manufacturers.
- **Food** – for example in fish caught from water contaminated by PFAS and dairy products from livestock exposed to PFAS.
- **Food packaging** – for example in grease-resistant paper, fast food containers/wrappers, microwave popcorn bags, pizza boxes, and candy wrappers.
- **Household products and dust** – for example in stain and water-repellent used on carpets, upholstery, clothing, and other fabrics; cleaning products; non-stick cookware; paints, varnishes, and sealants.
- **Personal care products** – for example in certain shampoo, dental floss, and cosmetics.
- **Biosolids** – for example fertilizer from wastewater treatment plants that is used on agricultural lands can affect ground and surface water and animals that graze on the land.

Due to their widespread production and use, as well as their ability to move and persist in the environment, surveys conducted by the Centers for Disease Control and Prevention (CDC) show that most people in the United States have been exposed to some PFAS. Most known exposures are relatively low, but some can be high, particularly when people are exposed to a concentrated source over long periods of time. Some PFAS chemicals can accumulate in the body over time.

Current research has shown that people can be exposed to PFAS by:

- Working in occupations such as firefighting or chemicals manufacturing and processing.
- Drinking water contaminated with PFAS.
- Eating certain foods that may contain PFAS, including fish.
- Swallowing contaminated soil or dust.
- Breathing air containing PFAS.
- Using products made with PFAS or that are packaged in materials containing PFAS.

Current scientific research suggests that exposure to certain PFAS may lead to adverse health outcomes. However, research is still ongoing to determine how different levels of exposure to different PFAS can lead to a variety of health effects. Research is also underway to better understand the health effects associated with low levels of exposure to PFAS over long periods of time, especially in children.

What We Know about Health Effects

Current peer-reviewed scientific studies have shown that exposure to certain levels of PFAS may lead to:

- Reproductive effects such as decreased fertility or increased high blood pressure in pregnant women.
- Developmental effects or delays in children, including low birth weight, accelerated puberty, bone variations, or behavioral changes.
- Increased risk of some cancers, including prostate, kidney, and testicular cancers.
- Reduced ability of the body's immune system to fight infections, including reduced vaccine response.
- Interference with the body's natural hormones.
- Increased cholesterol levels and/or risk of obesity.

Scientists at EPA, in other federal agencies, and in academia and industry are continuing to conduct and review the growing body of research about PFAS. However, health effects associated with exposure to PFAS are difficult to specify for many reasons, such as:

- There are thousands of PFAS with potentially varying effects and toxicity levels, yet most studies focus on a limited number of better known PFAS compounds.
- People can be exposed to PFAS in different ways and at different stages of their life.
- The types and uses of PFAS change over time, which makes it challenging to track and assess how exposure to these chemicals occurs and how they will affect human health.

Adults

Some people have higher exposures to PFAS than others because of their occupations or where they live. For example:

- Industrial workers who are involved in making or processing PFAS or PFAS-containing materials, or people who live or recreate near PFAS-producing facilities, may have greater exposure to PFAS.
- Pregnant and lactating women tend to drink more water per pound of body weight than the average person and as a result they may have higher PFAS exposure compared to other people if it is present in their drinking water.

Children

Because children are still developing, they may be more sensitive to the harmful effects of chemicals such as PFAS. They can also be exposed more than adults because:

- Children drink more water, eat more food, and breathe more air per pound of body weight than adults, which can increase their exposure to PFAS.
- Young children crawl on floors and put things in their mouths which leads to a higher risk of exposure

to PFAS in carpets, household dust, toys, and cleaning products.

Breast milk from mothers with PFAS in their blood and formula made with water containing PFAS can expose infants to PFAS, and it may also be possible for children to be exposed in utero during pregnancy. Scientists continue to do research in this area. Based on current science, the benefits of breastfeeding appear to outweigh the risks for infants exposed to PFAS in breast milk. To weigh the risks and benefits of breastfeeding, mothers should contact their doctors.

Mercury is a naturally occurring metal, a useful chemical in some products, and a potential health risk. Mercury exists in several forms – the types people are usually exposed to are methylmercury and elemental mercury. Elemental mercury at room temperature is a shiny, silver-white liquid, which can produce a harmful odorless vapor. Methylmercury, an organic compound, can build up in the bodies of long-living, predatory fish. To keep mercury out of the fish we eat and the air we breathe, it's important to take mercury-containing products to a hazardous waste facility for disposal. Common products sold today that contain small amounts of mercury include fluorescent lights and button-cell batteries.

Although fish and shellfish have many nutritional benefits, consuming large quantities of fish increases a person's exposure to mercury. Pregnant women who eat fish high in mercury on a regular basis run the risk of permanently damaging their developing fetuses. Children born to these mothers may exhibit motor difficulties, sensory problems and cognitive deficits. The poster below (published by the Maine Center for Disease Control & Prevention) identifies the typical (average) amounts of mercury in commonly consumed commercial and sport-caught fish.

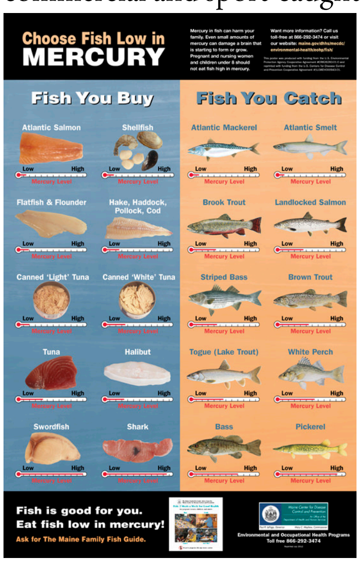

Figure: Mercury in Fish Poster

Bisphenol A (BPA) is a chemical produced in large quantities for use primarily in the production of polycarbonate plastics and epoxy resins. Polycarbonate plastics have many applications including use in some food and drink packaging, e.g., water and infant bottles, compact discs, impact-resistant safety equipment, and medical devices. Epoxy resins are used as lacquers to coat metal products such as food cans, bottle tops, and water supply pipes. Some dental sealants and composites may also contribute to BPA exposure. The primary source of exposure to BPA for most people is through the diet. Bisphenol A can leach into food from the protective internal epoxy resin coatings of canned foods and from consumer products such as polycarbonate tableware, food storage containers, water bottles, and baby bottles. The degree to which BPA leaches from polycarbonate bottles into liquid may depend more on the temperature of the liquid or bottle, than the age of the container. BPA can also be found in breast milk.

What can I do to prevent exposure to BPA?

Some animal studies suggest that infants and children may be the most vulnerable to the effects of BPA. Parents and caregivers, can make the personal choice to reduce exposures of their infants and children to BPA:

- Don't microwave polycarbonate plastic food containers. Polycarbonate is strong and durable, but over time it may break down from over use at high temperatures.
- Plastic containers have recycle codes on the bottom. Some, but not all, plastics that are marked with recycle codes 3 or 7 may be made with BPA.
- Reduce your use of canned foods.
- When possible, opt for glass, porcelain or stainless steel containers, particularly for hot food or liquids.
- Use baby bottles that are BPA free.

Dioxins are a class of chemical contaminants that are formed during combustion processes such as waste incineration, forest fires, and backyard trash burning, as well as during some industrial processes such as paper pulp bleaching and herbicide manufacturing. The highest environmental concentrations of dioxin are usually found in soil and sediment, with much lower levels found in air and water. We are primarily exposed to dioxins by eating food contaminated by these chemicals. Studies have also shown that chemical workers who are exposed to high levels of dioxins have an increased risk of cancer. Other studies of show that dioxins can cause reproductive and developmental problems, and an increased risk of heart disease and diabetes.

Phthalates are a group of chemicals used to soften and increase the flexibility of plastic and vinyl. Polyvinyl chloride is made softer and more flexible by the addition of phthalates. Phthalates are used in hundreds of consumer products. Phthalates are used in cosmetics and personal care products, including perfume, hair spray, soap, shampoo, nail polish, and skin moisturizers. They are used in consumer products such as flexible plastic and vinyl toys, shower curtains, wallpaper, vinyl miniblinds, food packaging, and plastic wrap. Exposure to low levels of phthalates may come from eating food packaged in plastic that contains phthalates or breathing dust in rooms with vinyl miniblinds, wallpaper, or recently installed flooring that contain phthalates. We can be exposed to phthalates by drinking water that contains phthalates. Phthalates are suspected to be endocrine disruptors.

Lead is a metal that occurs naturally in the rocks and soil of the earth's crust. It is also produced from burning fossil fuels such as coal, oil, gasoline, and natural gas; mining; and manufacturing. Lead has no distinctive taste or smell. The chemical symbol for elemental lead is **Pb**. Lead is used to produce batteries, pipes, roofing, scientific electronic equipment, military tracking systems, medical devices, and products to shield X-rays and nuclear radiation. It is used in ceramic glazes and crystal glassware. Because of health concerns, lead and lead compounds were banned from house paint in 1978; from solder used on water pipes in 1986; from gasoline in 1995; from solder used on food cans in 1996; and from tin-coated foil on wine bottles in 1996. The U.S. Food and Drug Administration has set a limit on the amount of lead that can be used in ceramics.

Lead and lead compounds are listed as "reasonably anticipated to be a human carcinogen". It can affect almost every organ and system in your body. It can be equally harmful if breathed or swallowed. The part of the body most sensitive to lead exposure is the central nervous system, especially in children, who are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead can develop brain damage that can cause convulsions and death; the child can also develop blood anemia, kidney damage, colic, and muscle weakness. Repeated low levels of exposure to lead can alter a child's normal mental and physical growth and result in learning or behavioral problems. Exposure to high levels of lead for pregnant women can cause miscarriage, premature births, and smaller babies. Repeated or chronic exposure can cause lead to accumulate in your body, leading to lead poisoning.

Polyvinyl chloride (PVC) is an odorless and solid plastic. It is most commonly white but can also be colorless or amber. It can also come in the form of white powder or pellets. PVC is made from vinyl chloride. PVC is made softer and more flexible by the addition of phthalates. Bisphenol A (BPA) is also used to make PVC plastics. PVC contains high levels of chlorine. PVC is used to make pipes, pipe fittings, pipe conduits, vinyl flooring, and vinyl siding. When softened with phthalates, PVC is used to make some medical devices (including intravenous (IV) bags, blood bags, blood and respiratory tubing) and consumer products (raincoats, toys, shower curtains, furniture, carpet backing, plastic bags and credit cards). Most vinyl chloride produced in the United States is used to make PVC.

Exposure to PVC often includes exposure to phthalates, which are used to soften PVC and may have adverse health effects. Because of PVC's heavy chlorine content, dioxins are released during the manufacturing, burning, or landfilling of PVC. Exposure to dioxins can cause reproductive, developmental, and other health problems, and at least one dioxin is classified as a carcinogen. Dioxins, phthalates, and BPA are suspected to be endocrine disruptors, which are chemicals that may interfere with the production or activity of hormones in the human endocrine system.

Formaldehyde is a colorless, flammable gas or liquid that has a pungent, suffocating odor. It is a volatile organic compound, which is an organic compound that easily becomes a vapor or gas. It is also naturally produced in small, harmless amounts in the human body. The primary way we can be exposed to formaldehyde is by breathing air containing it. Releases of formaldehyde into the air occur from industries using or manufacturing formaldehyde, wood products (such as particle-board, plywood, and furniture), automobile exhaust, cigarette smoke, paints and varnishes, and carpets and permanent press fabrics. Nail polish, and commercially applied floor finish emit formaldehyde.

Figure: Nail products are known to contain toxic chemicals, such as dibutyl phthalate (DBP), toluene, and formaldehyde.

In general, indoor environments consistently have higher concentrations than outdoor environments, because many building materials, consumer products, and fabrics emit formaldehyde. Levels of formaldehyde measured in indoor air range from 0.02–4 parts per million (ppm). Formaldehyde levels in outdoor air range from 0.001 to 0.02 ppm in urban areas.

Radiation

Radiation is energy given off by atoms and is all around us. We are exposed to radiation every day from natural sources like soil, rocks, and the sun. We are also exposed to radiation from man-made sources like medical X-rays and smoke detectors. We're even exposed to low levels of radiation on cross-country flights, from watching television, and even from some construction materials. You cannot see, smell or taste radiation. Some types of radioactive materials are more dangerous than others. So it's important to carefully manage radiation and radioactive substances to protect health and the environment.

Radon is a colorless, odorless radioactive gas. It comes from the natural decay of uranium or thorium found in nearly all soils. It typically moves up through the ground and into the home through cracks in floors, walls and foundations. It can also be released from building materials or from well water. Radon breaks down quickly, giving off radioactive particles. Long-term exposure to these particles can lead to lung cancer. Radon is the leading cause of lung cancer among nonsmokers, according to the U.S. Environmental Protection Agency, and the second leading cause behind smoking.

Risk Assessment and Management

Risk assessment is a scientific process used by federal agencies and risk management decision-makers to make informed decisions about actions that may be taken to protect human health by ascertaining potential human health risks or health hazard associated with exposure to chemicals in the environment. Some of the real-world examples of risk assessment includes: establishment of national ambient air quality and drinking water standards for protection of public health (e.g. ozone, particulate matter in outdoor air; chromium, chloroform or benzene in water); establishment of clean-up levels for hazardous waste site remediation;

development of fish consumption advisories for pregnant women and general population (e.g. PCBs, mercury); assessment of risks and benefits of different alternative fuels for sound energy policy development (e.g. oxygenated gasoline, biodiesel); and estimation of health risks associated with pesticide residues in food. The estimated risk is a function of exposure and toxicity. The regulatory risk assessment follows a four-step paradigm using qualitative and/or quantitative approaches. In quantitative risk assessment using either deterministic or probabilistic approaches, the risk estimates pertaining to an exposure scenario is particularly useful when comparing a number of exposure or risk reduction measures among one another as an optimization protocol to determine the best economically viable option for protection of public health and the environment. The four steps of risk assessment are i) hazard identification; ii) toxicity (or dose-response) assessment; iii) exposure assessment; and iv) risk characterization, which are described below in detail. The emphasis is given in documenting the resources necessary to successfully perform each step.

1. In the hazard identification step, a scientific weight of evidence analysis is performed to determine whether a particular substance or chemical is or is not causally linked to any particular health effect at environmentally relevant concentrations. Hazard identification is performed to determine whether, and to what degree, toxic effects in one setting will occur in other settings. The evidence comes from human but also animal studies.
2. Toxicity or dose-response assessment takes the toxicity data gathered in the hazard identification step from animal studies and exposed human population studies and describes the quantitative relationship between the amount of exposure to a chemical (or dose) and the extent of toxic injury or disease (or response). Generally, as the dose of a chemical increases, the toxic response increases either in the severity of the injury or in the incidence of response in the affected population.
3. The magnitude of exposure is determined by measuring or estimating the amount of an agent to which humans are exposed (i.e. exposure concentration) and the magnitude of dose (or intake) is estimated by taking the magnitude, frequency, duration, and route of exposure into account. Exposure assessments may consider past, present, and future exposures.
4. In the last step, a hazard quotient (HQ) as an indicator of risks associated with health effects other than cancer and excess cancer risk as the incremental probability of an exposed person developing cancer over a lifetime, are calculated by integrating toxicity and exposure information.

The improvement in the scientific quality and validity of health risk estimates depends on advancements in our understanding of human exposure to, and toxic effects associated with, chemicals present in environmental and occupational settings. Risk assessments are important for informed regulatory decision-making in environmental sustainability and to ensure that costs associated with different technological alternatives are scientifically justified and protest public health. Risk assessment helps federal agencies and risk management decision makers arrive at informed decisions about actions to take to protect human health from environmental hazards. Although significant uncertainties remain, this risk assessment methodology has been extensively peer-reviewed, is widely used and understood by the scientific community, and continues to expand and evolve as scientific knowledge advances.

Risk management (Figure below) is distinct from risk assessment, and involves the integration of risk assessment with other considerations, such as economic, social, or legal concerns, to reach regulatory decisions regarding the need for and practicability of implementing various risk reduction activities.

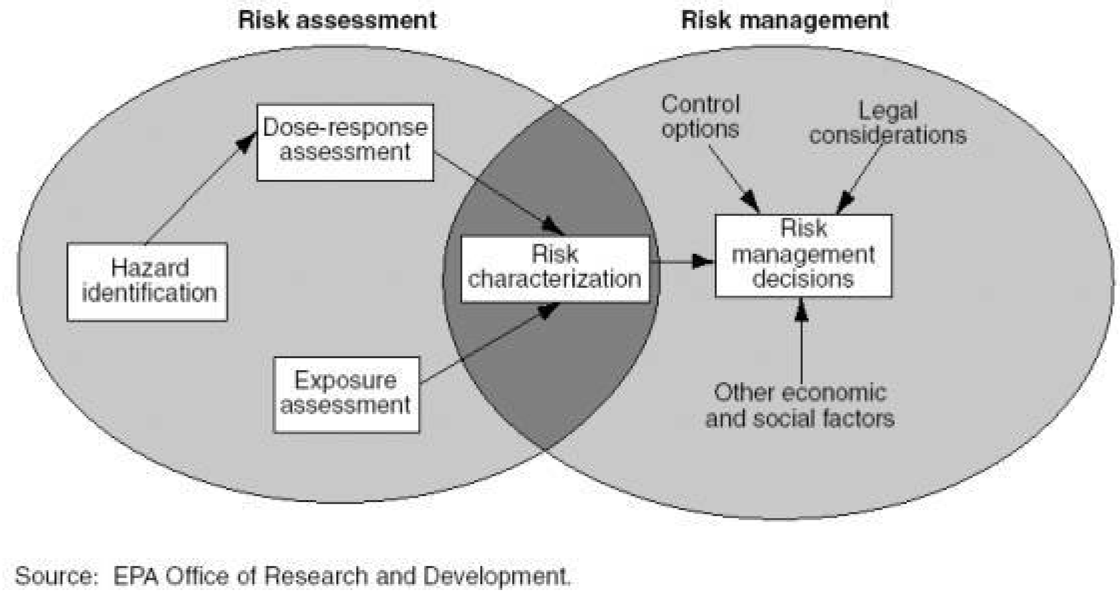

Figure: Risk Assessment and Management

Finally, **risk communication** consists of the formal and informal processes of communication among various parties who are potentially at risk from or are otherwise interested in the threatening agent/action. It matters a great deal how a given risk is communicated and perceived: do we have a measure of control, or are we subject to powerful unengaged or arbitrary forces?

Toxic Substances Control Act (TSCA)

Information on all chemical substances and the control of any of these substances which may have an unreasonable health risk has been granted to the EPA through the Toxic Substances Control Act (1976). The manufacturer or the importer of a new chemical must provide information on the identity and hazard, use, production volume and disposal characteristics of the chemical to the EPA. Toxicological tests and unpublished health and safety studies on listed chemicals may be required by the EPA. The EPA may approve, prohibit, or limit the manufacture and sale of the listed chemicals, or may require special labeling. Since some chemical substances such as pesticides, tobacco products, nuclear materials, pharmaceuticals and cosmetics substances are regulated under other acts, they are exempted from TSCA regulations.

The production and distribution of polychlorinated biphenyls (PCBs) are prohibited through TSCA. PCBs are synthetic organic compounds that were manufactured to be used as electrical transformer oil; exposure to

PCBs increases the risk of cancer, and may affect the reproductive and nervous systems. The EPA enforces the handling and disposal of PCBs based on established regulations on PCBs, in addition to management of PCBs found at hazardous waste sites. After the amendments of 1986 and 1990, TSCA through the Asbestos Hazard Emergency Response Act requires that all public and commercial buildings identify, control and mitigate the asbestos hazard in these buildings.

Furthermore, the TSCA provides EPA with authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics and pesticides.

Section 8 (b) of the Toxic Substances Control Act (TSCA) requires EPA to compile, keep current and publish a list of each chemical substance that is manufactured or processed, including imports, in the United States for uses under TSCA. Also called the "TSCA Inventory" or simply "the Inventory," it plays a central role in the regulation of most industrial chemicals in the United States.

The initial reporting period by manufacturers, processors and importers was January to May of 1978 for chemical substances that had been in commerce since January of 1975. The Inventory was initially published in 1979, and a second version, containing about 62,000 chemical substances, was published in 1982. The TSCA Inventory has continued to grow since then, and now lists more than 86,000 chemicals.

TSCA defines a "chemical substance" as any organic or inorganic substance of a particular molecular identity, including any combination of these substances occurring in whole or in part as a result of a chemical reaction or occurring in nature, and any element or uncombined radical.

Chemicals substances on the Inventory include:

- Organics;
- Inorganics;
- Polymers; and
- Chemical substances of unknown or variable composition, complex reaction products, and biological materials (UVCBs).

Chemical substances not on the Inventory are those with uses not regulated under TSCA. The use of these chemical substances is governed by other U.S. statutes on, for example:

- Pesticides,
- Foods and food additives,
- Drugs,
- Cosmetics,
- Tobacco and tobacco products,
- Nuclear materials, or
- Munitions.

For purposes of regulation under TSCA, if a chemical is on the Inventory, the substance is considered an "existing" chemical substance in U.S. commerce. Any chemical that is not on the Inventory is considered a "new chemical substance."

In addition to defining whether a specific substance is "new" or "existing," the Inventory also contains "flags" for those existing chemical substances that are subject to manufacturing or use restrictions.

Determining if a chemical is on the Inventory is a critical step before beginning to manufacture (which includes importing) a chemical substance. Section 5 of TSCA requires anyone who plans to manufacture a new chemical substance for a non-exempt commercial purpose to provide EPA with a Premanufacture Notice (PMN) at least 90 days before initiating the activity.

TSCA addresses the production, importation, use, and disposal of specific chemicals including polychlorinated biphenyls (PCBs), asbestos, radon and lead-based paint.

https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act

Regulatory and Guidance Information by Topic: Toxic Substances

U.S. Environmental Protection Agency (EPA)

Under a broad range of federal statutes, EPA gathers health, safety and exposure data; requires necessary testing; and controls human and environmental exposures for numerous chemical substances and mixtures. EPA regulates the production and distribution of commercial and industrial chemicals, in order to ensure that chemicals for sale and use in the United States do not harm human health or the environment.

https://www.epa.gov/regulatory-information-topic/regulatory-and-guidance-information-topic-toxic-substances

Food and Drug Administration (FDA)

The FDA helps to safeguard the food supply by evaluating the use of chemicals as food ingredients and substances that come into contact with food, such as through food packaging, storage or other handling to ensure these uses are safe. The FDA also monitors the food supply for chemical contaminants and takes action when we find that the level of a contaminant causes a food to be unsafe.

- Read more from the US Food and Drug administration (FDA) website about Food Chemical Safety – https://www.fda.gov/food/food-ingredients-packaging/food-chemical-safety

REACH Regulation – European Union Law

The REACH Regulation (EC 1907/2006)entered into force in 2007 and has since evolved to reflect the advancement of knowledge regarding various chemicals and their properties.

The Regulation on the registration, evaluation, authorisation and restriction of chemicals (REACH) is the main EU law to protect human health and the environment from the risks that can be posed by chemicals. This is done by better and earlier identification of the intrinsic properties of chemical substances and by taking measures, such as phasing out or restricting substances of very high concern. REACH also aims to enhance innovation and the competitiveness of the EU chemicals industry.

Under REACH, consumers have the right to know whether the products they buy contain harmful chemicals. These substances are found in everyday products, and they have been linked to serious and often irreversible effects on health or the environment.

REACH places responsibility on industry to manage the risks from chemicals and to provide safety information on the substances. To that end, manufacturers and importers are required to gather information on the properties of their chemical substances and to register that information in a central database in the European Chemicals Agency (ECHA). The Agency is the central point in the REACH system: it manages the databases necessary to operate the system, coordinates the in-depth evaluation of the information provided on chemicals and runs a public database where consumers and professionals can find hazard information.

The REACH Regulation aims to:

- ensure a high level of protection of human health and the environment against harmful substances
- assess the safety of chemical substances in use in the EU
- promote innovation and competitiveness
- promote alternative (non-animal) methods for the assessment of the hazards of substances

For more information visit https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en#related–links

Comprehensive Environmental Response, Composition, and Liability Act (CERCLA)

The CERCLA (1980) also known as 'Superfund" aims to provide for liability, compensation and the cleanup of inactive or abandoned hazardous waste disposal sites, and for emergency response to releases of hazardous materials into the environment. CERCLA gives the EPA the power and the funding to clean up abandoned hazardous waste sites and to respond to emergencies related to hazardous waste releases. The Superfund Amendments and Reauthorization Act (SARA) of 1986 solidified many of the provisions of CERCLA such as increasing the authority of the EPA to respond to remediation of hazardous waste sites with a faster startup for cleanup of contaminated sites, and greatly increased the available trust fund for cleanup.

The EPA uses the National Priority List (NPL) to identify contaminated sites that present a risk to public health or the environment and that may be eligible for Superfund money. A numeric ranking system known as the Hazard Ranking System (HRS) has been established to determine the eligibility of contaminated sites for Superfund money, where sites with high HRS scores are most likely to be added to the NPL. The National Contingency Plan (NCP) provides guidance for the initial assessment and the HRS ranking of contaminated sites. After the initial assessment of a contaminated site, a remedial investigation is carried out where the NCP provides for a detailed evaluation of the risks associated with that site. A remedial investigation results in a work plan, which leads to the selection of an appropriate remedy referred to as a feasibility study. The feasibility study assesses several remedial alternatives, resulting in Record of Decision (ROD) as the basis for the design of the selected alternative. The

degree of cleanup is specified by the NCP in accordance with several criteria such as the degree of hazard to the public health and the environment, where the degree of cleanup varies for different contaminated sites.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Insecticides, fungicides and rodenticides are compounds that are employed to control or eliminate pest populations (pesticides). The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1972 with several subsequent amendments set guidelines for the use of pesticides in the United States. All manufacturers or importers must

register their pesticide products with the EPA, where registration is allowed for a pesticide whose application does not have unreasonable adverse effects on the environment. Industries such as the agricultural sector employ pesticides to control vermin and other pests in industrial processes and in the workplace.

Occupational Safety and Health Act (OSHA)

The Occupational Safety and Hazard Act (OSHA) of 1970 and its amendment of 1990 aim to ensure safe and healthful working conditions for workers through enforcement of standards developed under OSHA, and to provide for research, training and education in the field of occupational safety and health. The standards for occupational health and safety are established by the Occupational Safety and Health Administration and its state partners, which are enforced through inspections of industry and providing guidance on better operating practices. The National Institute for Occupational Safety and Health (NIOSH) was established to recommend occupational safety and health standards based on extensive scientific testing, which are afterwards enforced by OSHA. Those industries which have followed OSHA standards have experienced a decline in overall injury and illness rates, where the costs due to worker injuries, illnesses and compensation associated with occupational safety are a major loss for industry. The OSHA standards for worker health and safety are recommended to be used in conjunction with various industrial pollution prevention programs.

Case Study – The Love Canal Disaster

One of the most famous and important examples of groundwater pollution in the U.S. is the Love Canal tragedy in Niagara Falls, New York. It is important because the pollution disaster at Love Canal, along with similar pollution calamities at that time (Times Beach, Missouri and Valley of Drums, Kentucky), helped to create Superfund, a federal program instituted in 1980 and designed to identify and clean up the worst of the hazardous chemical waste sites in the U.S.

Love Canal is a neighborhood in Niagara Falls named after a large ditch (approximately 15 m wide, 3–12 m deep, and 1600 m long) that was dug in the 1890s for hydroelectric power. The ditch was abandoned before it actually generated any power and went mostly unused for decades, except for swimming by local residents. In the 1920s Niagara Falls began dumping urban waste into Love Canal, and in the 1940s the U.S. Army dumped waste from World War II there, including waste from the frantic effort to build a nuclear bomb. Hooker Chemical purchased the land in 1942 and lined it with clay. Then, the company put into Love Canal an estimated 21,000 tons of hazardous chemical waste, including the carcinogens benzene, dioxin, and PCBs in large metal barrels and covered them with more clay. In 1953, Hooker sold the land to the Niagara Falls school board for $1, and included a clause in the sales contract that both described the land use (filled with chemical waste) and absolved them from any future damage claims from the buried waste. The school board promptly built a public school on the site and sold the surrounding land for a housing project that built 200 or so homes along the canal banks and another 1,000 in the neighborhood (see Figure below). During construction, the canal's clay cap and walls were breached, damaging some of the metal barrels.

Figure: Love Canal Source: US Environmental Protection Agency

Eventually, the chemical waste seeped into people's basements, and the metal barrels worked their way to the surface. Trees and gardens began to die; bicycle tires and the rubber soles of children's shoes disintegrated in noxious puddles. From the 1950s to the late 1970s, residents repeatedly complained of strange odors and substances that surfaced in their yards. City officials investigated the area, but did not act to solve the problem. Local residents allegedly experienced major health problems including high rates of miscarriages, birth defects, and chromosome damage, but studies by the New York State Health Department disputed that. Finally, in 1978 President Carter declared a state of emergency at Love Canal, making it the first human-caused environmental problem to be designated that way. The Love Canal incident became a symbol of improperly stored chemical waste. Clean up of Love Canal, which was funded by Superfund and completely finished in 2004, involved removing contaminated soil, installing drainage pipes to capture contaminated groundwater for treatment, and covering it with clay and plastic. In 1995, Occidental Chemical (the modern name for Hooker Chemical) paid $102 million to Superfund for cleanup and $27 million to Federal Emergency Management

Association for the relocation of more than 1,000 families. New York State paid $98 million to EPA and the US government paid $8 million for pollution by the Army. The total clean up cost was estimated to be $275 million.

The Love Canal tragedy helped to create Superfund, which has analyzed tens of thousands of hazardous waste sites in the U.S. and cleaned up hundreds of the worst ones. Nevertheless, over 1,000 major hazardous waste sites with a significant risk to human health or the environment are still in the process of being cleaned.

Biomagnification of Toxins

- Some toxicants can be excreted or metabolized, but fat-soluble toxicants (e.g. heavy metals) are stored in fatty tissues
- Bioaccumulation: toxicants build up in animal tissues
- Biomagnification: toxicants concentrate in top predators
- The result of biomagnifications include:
  - Near extinction of peregrine falcons, bald eagles, and brown pelicans
  - High PCB levels in polar bears
  - Mercury in humans from fish consumption (mercury is released into the environment from various sources e.g. from mines, burning of fossil fuels)
  - Figure on the right shows bioaccumulation of PCBs and mercury
  - PCB or Polychlorinated biphenyls is used in coolants, paints, cements, PVC plastic etc.

Chemicals are an unavoidable part of modern day life for people living in many parts of the world. The problem is that many nations use the innocent until proven guilty principle when it comes to allowing a new chemical to be sold to the public as paints, cosmetics, pesticides, insecticides, plastics, furnishings, electronics etc.

- This means that most of the chemicals we use today have not been tested for toxicity to humans and other living things.
- The threat of lawsuits and scandal will prevent manufacturers from selling chemicals that have immediate toxic effects (acute exposure) (e.g. if you became very ill after painting your house)
- But nothing stops them from selling chemicals that have less obvious long-term toxicity (chronic exposure) because it would be hard to trace this type of toxicity back it its sources. (e.g. if the paint in your house contains lead and it slowly poisons you so that after 20 years you suffer from liver failure, it is not obvious to you that your illness was caused by the paint)
- Therefore it is important to educate ourselves about these environmental hazards and take steps to minimize our exposure and risk.

Summary

Environmental health is concerned with preventing disease, death and disability by reducing exposure to adverse environmental conditions and promoting behavioral change. It focuses on the direct and indirect causes of diseases and injuries, and taps resources inside and outside the health care system to help improve health outcomes. Environmental health risks can be grouped into two broad categories. Traditional hazards related to poverty and lack of development affect developing countries and poor people most. Modern hazards, caused by development that lacks environmental safeguards, such as urban (outdoor) air pollution and exposure to agro-industrial chemicals and waste, prevail in industrialized countries, where exposure to traditional hazards is low. Each year contaminated water and poor sanitation contribute to 5.4 billion cases of diarrhea worldwide and 1.6 million deaths, mostly among children under the age of five. Indoor air pollution—a much less publicized source of poor health—is responsible for more than 1.6 million deaths per year and for 2.7 percent of global burden of disease. Emerging and reemerging diseases have been defined as infectious diseases of humans whose occurrence during the past two decades has substantially increased or threatens to increase in the near future relative to populations affected, geographic distribution, or magnitude of impacts. Antibiotic resistance is a global problem. New forms of antibiotic resistance can cross international boundaries and spread between continents. Environmental toxicology is the scientific study of the health effects associated with exposure to toxic chemicals and systems occurring in the natural, work, and living environments; the management of environmental toxins and toxicity; and the development of protections for humans, animals, and plants. Environmental contaminants are chemicals found in the environment in amounts higher than what would be there naturally. We can be exposed to these contaminants from a variety of residential, commercial, and industrial sources.

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European Commission REACH Regulation. https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en#related–links

References for PFAS

Federal Government Resources

- U.S. Environmental Protection Agency (EPA)
- Agency for Toxic Substances and Disease Registry (ATSDR)
- National Institutes of Health (NIH)
- Food and Drug Administration (FDA)
- United States Department of Defense (DOD)
- United States Navy
- United States Air Force, Civil Engineering Center

- Our Current Understanding of the Human Health and Environmental Risks of PFAS
    - https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas

State Government Resources

- Association of State Drinking Water Administrators (ASDWA)
- Interstate Technology and Regulatory Council (ITRC)
- Environmental Council of the States (ECOS)
- Environmental Research Institute of the States (ERIS)

7.

AIR POLLUTION: WHAT ARE WE BREATHING?

Composition and Structure of the Atmosphere

Atmosphere refers to the layer of gases that surrounds Earth and is held in place by Earth's gravitational attraction (gravity). The mix of gases in the atmosphere forms a complex system organized into layers that together support life on Earth. Although there are numerous gases the top four gases make up 99.998 % of the volume of *clean dry air* (unpolluted air that does not contain water vapor). Of this dry composition of the atmosphere **nitrogen**, by far, is the most common (78%).

Figure: Emissions from this power plant in New Mexico contained excessive amounts of sulfur dioxide. Image from National Parks Service (Public Domain).

Nitrogen dilutes oxygen and prevents rapid or instantaneous burning at the Earth's surface, as oxygen gas is a necessary reactant of the combustion process. Nitrogen is also needed and used by living things to make proteins, though as nitrogen gas, N_2, it is unavailable to most living things. **Oxygen** is used by all living things to make molecules that are essential for life. It is also essential for aerobic respiration as well as combustion or burning. **Argon** is a non-reactive gas and we use it in light bulbs, in double-pane windows, and to preserve priceless documents such as the original Declaration of Independence and the Constitution. **Carbon dioxide** is an essential gas used by plants and other organisms to make sugar (food) through photosynthesis. This process is essential for other life as well because during photosynthesis, water molecules are split apart and their oxygen is released back to the atmosphere. Carbon dioxide also acts as a blanket that prevents the escape of heat into outer space. The atmosphere is rarely, if ever, completely dry. **Water vapor** (water in a 'gas' state) is usually present up to about 4% of the total volume depending on location. In the Earth's desert regions (30° N/S) when dry winds are blowing, the water vapor contribution to the composition of the atmosphere will be near zero.

Average Composition of Clean Dry Air in the Lower Atmosphere

Gas	**Symbol**	**Content**
Nitrogen	N_2	78.08%
Oxygen	O_2	20.95%
Argon	Ar	0.93%
Carbon	CO_2	0.03% (this and the above three add to 99.998%)
Neon	Ne	18.20 parts per million
Helium	He	5.20 ppm
Krypton	Kr	1.10 ppm
Sulfur Dioxide	SO_2	1.00 ppm
Methane	CH_4	2.00 ppm
Hydrogen	H_2	0.50 ppm
Nitrous Oxide	N_2O	0.50 ppm
Xenon	Xe	0.09 ppm
Ozone	O_3	0.07 ppm
Nitrogen Dioxide	NO_2	0.02 ppm
Iodine	I_2	0.01 ppm
Carbon Monoxide	CO	Trace
Ammonia	NH_3	Trace

Source: National Weather Service www.srh.noaa.gov/jetstream/at...tmos_intro.htm

Earth's atmosphere is divided into four distinct layers based on thermal characteristics (temperature changes), chemical composition, movement, and density. The **Troposphere** is the lowest layer extending from the surface up to roughly 18 km above the surface depending on location (varies from as low as 6 km to as high as 20 km). There is continuous flow and swirling of air constantly through convection currents redistributing heat and moisture around the globe. This results in the short-lived and local patterns of temperature and moisture that we call **weather**. Because gravity holds most air molecules close to the Earth's surface, the troposphere is the densest of all layers, containing about 75% of the total mass of the atmosphere. The density of the gases in this layer decrease with height so the air becomes thinner. In response, the temperature in the troposphere also decreases with height. As one climbs higher, the temperature drops from an average around 17°C (62°F) at sea level to about -51°C (-60°F) at the tropopause, a sharp boundary at the top of the troposphere that limits mixing between the troposphere and the upper layers.

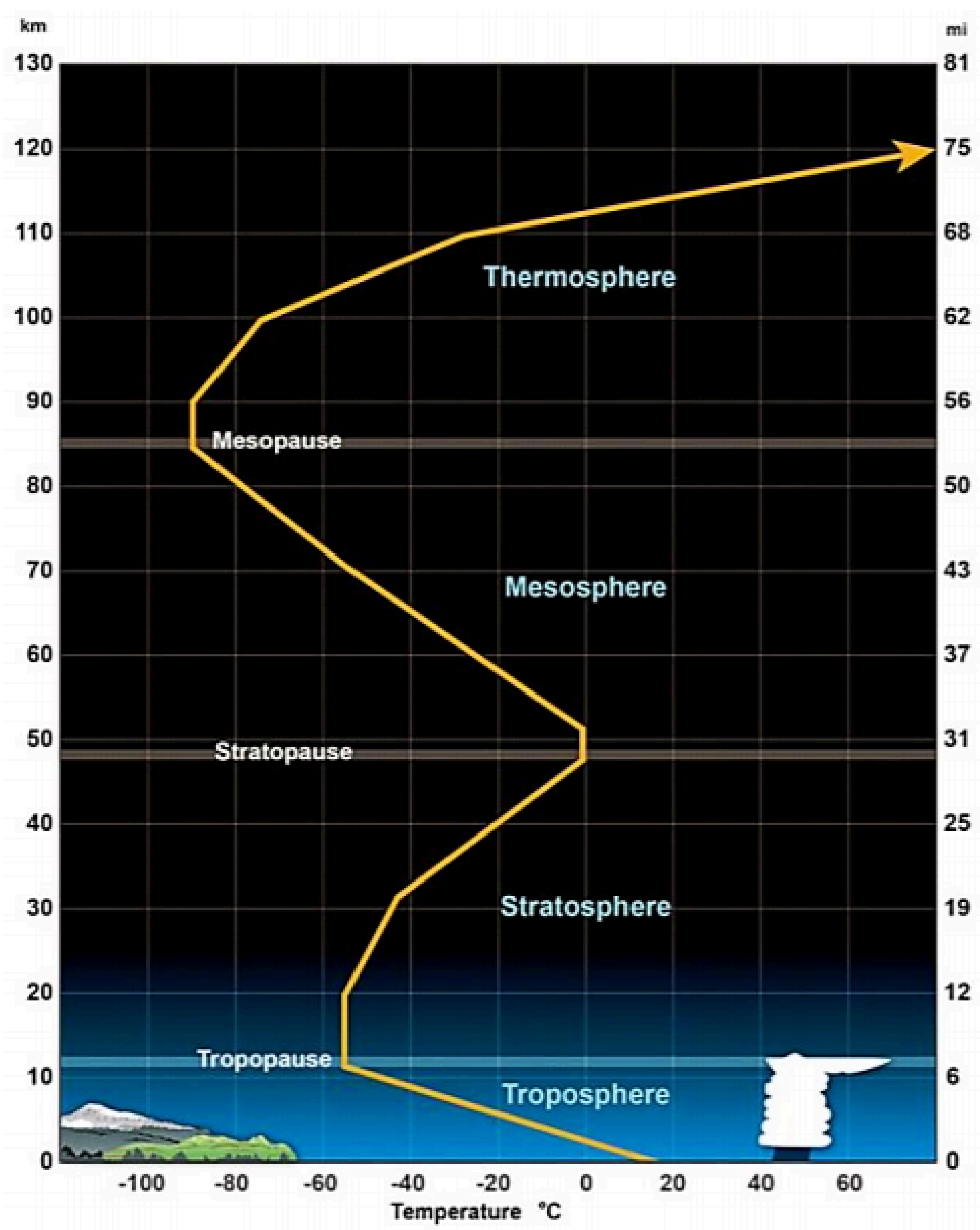


Figure: An average temperature profile through the lower layers of the atmosphere. Height (in miles and kilometers) is indicated along each side. Source: National Weather Service *www.srh.noaa.gov/jetstream/at...atmprofile.htm*

The **stratosphere** is the layer that extends from the tropopause up to about 50 km to 53 km above the Earth's surface depending on location. The proportions of most gases in this layer is similar to that of the troposphere with two main exceptions: 1) there is almost no water vapor in the stratosphere and 2) the stratosphere has nearly 1,000 times more ozone (O_3) than the troposphere. With only about 19% of the total mass of the atmosphere, the density of the stratosphere is significantly lower than the troposphere. However, temperature in this region increases with height as a result of heat that is produced during the formation of ozone (more on ozone in section 6.2). This heat is responsible for temperature increases from an average -51 °C (-60°F) at tropopause to a maximum of about -15°C (5°F) at the top of the stratosphere. This increase in temperature with height means warmer air is located above cooler air. This prevents "convection" as there is no upward vertical movement of the gases. The consequence of this little to no mixing of gases in the stratosphere makes it relatively calm but also means that once substances such as pollutants enter this zone, they can remain suspended for many years. The top of the stratosphere is bound by a boundary known as the **stratopause**.

Above the stratosphere is the **mesosphere** which extends to about 85 km above the Earth's surface. The mesosphere has no ozone molecules and the other gases such as oxygen and nitrogen continue to become less dense with height. As a result, not much ultraviolet and x-ray radiation from the sun is absorbed by molecules in this layer so temperature decreases with altitude. Both the stratosphere and the mesosphere are considered the middle atmosphere.

Between about 85 km and 600 km lies the **thermosphere**. This layer is known as the upper atmosphere. Unlike the mesosphere, the gases in this layer readily absorb incoming high energy ultraviolet and x-ray radiation from the sun. Because of this absorption, the temperature in the thermosphere increases with height and can reach as high as 2,000°C (3,600°F) near the top depending on solar activity. However, despite the high temperature, this layer of the atmosphere would still feel very cold to our skin due to the very thin atmosphere. The high temperature indicates the amount of energy absorbed by molecules but with so few in this layer, the total number of molecules is not enough to heat our skin. There's no sharp boundary that marks the end of the atmosphere. Pressure and density simply continue to decrease with distance until they become indistinguishable from the near-vacuum of outer space.

Ozone

Ozone (O_3) is a molecule in which three atoms of oxygen are bonded together. The oxygen gas in the air we breathe has two oxygen atoms bonded together (O_2). Ozone is relatively unstable and releases its third oxygen atom readily so it oxidizes and burns things more readily than oxygen gas. This characteristic makes ozone in the troposphere (ground-level ozone) an air pollutant but in the stratosphere, ozone is essential for protecting life on Earth. Ozone in the stratosphere is formed when an oxygen molecule (O_2) is broken apart into two separate oxygen atoms (O) by high-energy ultra violet (UV) solar radiation. Each of the resulting oxygen atoms

(O) in turn reacts with an oxygen molecule (O_2) creating ozone (O_3). Once produced, ozone can absorb UV radiation breaking the molecule to regenerate an oxygen molecule and a single oxygen atom. So, while ozone is continually being replenished, it is also continually being destroyed. If the rate of ozone creation is equal to the rate of destruction, the total amount will remain the same. Because there is so much oxygen in our atmosphere, this "ozone-oxygen cycle" is continuously absorbing UV radiation.

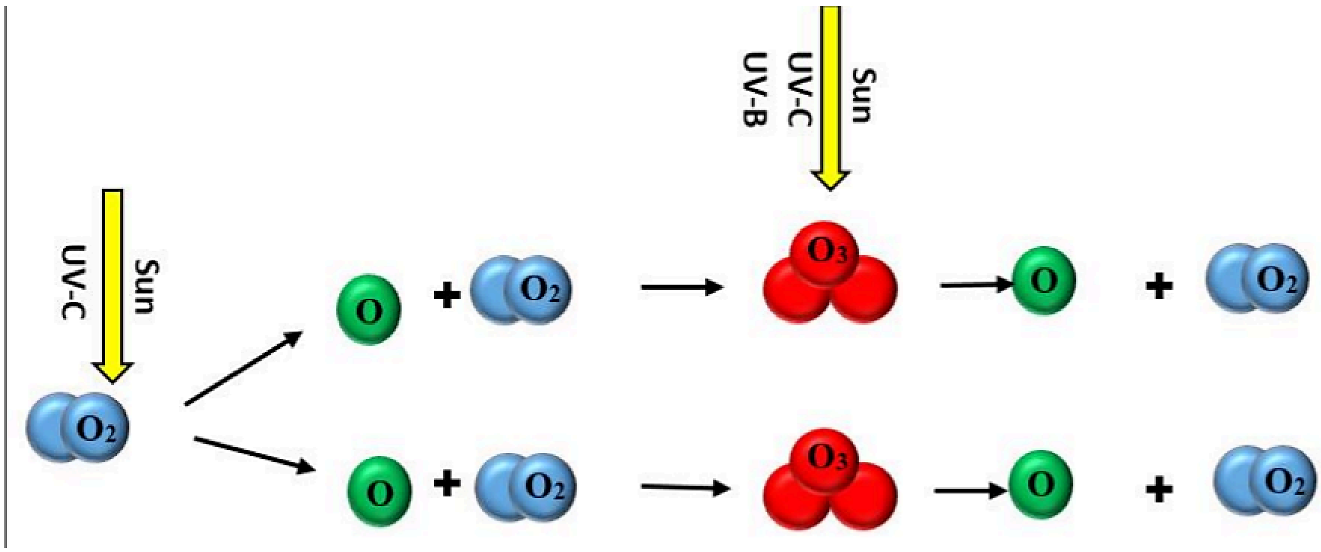


Figure: The "ozone-oxygen cycle" showing the natural formation and breaking of ozone (O3) in the stratosphere

The Ozone Layer

Ozone makes up a very small proportion of the gases in our atmosphere and most of it is concentrated in a portion of the stratosphere roughly 17–30 km above the surface. This region, called the **ozone layer**, acts as a protective shield that protects life on the surface of the Earth by absorbing most of the harmful portions of the high-energy UV radiation coming from the sun. UV is subdivided into three types namely UV-A, UV-B, and UV-C. Of these three types, UV-A is the least energetic and least harmful but can cause some damage to living cells, resulting in sunburns and skin damage. UV-A is also not absorbed by ozone in the stratosphere and is therefore transmitted through the atmosphere to the surface of the Earth. UV-C is the most harmful and most energetic of all UV, but is strongly absorbed in both the thermosphere and the stratosphere and does not make it to the Earth's surface. UV-C is the one responsible for the splitting of oxygen molecules in the stratosphere that leads to the formation of ozone. When ozone absorbs UV it regenerates oxygen atoms and releases heat which warms the upper part of the stratosphere. Since UV-C does not make it to the Earth's surface, the most harmful form of UV radiation that reaches the surface is UV-B. However, the amount of UV-B that reaches Earth's surface is significantly reduced because most of it is absorbed by ozone in the stratosphere. Ozone is the only known gas that absorbs UV-B.

Natural conditions in the stratosphere sustain a dynamic balance between the creation and destruction of ozone which helps to ensure the continued existence of the ozone layer. Any disruption of this balance that results in a higher rate of ozone destruction than ozone creation would result in depletion of ozone. Ozone depletion, consequently, leads to significant increase in the amount of harmful UV-B radiation that reaches the Earth's surface and this what we are talking about when we discuss the **ozone problem**.

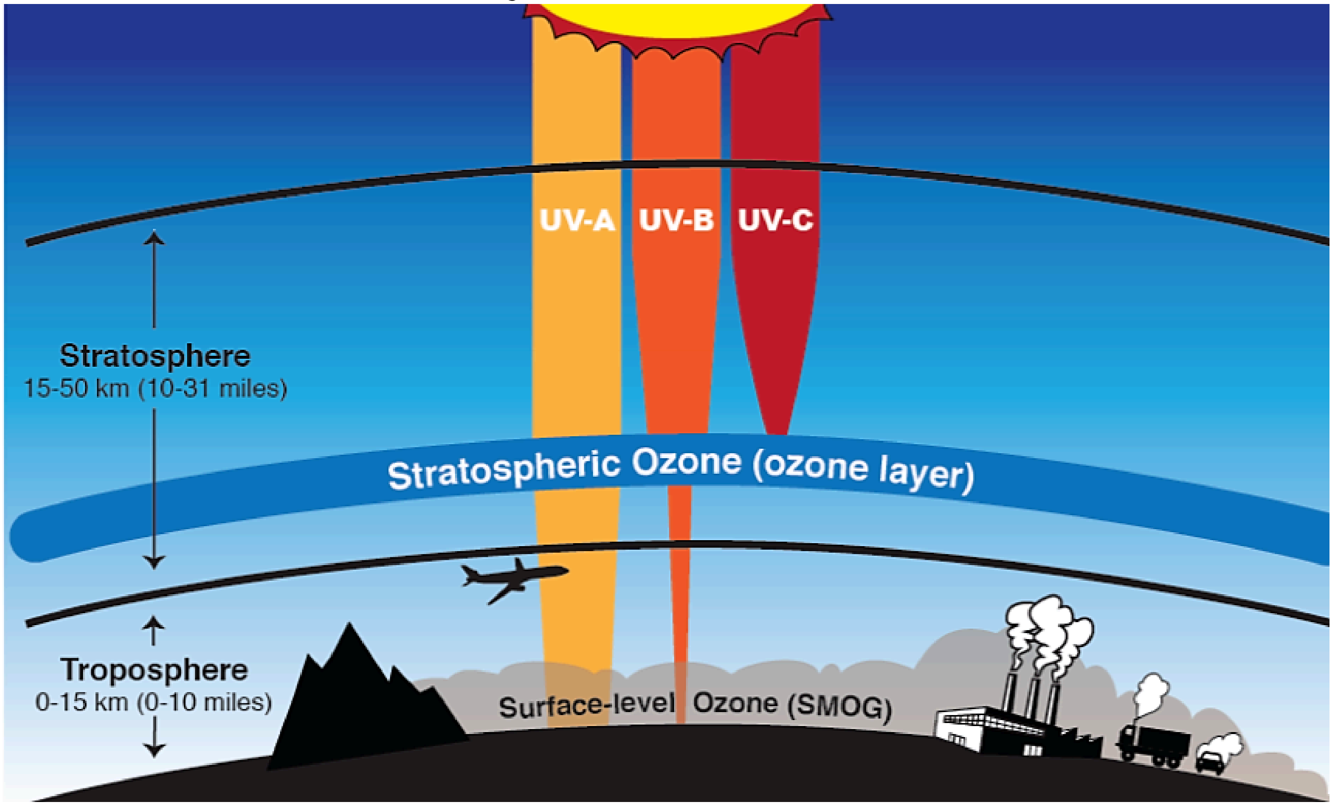


Figure: Ozone is "good" in the stratosphere because it absorbs most ultraviolet radiation. Ozone is "bad" in the troposphere because it is harmful to breathe and is the primary component of smog in summer. Source: www.nasa.gov

The Ozone Hole

The **Ozone Hole** is not really a "hole" but rather an area where the thickness of the ozone layer is greatly reduced. This hole is a result of ozone depletion that occurs every year during the Antarctic spring and was first reported to the public by the British Antarctic Survey in 1985. The thickness of the ozone layer above the Antarctic continued to decline while the geographic area covered by the ozone hole continued to increase, reaching its lowest concentration (thickness) in 1994 and largest geographic area in 2000. Recent data shows that ozone concentration globally and in the Arctic and Antarctic is no longer declining.

During the long winter months of darkness over the Antarctic, atmospheric temperatures drop, creating unique conditions for chemical reactions that are not found anywhere else in the atmosphere. During this time, the Antarctic air mass is isolated from the rest of the atmosphere and circulates around the pole in what is known as the *polar vortex*. This isolation allows temperatures to drop low enough to create ice crystals at high altitudes. Ozone, nitric acid, sulfuric acid and other chlorine-containing molecules are absorbed on the surfaces of these ice particles. When the sun rises over the Antarctic in the southern spring (October), light rapidly releases free chlorine atoms into the stratosphere. The chlorine atoms react with ozone breaking it down to molecular oxygen and an oxygen atom. The polar vortex keeps the ozone-depleted air inside the vortex from mixing with the undepleted air outside the vortex, hence the formation of an ozone hole.

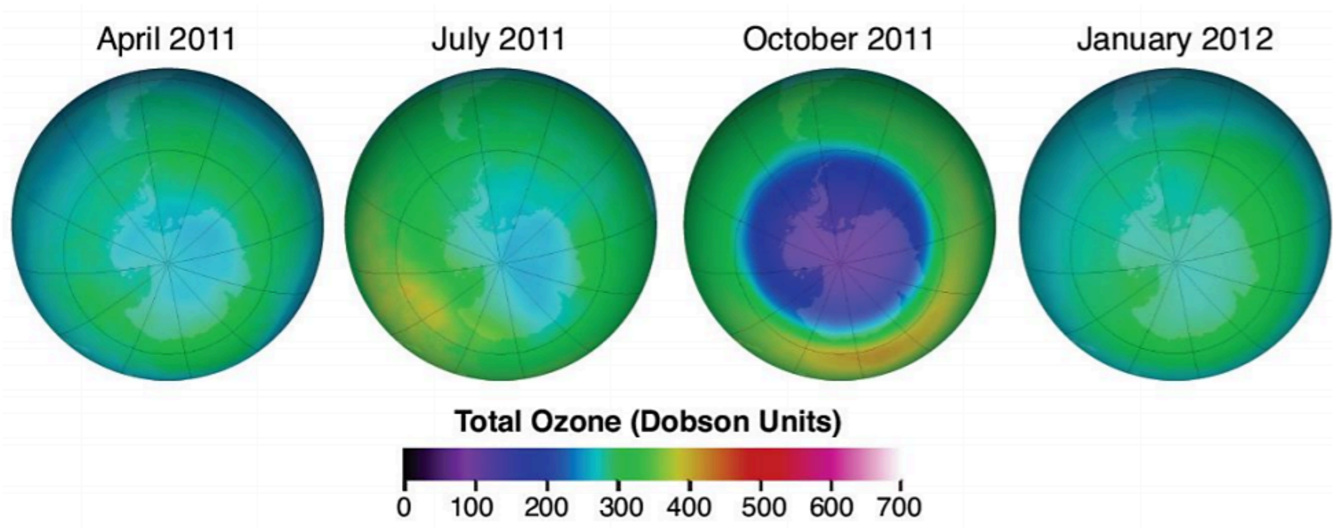


Figure: Ozone concentrations over the Antarctic region for four months representing the four seasons. Ozone concentration drops significantly during the Antarctic spring (October). Source: www.nasa.gov

Ozone Depletion

Global ozone concentrations change periodically with regular natural cycles such as changing seasons, winds, and long time scale sun variations. Concentrations of ozone in the atmosphere are measured in parts per billion (ppb). Scientists have been measuring ozone since the 1920's using ground-based instruments that look skyward. Satellite measurements of concentrations of atmospheric ozone began in 1970 and continue today.

Ozone depletion occurs when the rate at which ozone is broken down is greater than the rate of its creation, interfering with the dynamic balance between creation and destruction that maintains the ozone layer. When this happens, the amount of harmful UV-B radiation that reaches the Earth's surface increases. Ozone depletion was first identified over the Antarctic. Scientists suggested that reactions involving man-made chlorine-containing compounds were responsible for depleting ozone in the stratosphere. This hypothesis was based mostly on the physical and chemical properties of these compounds and knowledge about atmospheric conditions.

Chlorofluorocarbons (CFCs) are man-made compounds made up of chlorine, fluorine and carbon. These compounds were commonly used as propellants in everyday products such as shaving cream, hair spray, deodorants, paints and insecticides and as coolants in refrigerators and air conditioners. CFCs are extremely stable molecules and do not react with other chemicals in the lower atmosphere, part of the reason why they were considered a safe choice. Their stability means that they tend to remain in the atmosphere for a very long time. With the constant movement of air in the lower atmosphere, CFCs eventually make their way into the stratosphere. Exposure to ultraviolet radiation in the stratosphere breaks them apart, releasing chlorine atoms. Free chlorine (Cl) atoms then react with ozone molecules, taking one oxygen atom to form chlorine monoxide (ClO) and leaving an oxygen molecule (O_2). The ClO reacts with other atoms freeing up the Cl making it available to react with another ozone molecule, repeating the cycle over and over resulting in ozone depletion.

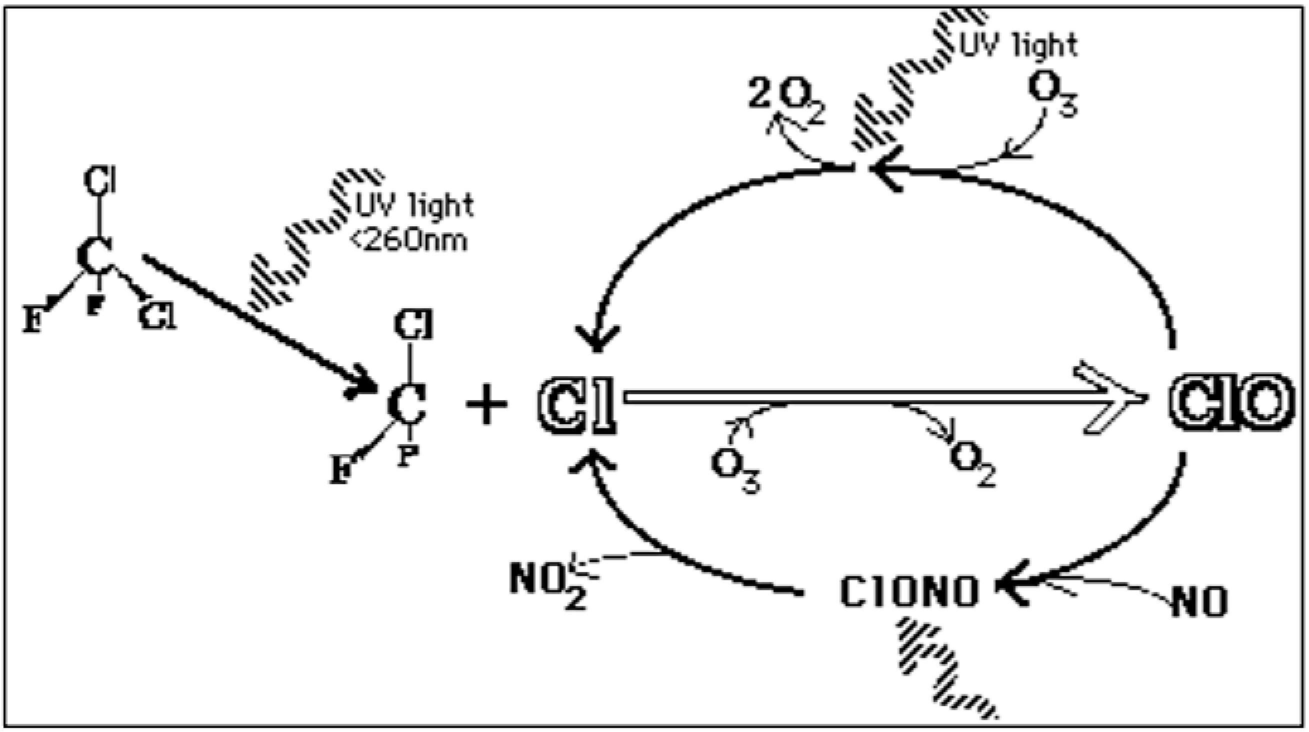
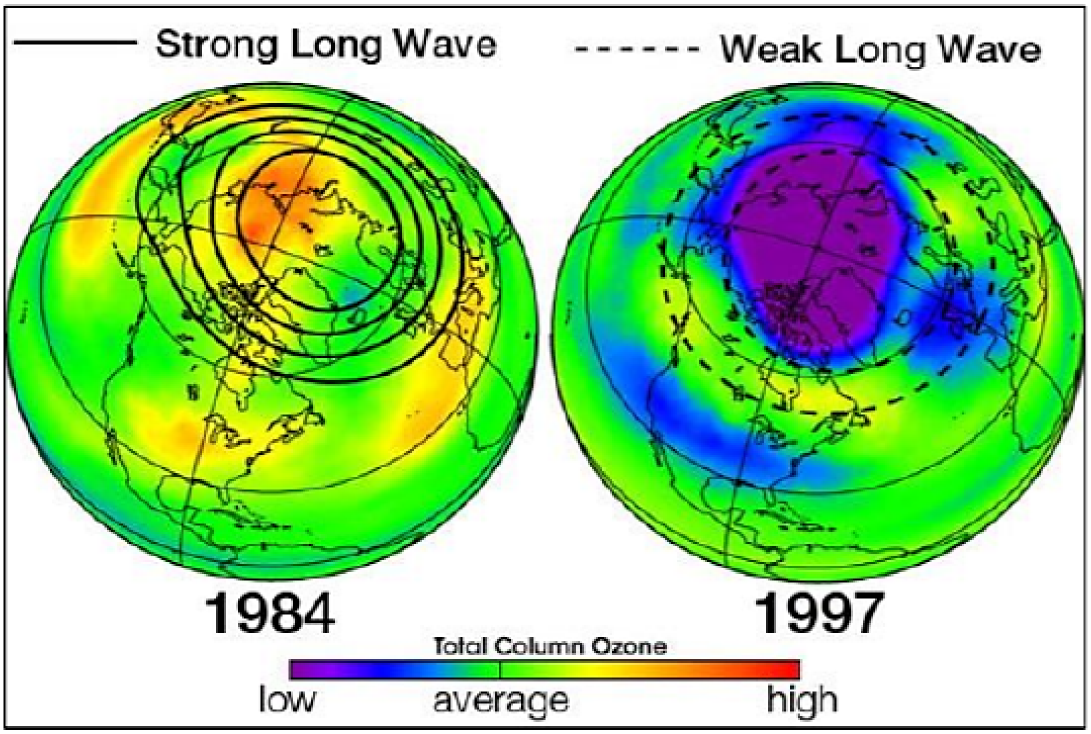


Figure: Ozone destruction. UV radiation frees a chlorine (Cl) atom from a CFC molecule, this atom reacts with ozone and produces an oxygen gas molecule and chlorine monoxide (ClO). ClO reacts with another oxygen atom, it frees up the Cl atom which then proceeds to destroy another ozone molecule. Source: Wiki commons https://commons.wikimedia.org/wiki/C..._catalysis.GIF

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy another ozone molecule. These two reactions happen over and over again, so that a single atom of chlorine, acting as a catalyst, destroys many molecules (about 100,000) of ozone. The consequence of stratospheric ozone depletion is increased levels of UV-B radiation reaching the Earth's surface, posing a threat to human health and the environment. The figure below shows a lower than average amount of stratospheric ozone over North America in 1997 when it was abnormally cold compared to 1984, which was warmer than average, showing that ozone depletion does not exclusively affect just the South Pole (Antarctic).



Formula does not parse Figure: Seasonal ozone depletion over North America was lower in 1984 and greater in 1997. Source: NASA http://earthobservatory.nasa.gov/IOT...ew.php?id=1771

The Montreal Protocol

International policy efforts to restrict production of ozone depleting CFCs culminated in the 1987 treaty known as the **Montreal Protocol** in which signing nations agreed to cut CFC production in half by 1998. At least five follow-up agreements since then helped to deepen the cuts, advanced timetables for compliance, and addressed additional ozone-depleting substances such as halons, methyl chloroform, carbon tetrachloride, and hydrochlorofluorocarbons (HCFCs). Most countries around the world have phased out production of the substances covered by the agreements and industry has been able to shift to safer alternative chemicals. As a result, there's evidence that the Antarctic ozone hole has stopped growing worse, although recovery is not expected anytime soon. Phasing out CFCs and HCFCs is also beneficial in protecting the earth's climate, as these substances are also very damaging greenhouse gases.

As part of the United States' commitment to implementing the Montreal Protocol, the U.S. Congress amended the Clean Air Act, adding provisions for protection of the ozone layer. Most importantly, the amended Act required the gradual end to the production of chemicals that deplete the ozone layer. The Clean Air Act amendments passed by Congress requires the Environmental Protection Agency (EPA) to develop and implement regulations for the responsible management of ozone-depleting substances in the United States. Under the Clean Air Act, EPA has created several regulatory programs to address numerous issues, including:

- ending the production of ozone-depleting substances,
- ensuring that refrigerants and halon fire extinguishing agents are recycled properly,
- identifying safe and effective alternatives to ozone-depleting substances,
- banning the release of ozone-depleting refrigerants during the service, maintenance, and disposal of air conditioners and other refrigeration equipment,
- requiring that manufacturers label products either containing or made with the most harmful ozone depleting substances.

Whatever happened to the hole in the ozone layer? – Stephanie Honchell Smith

In the 1980s, the world faced a huge problem: there was a rapidly expanding hole in the ozone layer. If it continued to grow, rates of skin cancer could skyrocket, photosynthesis would be impaired, agricultural production would plummet, and entire ecosystems would collapse. So, what happened? Stephanie Honchell Smith shares how decisive global cooperation helped restore the ozone layer.

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=99#oembed-1

Outdoor Air Pollution

Air pollution refers to the introduction, into the atmosphere, of substances that have harmful effects on humans, other living organisms, and the environment either as solid particles, liquid droplets or gases. Air pollution can result from natural processes such as dust storms, forest fires, and volcanic eruptions, or from human activities such as biomass burning, vehicular emissions, mining, agriculture, and industrial processes. Improved technology and government policies have helped reduce most types of outdoor air pollution in many industrialized countries including the United States, in recent decades. However, outdoor air quality is still a problem in less industrialized nations, especially in megacities of rapidly industrializing nations such as China and India.

Outdoor pollutants can come from **stationary (point)** sources or **mobile (nonpoint)** sources. Stationary sources have a fixed location, for example power plant smokestacks, burning, construction sites, farmlands and surface mines among others. Mobile sources of air pollutants move from place to place while emitting pollutants. Examples of mobile sources include vehicles, aircrafts, ships, and trains.

A mobile source of pollution

Volcanic eruption, a natural source — Aircraft, a mobile source — Smokestack, a stationary source

Figure: Images showing various sources of air pollution, including natural and anthropogenic, stationary and mobile. Source: All images obtained from Wiki Commons commons.wikimedia.org/wiki/Air_pollution

Pollutants are categorized into two major types based on how they originated namely primary and secondary pollutants. **Primary pollutants** are those released directly from the source into the air in a harmful form. The primary pollutants that account for nearly all air pollution problems are carbon monoxide (58%), volatile organic compounds (VOCs, 11%), nitrogen oxides (15%), sulfur dioxides (13%), and particulate material (3%). **Secondary pollutants** are produced through reactions between primary pollutants and normal atmospheric compounds. For example, ground-level ozone forms over urban areas through reactions, powered by sunlight, between primary pollutants (oxides of nitrogen) and other atmospheric gases such as VOCs.

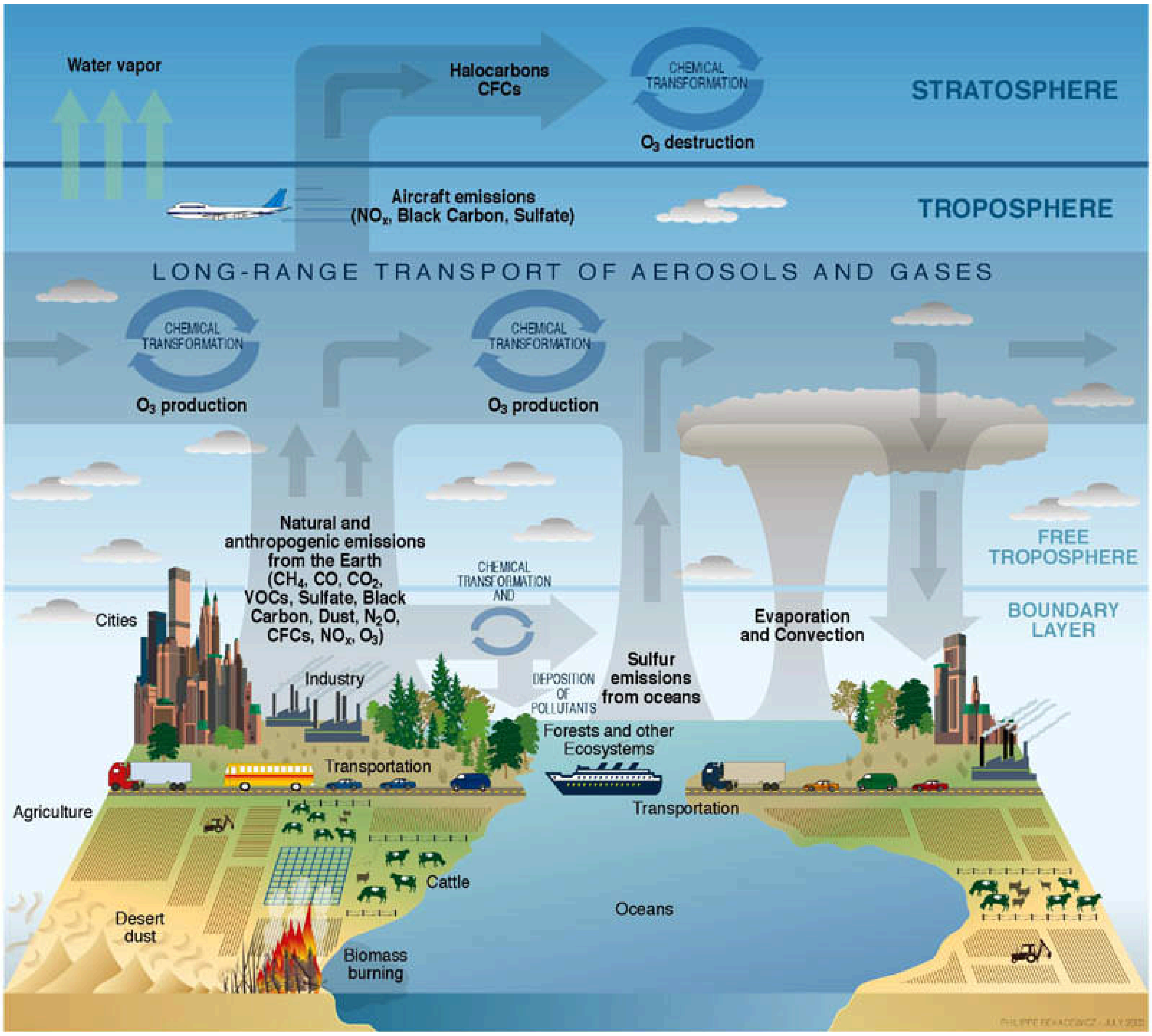
The majority of air pollutants can be traced to the burning of fossil fuels. We burn fuels in power plants to generate electricity, in factories to power machinery, in stoves and furnaces for heat, in airplanes, ships, trains, and motor vehicles for transportation, and in waste facilities to incinerate waste. Since long before fossil fuels powered the Industrial Revolution, we have burned wood for heat, fireplaces, and campfires and vegetation for agriculture and land management. The resulting primary and secondary pollutants and the problems to which they contribute are included in **Table** below.

Pollutant	Example/Major Source	Problem
Sulfur oxides (SO_x)	Coal-fired power plants	Acid Rain
Nitrogen oxides (NO_x)	Motor vehicle exhaust	Acid Rain
Carbon monoxide (CO)	Motor vehicle exhaust	Poisoning
Carbon dioxide (CO_2)	All fossil fuel burning	Global Warming
Particulate matter (smoke, dust)	Wood and coal burning	Respiratory disease, Global Dimming
Mercury	Coal-fired power plants, medical waste	Neurotoxicity
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

Beyond the burning of fossil fuels, other **anthropogenic** (human-caused) **sources** of air pollution are shown in **Table** below.

Activity	Pollutant	Problem
Agriculture: Cattle Ranching Fertilizers Herbicides and Pesticides Erosion	Methane (CH_4) Ammonia (NH_3), Volatile Organic Chemicals(VOCs) Persistent Organic Pollutants(POP): DDT, PCBs, PAHs* Dust	Global Warming Toxicity, Global Warming Cancer Global Dimming
Industry (solvents, plastics) Refrigerants, Aerosols	VOCs, POPs CFCs	Cancer, Global Warming Ozone Depletion
Nuclear power and defense	Radioactive waste	Cancer
Landfills	Methane (CH_4)	Global Warming
Mining	Asbestos	Respiratory problems
Biological Warfare	Microorganisms	Infectious Disease
Indoor Living	CO, VOCs, asbestos, dust, mites, molds, particulates	Indoor air pollution

- DDT = an organic pesticide; PCB = poly-chlorinated biphenyls, used as coolants and insulators; DDT and most PCBs are now banned at least in the U.S., but persist in the environment; PAHs = polycyclic aromatic hydrocarbons – products of burning fossil fuels, many linked to health problems



Many processes contribute to atmospheric pollution and trace gases. Click on image for a zoom. From US Strategic Plan for the Climate Change Science Program, Final Report July 2003: Chapter 3 Atmospheric Composition.

Criteria pollutants

Under the Clean Air Act (section 6.7.1), the Environmental Protection Agency (EPA) establishes air quality standards to protect public health and the environment. EPA has set national air quality standards for six common air pollutants namely: 1) carbon monoxide; 2) ground-level ozone; 3) nitrogen dioxide; 4) Sulfur dioxide; 5) lead; and 6) particulate matter (also known as particle pollution). Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels. The set of limits based on human health is called primary standards. Another set of limits intended to prevent environmental and property damage is called secondary standards.

1. **Carbon Monoxide (CO)**: is a colorless, odorless gas emitted from combustion processes, specifically, the incomplete combustion of fuel. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death.
2. **Ground-level ozone (O_3)**: is a colorless gas with a slightly sweet odor that is not emitted directly into the air, but is created by the interaction of sunlight, heat, oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Ozone is likely to reach unhealthy levels on hot sunny days in urban environments. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_x and VOCs.
3. **Nitrogen dioxide (NO_2)**: is one of a group of highly reactive gasses known as "oxides of nitrogen," or "nitrogen oxides (NO_x)." Other nitrogen oxides include nitrous acid and nitric acid. NO_2 is a yellowish-brown to reddish-brown foul-smelling gas that is a major contributor to smog and acid rain. Nitrogen oxides result when atmospheric nitrogen and oxygen react at the high temperatures created by combustion engines. Most emissions in the U.S. result from combustion in vehicle engines, electrical utility, and industrial combustion.
4. **Sulfur dioxide (SO_2)**: Sulfur dioxide is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes such as extracting metals from their ores, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment.
5. **Lead (Pb)**: is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in motor vehicles (such as cars and trucks) and industrial sources. As a result of EPA's regulatory efforts to remove lead from gasoline, emissions of lead from the transportation sector dramatically declined by 95 percent between 1980 and 1999, and levels of lead in the air decreased by 94 percent during that time period. The major sources of lead emissions today are ore and metal processing and piston-engine aircraft operating on leaded aviation gasoline. Today, the highest levels of lead in air are usually found near lead smelters.
6. **Particulate material (PM)**, sometimes known simply as "**particulates**" refers to solid particles and liquid droplets suspended in the air we breathe. Particulate pollution is made up of a variety of components, including acids (nitrates and sulfates), organic chemicals, metals, soil or dust particles, and allergens (pollen and mold spores). The size of the particles in directly linked to their potential for causing health problems. Particles that are 10 micrometers in diameter or smaller generally pass through the throat and nose and enter the lungs. EPA groups these into two types: "**inhalable coarse particles**," with diameters larger than 2.5 micrometers and smaller than 10 micrometers and "**fine particles**," with diameters that are 2.5 micrometers and smaller. How small is 2.5 micrometers? Think about a single hair from your head. The average human hair is about 70 micrometers in diameter – making it 30 times

larger than the largest fine particle.Our respiratory systems are equipped to filter larger particles out of the air once it is inhaled. However, the lungs are vulnerable to both coarse particles (PM_{10}), and fine particles ($PM_{2.5}$). These can slip past the respiratory system's natural defenses and get deep into the lungs and some may even get into the bloodstream. Coarse particles come from road dust while fine particles come from combustion processes.

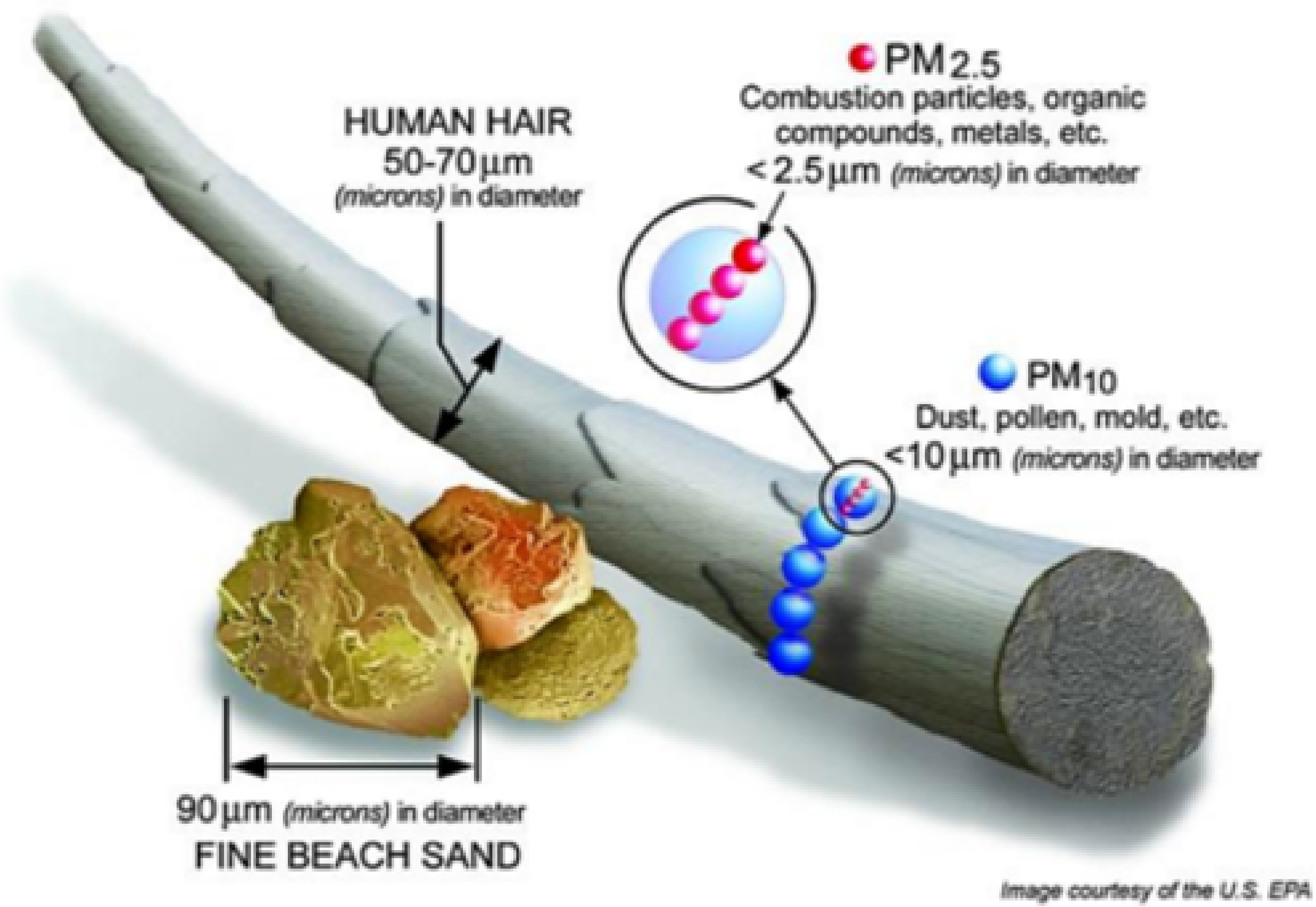


Figure: Graphic showing size comparison of particulate material (PM_{10} and $PM_{2.5}$) compared to fine beach sand and human hair. Source: US EPA www.epa.gov/air/particlepollution/basic.html

Volatile Organic Compounds

Volatile organic compounds (VOCs) are carbon-containing chemicals emitted as gases from natural and human-made sources. Natural sources of VOCs include plants, the largest source, and bacteria in the guts of termites and ruminant animals. These compounds are generally oxidized to carbon monoxide and carbon dioxide in the atmosphere. VOCs are of great concern because they are precursors for the formation of ozone, a secondary air pollutant.

A large number of synthetic organic chemicals such as benzene, toluene, formaldehyde, vinyl chloride, chloroform, and phenols are widely used as ingredients in countless household products. Paints, paint strippers, varnishes, many cleaning, disinfecting, cosmetic, degreasing, and hobby products all contain VOCs. Fuels are also made up of organic chemicals. All of these products can release organic compounds while you are using them, and, to some degree, when they are stored. The "new car smell" characteristic of new cars is from a complex mix of dozens of VOC. Also, concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. They are often held responsible for sick building syndrome, an illness resulting from indoor pollution in which the specific cause is not identified.

Smog

Smog is a mixture of air pollutants (sulfur dioxide, nitrogen oxides, ozone, and particulates) that often form over urban areas as a result of fossil fuel combustion. The term was coined from the terms "smoke" and "fog" referring to a brownish haze that pollutes the air, greatly reducing visibility and making it difficult for some people to breathe. There are two main types of smog: industrial and photochemical smog. **Industrial smog** is produced primarily by the burning of fossil fuels which produces carbon dioxide (from complete combustion), carbon monoxides (from partial combustion), sulfur, and mercury. The sulfur reacts with other chemicals in the atmosphere producing several sulfur compounds including sulfur dioxide. These compounds along with particulate material make up industrial smog. **Photochemical smog** is formed when sunlight drives chemical reactions between primary pollutants from automobiles and normal atmospheric compounds. The product is a mix of over 100 different chemicals with the most abundant being ground-level ozone.

Figure: Smog over Almaty city, Kazakhstan. Photo by Igors Jefimovs. Source: Wikicommons commons.wikimedia.org/wiki/C...dia/File:Smog_ over_Almaty.jpg

Figure: Smog over Santiago in Chile. Source: German Wikipedia commons.wikimedia.org/wiki/C...#/media/File:S antiago30std.jpg

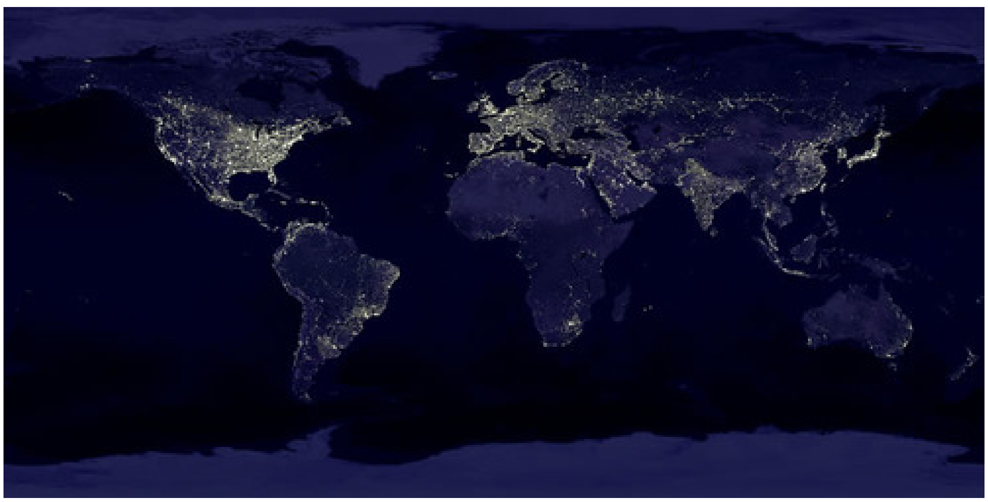
Toxic pollutants

Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. Examples of toxic air pollutants include benzene, which is found in gasoline; perchloroethylene, which is emitted from some dry cleaning facilities; methylene chloride, which is used as a solvent and paint stripper by a number of industries; and others such as dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

Most air toxics originate from human-made sources, including mobile sources (e.g., cars, trucks, buses) and stationary sources (e.g., factories, refineries, power plants), as well as indoor sources (e.g., some building materials and cleaning solvents). Some air toxics are also released from natural sources such as volcanic eruptions and forest fires. Exposure to air toxics is mainly through breathing but some toxic air pollutants such as mercury can deposit onto soils or surface waters, where they are taken up by plants and ingested by animals and are eventually magnified up through the food chain. Like humans, animals may experience health problems if exposed to sufficiently high quantities of air toxics over time.

Light Pollution

One additional topic relates to atmospheric change. **Light pollution** (**Figure** below) results from humans' production of light in amounts which are annoying, wasteful, or harmful. Light is essential for safety and culture in industrial societies, but reduction in wasteful excess could mitigate its own harmful effects, as well as the amounts of fossil fuel used to generate it. Astronomers – both amateur and professional – find light interferes with their observations of the night skies. Some studies show that artificial spectra and excessive light exposure has harmful effects on human health. Life evolved in response to natural cycles and natural spectra of light and dark, so it is not surprising that our changes in both of those might affect us and other forms of life. Light pollution can affect animal navigation and migration and predator/prey interactions. Because many birds migrate by night, Toronto, Canada has initiated a program to turn out lights at night during spring and fall migration seasons. Light may interfere with sea turtle egg-laying and hatching, because both happen on coasts at nighttime. The behavior of nocturnal animals from owls to moths can be changed by light, and night-blooming flowers can be affected directly or through disruption of pollination. Zooplankton normally show daily vertical migration, and some data suggests that changes in this behavior can lead to **algal blooms**.



When light produced by humans becomes annoying, wasteful, or harmful, it is considered light pollution. This composite satellite image of Earth at night shows that light is concentrated in urban

Solutions to problems caused by light pollution include

- reducing use
- changing fixtures to direct light more efficiently and less harmfully
- changing the spectra of light released
- changing patterns of lighting to increase efficiency and reduce harmful effects

Many cities, especially those near observatories, are switching to low-pressure sodium lamps, because their light is relatively easy to filter.

Indoor Air Pollutants

In both developed and developing nations, indoor air pollution poses a greater health risk than outdoor air pollution. According to the World Health Organization (WHO) and other agencies such as the Environmental Protection Agency (EPA), indoor air generally contains higher concentrations of toxic pollutants than outdoor air. Additionally, people generally spend more time indoors than outdoors, hence, the health effects from indoor air pollution in workplaces, schools, and homes are far greater than outdoor. Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home.

Outdoor air enters and leaves a building by infiltration, natural ventilation, and mechanical ventilation. In infiltration, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors. In natural ventilation, air moves through opened windows and doors. Air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and by wind. Finally, there are a number of mechanical ventilation devices, from outdoor-vented fans that intermittently remove air from a single room, such as bathrooms and kitchen, to air handling systems that use fans and duct work to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the house. The rate at which outdoor air replaces indoor air is described as the air exchange rate. When there is little infiltration, natural ventilation, or mechanical ventilation, the air exchange rate is low and pollutant levels can increase. High temperature and humidity levels can also increase concentrations of some pollutants.

There are many sources of indoor air pollution in any home. These include combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products; building materials and furnishings as diverse as deteriorated, asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products; products for household cleaning and maintenance, personal care, or hobbies; central heating and cooling systems and humidification devices. Pollutants causing indoor air pollution can also originate from outside sources such as radon, pesticides, and outdoor air pollution. Radon is a naturally occurring radioactive gas produced from the decay of uranium in rock. If a building/home is constructed in an area with uranium containing rock, the gas can seep through the foundations and accumulate in basements. Exposure to radon can cause lung cancer.

The relative importance of any single source depends on how much of a given pollutant it emits and how hazardous those emissions are. In some cases, factors such as how old the source is and whether it is properly maintained are significant. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted. Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home, release pollutants intermittently. These include smoking, the use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides in house-keeping. High pollutant concentrations can remain in the air for long periods after some of these activities.

Risks from indoor air pollution differ between less industrialized and industrialized nations. Indoor pollution has a greater impact in less industrialized nations where many people use cheaper sources of fuel such as wood, charcoal, and crop waste among others for cooking and heating, often with little or no ventilation. The most significant indoor pollutant, therefore, is soot and carbon monoxide. In industrialized nations, the primary indoor air health risks are cigarette smoke and radon.

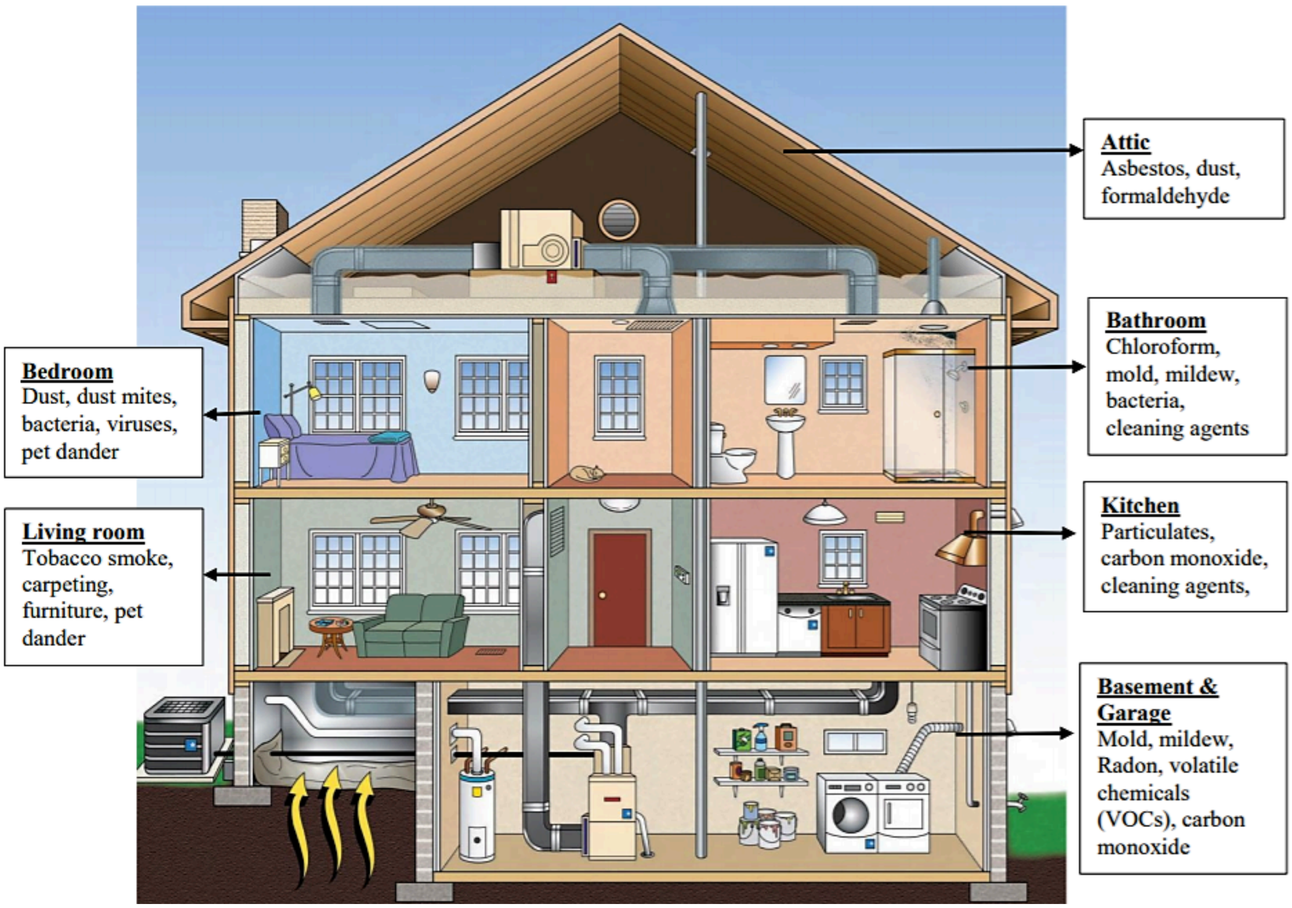


Figure: Sources of indoor air pollution. Image source: EPA http://www.epa.gov/iaq/pdfs/careforyourair.pdf

Effects of Air Pollution on Human Health

The World Health Organization (WHO) and other international agencies recognize air pollution as a major threat to human health. Numerous scientific studies have linked air pollution to a variety of health problems including: aggravation of respiratory and cardiovascular diseases; decreased lung function; increased frequency and severity of respiratory symptoms such as difficulty breathing and coughing; increased susceptibility to respiratory infections; effects on the nervous system, including the brain, such as IQ loss and impacts on learning, memory, and behavior; cancer; and premature death. Immediate effects of air pollution may show up after a single exposure or repeated exposures. Other health effects may show up either years after exposure has occurred or only after long or repeated periods of exposure.

Immediate effects of air pollution include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment is simply eliminating the person's exposure to the source of the pollution, if it can be identified. Symptoms of some diseases, including asthma, hypersensitivity pneumonitis, and humidifier fever , may also show up soon after exposure to some indoor air pollutants.

Table: Sources and health effects of criteria pollutants

Pollutant	Sources	Health Effects
Ground-level Ozone (O_3)	Secondary pollutant typically formed by chemical reaction of volatile organic compounds (VOCs) and NO_x in the presence of sunlight.	Decreases lung function and causes respiratory symptoms, such as coughing and shortness of breath; aggravates asthma and other lung diseases leading to increased medication use, hospital admissions, emergency department (ED) visits, and premature mortality.
Particulate Matter (PM)	Emitted or formed through chemical reactions; fuel combustion (e.g., burning coal, wood, diesel); industrial processes; agriculture (plowing, field burning); and unpaved roads.	Short-term exposures can aggravate heart or lung diseases leading to respiratory symptoms, increased medication use, hospital admissions, ED visits, and premature mortality; long-term exposures can lead to the development of heart or lung disease and premature mortality.
Lead	Smelters (metal refineries) and other metal industries; combustion of leaded gasoline in piston engine aircraft; waste incinerators; and battery manufacturing.	Damages the developing nervous system, resulting in IQ loss and impacts on learning, memory, and behavior in children. Cardiovascular and renal effects in adults and early effects related to anemia.
Oxides of Nitrogen (NO_x)	Fuel combustion (e.g., electric utilities, industrial boilers, and vehicles) and wood burning.	Aggravate lung diseases leading to respiratory symptoms, hospital admissions, and ED visits; increased susceptibility to respiratory infection.
Carbon Monoxide (CO)	Fuel combustion (especially vehicles), industrial processes, fires, waste combustion, and residential wood burning.	Reduces the amount of oxygen reaching the body's organs and tissues; aggravates heart disease, resulting in chest pain and other symptoms leading to hospital admissions and ED visits.
Sulfur Dioxide (SO_2)	Fuel combustion (especially high-sulfur coal); electric utilities and industrial processes; and natural sources such as volcanoes.	Aggravates asthma and increased respiratory symptoms. Contributes to particle formation with associated health effects.

Source: www.epa.gov

The likelihood of immediate reactions to air pollutants depends on several factors. Age and preexisting medical conditions are two important influences. Some sensitive individuals appear to be at greater risk for air pollution-related health effects, for example, those with pre-existing heart and lung diseases (e.g., heart failure/ ischemic heart disease, asthma, emphysema, and chronic bronchitis), diabetics, older adults, and children. In other cases, whether a person reacts to a pollutant depends on individual sensitivity, which varies tremendously from person to person. Some people can become sensitized to biological pollutants after repeated exposures, and it appears that some people can become sensitized to chemical pollutants as well.

Acid Rain

Pure rainfall is slightly acidic, pH 5.6, because water reacts with atmospheric carbon dioxide to produce weak carbonic acid. When higher than normal amounts of nitric and sulfuric acid occur in the atmosphere, the result is precipitation with a pH below 5.6 which is referred to as **acid rain**. Acid rain includes both wet deposition (rainfall, snow, fog) and dry deposition (particulates). Acid rain formation results from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from fossil fuel combustion. In the United States, roughly 2/3 of all SO_2 and ¼ of all NO_x come from electric power generation that relies on burning fossil fuels, like coal. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds. The result is a mild solution of sulfuric acid and nitric acid. When sulfur dioxide and nitrogen oxides are released from power plants and other sources, prevailing winds blow these compounds across state and national borders, sometimes over hundreds of miles. Regions of greatest acidification tend to be downwind from heavily industrialized source areas of pollution.

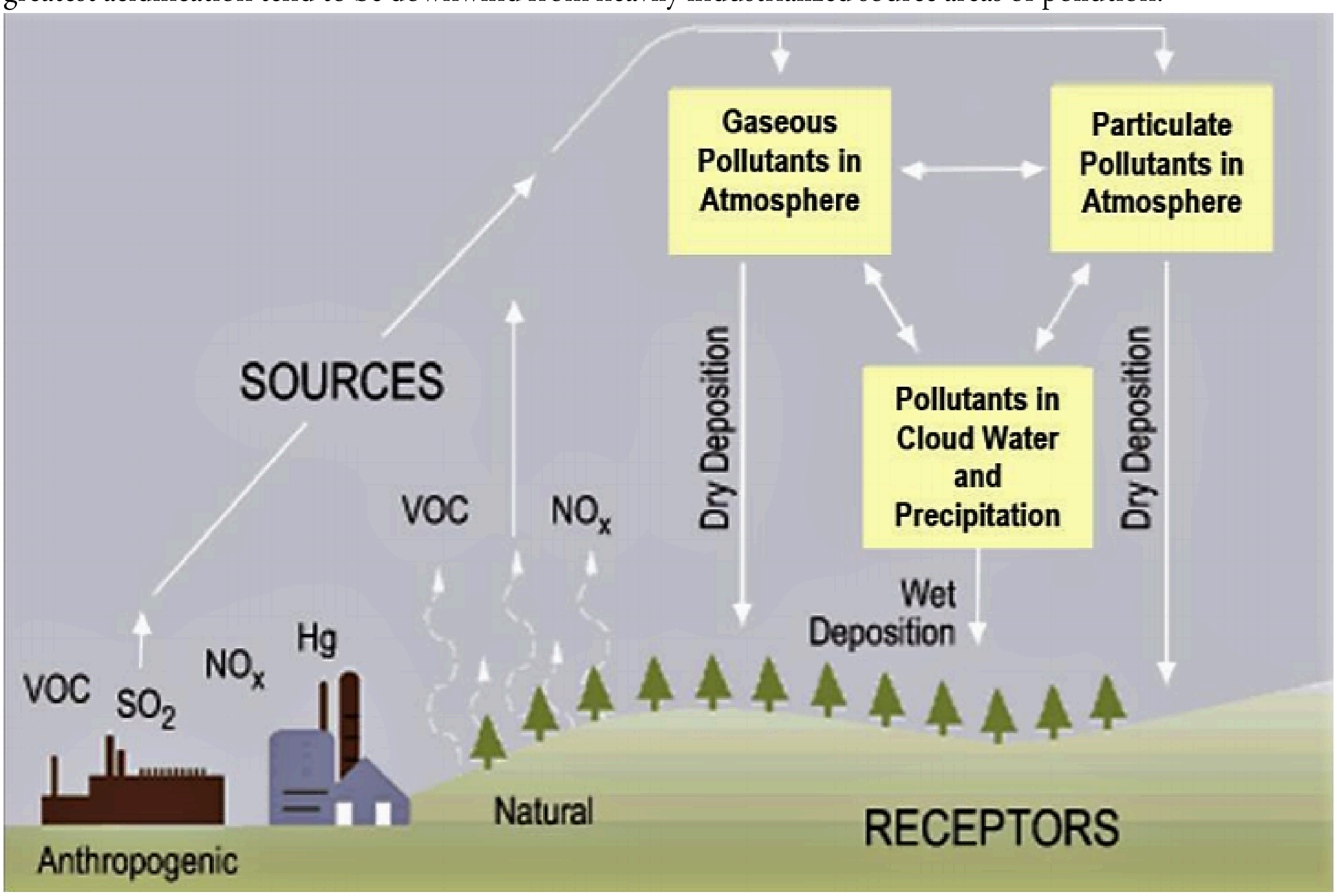


Figure: Formation of acid rain from both natural and anthropogenic pollutants Source: US EPA www.epa.gov/acidrain/images/origins.gif

- Acid rain is a serious environmental problem that is particularly damaging to lakes, streams, and forests and the plants and animals that live in these ecosystems, as well as to infrastructure. Some of the impacts include:
- Leaching of soil nutrients such as calcium, magnesium, and potassium out of the topsoil, altering soil chemistry and harming plants and soil organisms.
- Acid rain causes the release of substances that are toxic to trees and other plants, such as aluminum, into the soil. Scientists hypothesize that this combination of loss of soil nutrients and increase of toxic aluminum may be one way that acid rain harms trees. Such substances also wash away in the runoff and are carried into streams, rivers, and lakes.
- Damage to automotive paints and other coatings. The reported damage typically occurs on horizontal surfaces and appears as irregularly shaped, permanently etched areas.
- Acidic particles contribute to the corrosion of metals (such as bronze) and the deterioration of paint and stone (such as marble and limestone). These effects significantly reduce the societal value of buildings, bridges, cultural objects (such as statues, monuments, and tombstones).
- Sulfates and nitrates that form in the atmosphere contribute to visibility impairment, meaning we cannot see as far or as clearly through the air. Sulfate particles account for 50 to 70 percent of the visibility reduction in the eastern part of the U.S., affecting our enjoyment of national parks, such as the Shenandoah and the Great Smoky Mountains

Figure: Effects of acid rain on trees, Jizera Mountains, Czech Republic. Image from Wikimedia commons, Public Domain. commons.wikimedia.org/wiki/C...:Acid_rain#/media/File:Acid_rain_woods1.JPG

Figure: Effects of acid rain on a monument in Greenwood cemetery, Brooklyn New York. Photo by James P. Fischer. commons.wikimedia.org/wiki/C...rain#/media/File:Charlotte_Canda_Memorial_(Angel).jpg

Air Pollution Legislation

In 1930, 63 people died and 1000 were sickened in Belgium when a phenomenon referred to as temperature inversion caused pollutants to be trapped near the surface, leading to a sudden spike in atmospheric sulfur levels. In October 1948, a thick cloud of air pollution formed above the industrial town of Donora, Pennsylvania. The cloud which lingered for five days, killed 20 people and caused sickness in 6,000 of the town's 14,000 people. In 1952, the infamous London fog in which acid aerosols trapped in the lower atmosphere killed 4000 people. Events like these alerted us to the dangers that air pollution poses to public health.

Clean Air Act

In the United States, several federal and state laws were passed, including the original Clean Air Act of 1963, which established funding for the study and cleanup of air pollution. But there was no comprehensive federal response to address air pollution until Congress passed a much stronger Clean Air Act in 1970. That same year Congress created the Environmental Protection Agency (EPA) and gave it the primary role in carrying out the law. Since 1970, EPA has been responsible for a variety of Clean Air Act programs to reduce air pollution nationwide. The Clean Air Act is a federal law covering the entire country. However, states, tribes and local governments do a lot of the work to meet the Act's requirements. For example, representatives from these agencies work with companies to reduce air pollution. They also review and approve permit applications for industries or chemical processes.

The Plain English Guide to the Clean Air Act

EPA's Role

EPA's mission is basic health and environmental protection from air pollution for all Americans. To achieve this mission, EPA implements a variety of programs under the Clean Air Act that focus on:

- reducing outdoor, or ambient, concentrations of air pollutants that cause smog, haze, acid rain, and other problems;
- reducing emissions of toxic air pollutants that are known to, or are suspected of, causing cancer or other serious health effects; and
- phasing out production and use of chemicals that destroy stratospheric ozone.

Under the Clean Air Act, EPA sets limits on certain air pollutants, including setting limits on how much can be in the air anywhere in the United States. The Clean Air Act also gives EPA the authority to limit emissions of air pollutants coming from sources like chemical plants, utilities, and steel mills. Individual states or tribes may have stronger air pollution laws, but they may not have weaker pollution limits than those set by EPA. EPA must approve state, tribal, and local agency plans for reducing air pollution. If a plan does not meet the necessary requirements, EPA can issue sanctions against the state and, if necessary, take over enforcing the Clean Air Act in that area. EPA assists state, tribal, and local agencies by providing research, expert studies, engineering designs, and funding to support clean air progress. Since 1970, Congress and the EPA have provided several billion dollars to the states, local agencies, and tribal nations to accomplish this.

State and Local Governments' Role

It makes sense for state and local air pollution agencies to take the lead in carrying out the Clean Air Act. They are able to develop solutions for pollution problems that require special understanding of local industries, geography, housing, and travel patterns, as well as other factors. State, local, and tribal governments also monitor air quality, inspect facilities under their jurisdictions and enforce Clean Air Act regulations. States have to develop State Implementation Plans (SIPs) that outline how each state will control air pollution under the Clean Air Act. A SIP is a collection of the regulations, programs and policies that a state will use to clean up polluted areas. The states must involve the public and industries through hearings and opportunities to comment on the development of each state plan.

Outcomes of the Clean Air Act

For more than forty years, the Clean Air Act has cut pollution as the U.S. economy has grown. The combined emissions of the six criteria pollutants has continued to decrease while population, gross domestic product, energy consumption, and vehicle miles travelled have all continued to increase. The following is a summary of some of the accomplishments of the Clean Air Act:

- Clean Air Act programs have lowered levels of the six criteria pollutants – particulates, ozone, lead, carbon monoxide, nitrogen dioxide and sulfur dioxide – as well as numerous toxic pollutants.

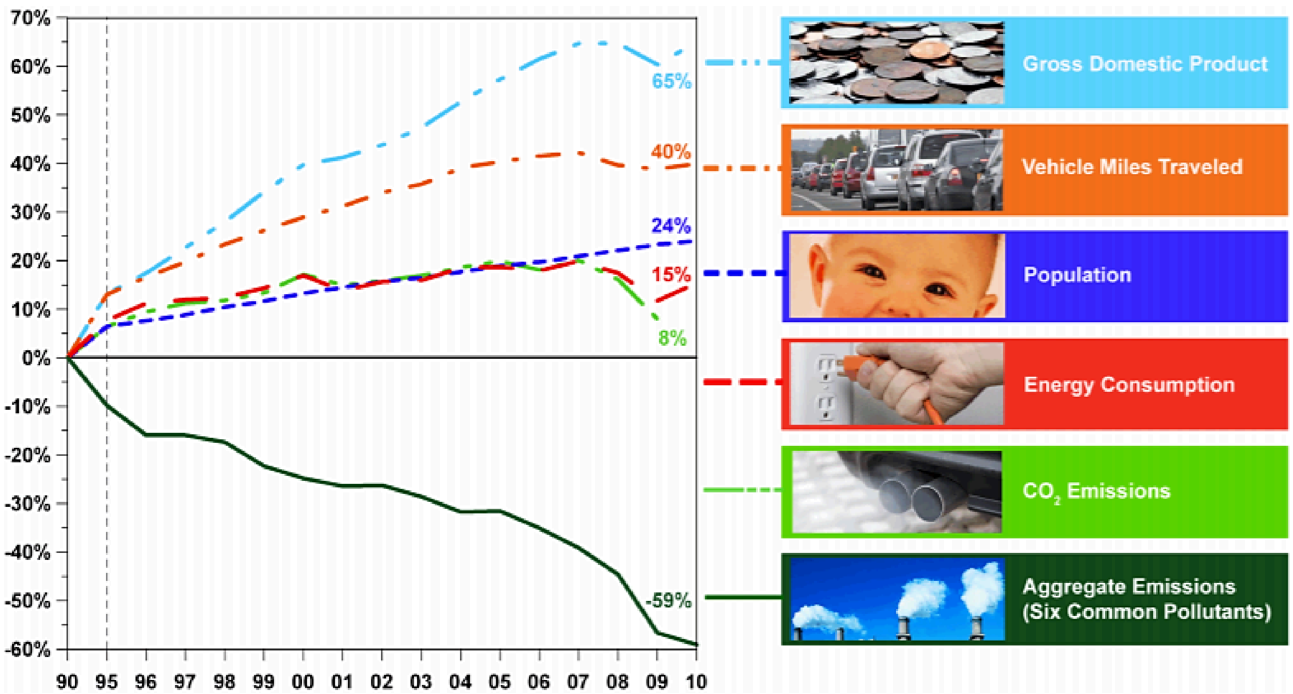


Figure: Showing a decrease in the combined emissions for the six criterial pollutants in the past two decades. Meanwhile, population, energy consumption, vehicle miles travelled, and gross domestic product have all increased. Source: US EPA

- From 1970 to 2012, aggregate national emissions of the six common pollutants alone dropped an average of 72 percent while gross domestic product grew by 219 percent (Figure 6.7.1). This progress reflects efforts by state, local and tribal governments; EPA; private sector companies; environmental groups and others.
- The emissions reductions have led to dramatic improvements in the quality of the air that we breathe.
- These air quality improvements have enabled many areas of the country to meet national air quality standards set to protect public health and the environment. For example, all of the 41 areas that had unhealthy levels of carbon monoxide in 1991 now have levels that meet the health based national air

quality standard. A key reason is that the motor vehicle fleet is much cleaner because of Clean Air Act emissions standards for new motor vehicles.

- Airborne lead pollution, a widespread health concern before EPA phased out lead in motor vehicle gasoline under Clean Air Act authority, now meets national air quality standards in most areas of the country.

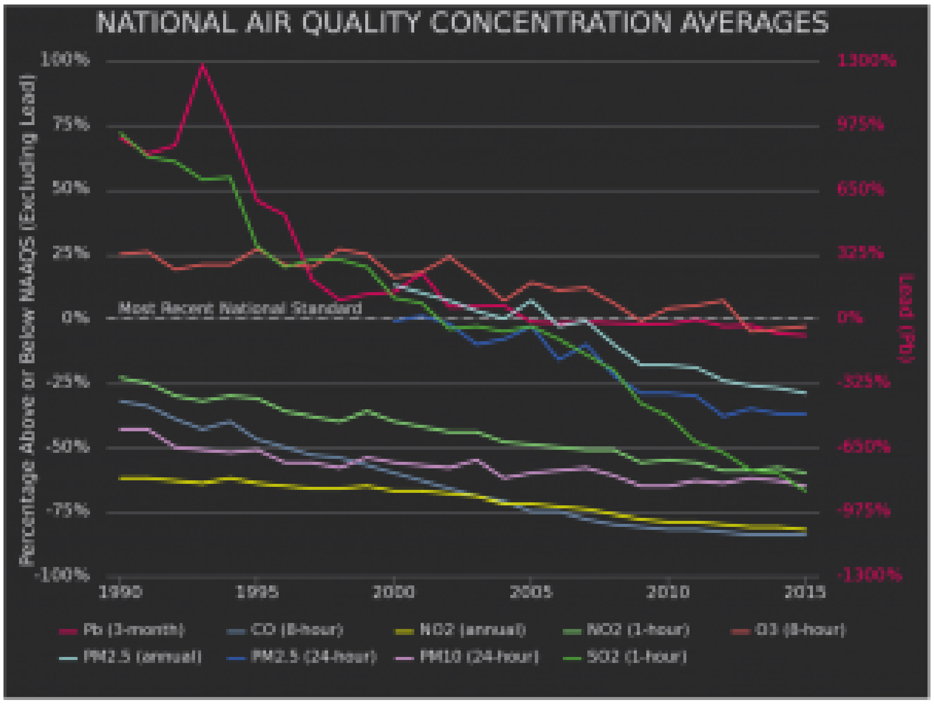


Figure: Atmospheric concentrations of lead (Pb), carbon monoxide (CO), nitrous oxide (NO2), ozone (O3), particulate matter (PM2.5 and PM10), and sulfur dioxide (SO2) have all decreased in the United States since the Clean Air Act was amended in 1990.

Monitoring air quality is the best way to tell if the air is getting cleaner, because the monitors accurately report how much of a pollutant is in the air. You can request EPA, state, local, or tribal monitoring reports that show changes over time. It is updated frequently, so you can get recent information on what's happening to the air in your community. Visit www.epa.gov/airtrends for more information.

The "Air Quality Index" (AQI) is a "public-friendly" way of using actual monitoring data to help us assess how clean our air is. Americans are familiar with many radio, TV, and newspaper weather forecasters talking about the AQI— telling you that the air is so polluted that a "Code Orange" or "Code Red" air quality condition is in effect. Information on the AQI can be found at: www.airnow.gov. The National Air Toxics Assessment is an on-going,

comprehensive evaluation of air toxics in the United States. Visit www.epa.gov/ttn/atw for air toxics information on emissions, risk, and exposure in

your area.

Clean Air Interstate Rule (CAIR)

Air pollution can travel hundreds of miles and cause multiple health and environmental problems on regional or national scales. EPA's Clean Air Interstate Rule (CAIR) addressed regional interstate transport of soot (fine particulate matter) and smog (ozone), which are associated with thousands of premature deaths and illnesses each year. CAIR required 28 eastern states to make reductions in sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions that contribute to unhealthy levels of fine particle and ozone pollution in downwind states. CAIR was replaced by the Cross-State Air Pollution Rule, as of January 1, 2015.

Under CAIR, States must achieve the required emission reductions using one of two compliance options:

1. Meet the state's CAIR requirements by requiring power plants to participate in an EPA-administered interstate cap and trade system that caps emissions in two stages, or
2. Meet an individual state emissions budget through measures of the state's choosing.

All affected states chose to meet their emission reduction requirements by controlling power plant emissions through three separate interstate cap and trade programs: the CAIR SO_2 annual trading program, the CAIR NO_X annual trading program, and the CAIR NO_X ozone season trading program.

By the year 2015, the Clean Air Interstate Rule will result in:

- $85 to $100 billion in annual health benefits, annually preventing 17,000 premature deaths, millions of lost work and school days, and tens of thousands of non-fatal heart attacks and hospital admissions.
- Nearly $2 billion in annual visibility benefits in southeastern national parks, such as Great Smoky and Shenandoah.
- Significant regional reductions in sulfur and nitrogen deposition, reducing the number of acidic lakes and streams in the eastern U.S.

Charts and Tables – A collection of printable charts, tables, and graphics demonstrating the health and environmental benefits of CAIR.

Preventing Air Pollution

Ways to maintain our atmosphere and its ecosystem services:

- Reducing use of fossil fuels
- Switching to cleaner fuels
- Switching to renewable energy sources

- Increasing fuel efficiencies
- Supporting legislation for fuel efficiencies
- Supporting national and international agreements to limit emissions
- Utilizing pollution control technologies: e.g., scrubbers on smokestacks and catalytic converters for motor vehicles
- Creating and supporting urban planning strategies

As always, costs are high and tradeoffs must be considered. The classic example is nuclear power, whose effects on the atmosphere are less than those of fossil fuels. Unfortunately, it has high potential for health damage and high costs – both economic and environmental – for storage and transport of nuclear waste.

Attributes

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EPA Clean Air Interstate Rule (CAIR). https://archive.epa.gov/airmarkets/programs/cair/web/html/index.htmlLinks to an external site. https://wwwLinks to an external site..epa.gov/sites/default/files/2015-08/documents/cair09_ecm_analyses.pdf

Figure: Atmospheric concentrations of lead (Pb), carbon monoxide (CO), nitrous oxide (NO2), ozone (O3), particulate matter (PM2.5 and PM10), and sulfur dioxide (SO2) have all decreased in the United States since the Clean Air Act was amended in 1990. Copyright © by Sean Whitcomb is licensed under a Creative Commons Attribution 4.0 International License, except where otherwise noted. Modifications to this photo include cropping.

*W*hatever happened to the hole in the ozone layer? Video by Stephanie Honchell Smith. *https://www.youtube.com/watch?v=5wVJeq4mLL0Links to an external site.*

Summary of the Clean Air Act 42 U.S.C. §7401 et seq. (1970). https://www.epa.gov/laws-regulations/summary-clean-air-act

8.

CONSERVATION AND BIODIVERSITY

Introduction

Humans, like all species, depend on certain natural resources for survival. We depend on land and soils to grow crops, which transform solar energy into food. We use the Earth's freshwater lakes, rivers, and groundwater for drinking. We rely on the atmosphere to provide us with oxygen and to shield us from radiation. We rely on Earth's biodiversity for food, clothing, and medicines. We utilize all of the "basic four" (biodiversity, land, water, air) for recycling of nutrients and disposal of waste. Natural ecosystems, as Odum suggests, provide services for all species: they maintain soil, renew the atmosphere, replenish freshwater supplies, dispose of wastes, and recycle nutrients. In our dependence on these services, we are like all other species.

Yet in many ways, we do not behave like other species. We supplement food and animal energy with fossil fuel energy. We harvest natural resources to exhaustion, and produce waste beyond levels that the Earth can process. We alter biodiversity, land, water, air and fossil fuels beyond nature's ability to repair. As you learned in your study of population biology, our population has grown beyond Earth's carrying capacity, compounding problems of resource use and waste disposal. Only recently have we learned to appreciate the full value of these resources – and the potential for harm from our own activities. Our economics have not caught up to our relatively new understanding: we do not yet pay the costs of maintaining all of "nature's services."

This lesson will explore biodiversity – the "millions of organisms and hundreds of processes – operating to maintain a livable environment." The topic is timely, critical, and colorful: you will encounter warnings of a Biodiversity Crisis and the Sixth Extinction (created by the Anthropocene), and species identified as "an Elvis taxon" or "a Lazarus taxon." More importantly, by the end of your study, you will have some tools you can use in your daily life to help protect the great diversity of Earth's life.

What is Biodiversity?

"The first rule of intelligent tinkering is to save all the pieces." –attributed to Aldo Leopold, but probably a shortened version of: ***"To save every cog and wheel is the first precaution of intelligent tinkering."*** **– Aldo Leopold, *Round River: from the Journals of Aldo Leopold*, 1953**

What are the "cogs" and "wheels" of life?

Although the concept of **biodiversity** did not become a vital component of biology and political science until nearly 40 years after Aldo Leopold's death in 1948, Leopold – often considered the father of modern ecology – would have likely found the term an appropriate description of his "cogs and wheels." Literally, biodiversity is the many different kinds (*diversity*) of life (*bio-*). Biologists, however, always alert to levels of organization, have identified three measures of life's variation. **Species diversity** best fits the literal translation: the number of different species (see the chapter on Evolution of Populations) in a particular ecosystem or on Earth (**Figure** below). A second measure recognizes variation *within* a species: differences among individuals or populations make up **genetic diversity**. Finally, as Leopold clearly understood, the "cogs and wheels" include not only life but also the land (and sea and air) which supports life. **Ecosystem diversity** describes the many types of functional units formed by living communities interacting with their environments.

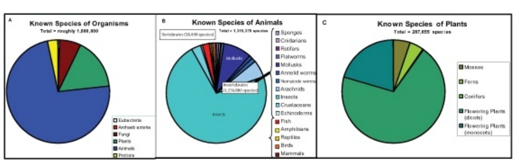
Although all three levels of diversity are important, the term biodiversity usually refers to species diversity. How many species do you think exist on Earth? What groups of species do you think are most abundant? Consider your own experience, and your study of biology up to this point. Think carefully, and write down your answer or exchange ideas with a classmate before you read further.

The most accessible definition of biodiversity is species diversity. How many species exist on Earth?

What is the Species Diversity of Earth?

There are three good answers to this question. As a member of one of Earth's most intriguing species, you should know them all!

1) Scientists have identified about 1.8 million species. (**Figure** below)



Among 1.8 million identified species (A), 1,315,378 are Animals (B), 287,655 are Plants (C), and only 259 are Archaebacteria. The Animal Kingdom is dominated by the Class Insecta, and the Plant Kingdom is dominated by flowering plants.

The relative numbers of species in each of the six kingdoms of life is shown in **Figure A** above. The Animal Kingdom (dominated by the Insects, as shown in **Figure B** above) includes the great majority of known species, and Archaebacteria, by far the fewest. Most scientists agree that Eubacteria and Archaebacteria are seriously underrepresented, due to their small size and chemistry-based diversity. This leads to a second, and perhaps better answer to our question:

2) No One Knows How Many Species Currently Live on Earth!

Does this lack of knowledge surprise you? Scientists are still discovering new species – not only microorganisms but also plants, animals, and fungi. At least 5 new species of marsupials, 25 primates, 3 rabbits, 22 rodents, 30 bats, 4 whales or dolphins, a leopard, and a sloth were identified between 2000 and 2007 – and these include only mammals! The vast majority of Eubacteria, Archaebacteria, Protist, and even Insect species may be yet unknown because their small size, remote habitats, and the chemical distinctions between species make them so difficult to detect. These challenges, however, have not prevented scientists from estimating Earth's biodiversity – bringing us to the third answer to our question:

3) Scientists Estimate that Between 5 and 30 Million Species Inhabit the Earth.

Estimates vary widely – from 2 million to 117.7 million, underlining our lack of knowledge. Most estimates fall between 5 and 30 million. Much remains to be learned about the diversity of microorganisms. For example, scientists have recently discovered that Archaebacteria – originally considered limited to extreme environments – may constitute as much as 40% of the ocean's microbial biomass. Few species have been identified. Estimates of global diversity of the better-studied Eubacteria vary from millions to billions, with orders of magnitude of error. As for multicellular organisms, the most "species-dense" terrestrial ecosystems, such as coral reefs and tropical rain forests, harbor most of the undiscovered species (**Figure** below). Ironically, these ecosystems are also disappearing quickly. In summary, our estimates of biodiversity remain crude. However, the following conclusion is clear: given the current rapid loss of species, we will never know many of the species we are losing.

4) **The importance of some species still is not known.**

If they are important to the stability of an ecosystem and go extinct, this could have long-reaching affects on humans.

As a review from *The Principles of Ecology Chapter*, remember that according to Barry Commoner, there are Four Laws of Ecology (as follows). Explain how his laws govern the way nature does – and humans should – use energy and material resources in order to protect biodiversity.

- Everything is connected to everything else.
- Everything must go somewhere.
- Nature knows best.
- There is no such thing as a free lunch.

When we affect the ecosystem and biodiversity health in one region or biome, it is ultimately connected to others through geochemical and matter cycles.

Coral reefs (above) and tropical rain forests (below) have the greatest biodiversity of the many ecosystems on earth. They are also among the most threatened habitats. Because our knowledge of their species is incomplete, we are clearly losing species we do not (and never will) know.

Biodiversity Patterns in Space

Are Earth's 1.8 million known species evenly distributed across its surface? You may already be aware that the answer is a resounding "No!" We will compare two regions with relatively high diversity to begin our analysis.

Minnesota has relatively high ecosystem diversity, because three of the Earth's six major terrestrial biomes converge in this state (Prairie, Deciduous Forest, and Coniferous Forest). By contrast, Costa Rica comprises almost entirely of Tropical Rain Forest, and has only one quarter of the land area of Minnesota (**Figure** below).

The state of Minnesota (

You might expect, then, that Minnesota would have a higher species diversity. Several groups of organisms are compared in the **Figure** below. Note that a column is included for you to research your own state or region!

Group of Organisms	Number of Species: Minnesota	Number of Species: Costa Rica	Number of Species: Your State
Amphibians	18	150 	
Reptiles	27 	210	
Birds	400 (but 96 of these migrate, spending winter in the Rainforest)	848 	
Hummingbirds	1 	852	
Mamma ls	80	200 	
Bats	7 	100	
Butterflies	140	1000 	
Orchids	42 	1200	
Trees	43	2500 	

A comparison of species diversity within categories supports the increase in diversity from the poles to the equators. Costa Rica

Clearly, biodiversity is much higher in Costa Rica than in Minnesota. Collecting leaves for your biology class in Costa Rica, you would need to study 2,500 different trees in order to identify the species! And you'd need to look carefully to distinguish tree leaves from those of the many **epiphytes** (plants which grow on top of others), vines, and strangler figs which climb the trunks and branches, "cheating" their way to the sunlight at the top of the canopy. In Minnesota, keys to native trees include just 42 species of conifers and deciduous broadleaved species. There, vines are relatively rare, and epiphytes are limited to colorful lichens.

The differences in biodiversity between Minnesota and Costa Rica are part of a general worldwide pattern: biodiversity is richest at the equators, but decreases toward the poles. Temperature is undoubtedly a major factor, with warmer, equatorial regions allowing year-round growth in contrast to seasonal limitations nearer the poles.

Generally, the more species, the more niches – so diversity begets diversity.

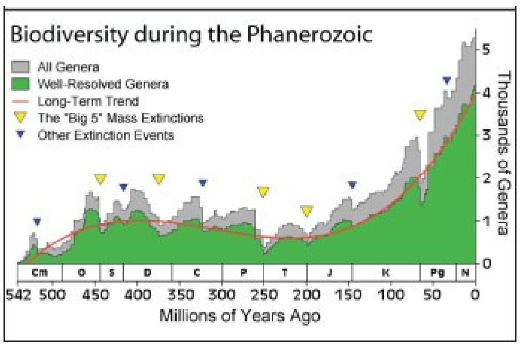
Does your country, state or region fit the general pattern of decreasing biodiversity from equator to poles?

Biodiversity Patterns in Time

How has Earth's biodiversity changed across time? The fossil record is our window into this pattern, although the window has limitations. Microorganisms are poorly preserved and distinguished only with difficulty; gene sequence studies of living bacteria have begun to fill in some missing data. For all organisms, recent rock layers are more accessible and better preserved than ancient ones.

Despite these drawbacks, fossils and gene studies show a distinct pattern of increasing biodiversity through time. As discussed in the chapter on the *History of Life,* the origin of life is not clearly understood; evidence suggests that life did not appear on Earth until perhaps 4 billion years ago. For several billion years, unicellular organisms were the only form of life. During that time, biodiversity clearly increased, as Eubacteria and Archaebacteria emerged from a common ancestor some 3 billion years ago, and Eukaryotes emerged by endosymbiosis about 2 billion years ago. However, we have not accurately measured the diversity of even today's microorganisms, so we have little understanding of changes in the diversity of microorganisms beyond these major events.

The emergence of multicellular life about 1 billion years ago certainly increased biodiversity, although we have little way of knowing whether it might have negatively affected the diversity of microorganisms. Fossils remain relatively rare until the famed Cambrian explosion 542 million years ago. Since then, a much more detailed fossil record (**Figure** below) shows a pattern of increasing biodiversity marked by major extinctions.



The fossil record for marine species over the past 542 million years shows a gradual increase in biodiversity interrupted by five major extinctions. Some scientists view the recent rapid rise in diversity as a result of better preservation of more recent rock layers and fossils.

The dramatic increase indicated for the last 200 million years is somewhat disputed. Some scientists believe it is a real increase in diversity due to expanding numbers of niches – diversity begets diversity, again. Others believe it is a product of sampling bias, due to better preservation of more recent fossils and rock layers. Most scientists accept the general pattern of increasing diversity through time, interpreting the magnificent biodiversity of life on Earth today as the result of billions of years of evolution.

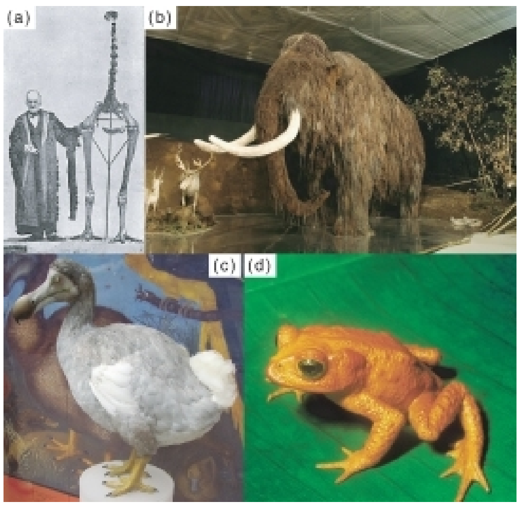
Most scientists also accept at least the five major mass extinctions shown in **Figure** above, and some hold that regular cycles govern extinction. Causes for these extinctions (more completely discussed in the *History of Life* chapter) remain incompletely understood; hypotheses include global climate change, major volcanic and continental drift events, dramatic oceanic change, and/or extraterrestrial impact or supernova events.

Increasingly accepted is a current Sixth or Holocene Extinction event. According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event – perhaps one of the fastest ever. We will explore the Sixth, or Holocene, Extinction in the next section of this lesson.

The Current Loss of Biodiversity

"For one species to mourn the death of another is a new thing under the sun." **-Aldo Leopold** *A Sand County Almanac,* 1949

Over 99% of all species that have ever lived on Earth are extinct. During the 5 major extinctions recorded in the Phanerozoic fossil record (**Figure** above), more than 50% of animals disappeared. Evidently, extinction is natural. However, current extinctions may differ significantly in rate and cause. The IUCN (International Union of Concerned Scientists) has documented 758 extinctions since 1500 CE; for example, 6 species of giant, flightless *Moa* (**Figure A** below) disappeared from New Zealand shortly after the arrival of Polynesians. Estimates of extinctions for the last century range from 20,000 to 2,000,000 species; as for diversity, we simply do not know the true figure.



A gallery of species which have succumbed to the Sixth Extinction: A: one of six species of

Many scientists begin the Sixth Extinction with the Ice Age loss of large mammals and birds – part of a continuum of extinctions between 13,000 years ago and now. During that time, 33 of 45 genera of large mammals became extinct in North America, 46 of 58 in South America, and 15 of 16 in Australia. Climate change and/or human "overkill" are hypothetical causes. Supporting the significance of the "sudden" arrival of humans are the low numbers in Europe and South Africa, where humans had coevolved with large animals. The woolly mammoth (**Figure B** above) is one of the many examples of large mammal extinctions from this period.

The first species to become extinct during recorded human history was the Dodo (**Figure C** above), a flightless bird which had evolved without predators on an island in the Indian Ocean. Described in 1581, the fearless Dodo experienced hunting, forest habitat destruction, and introduced predators, and became extinct before 1700 – a story repeated for many more species over the following three centuries. Unfortunately, the story extends back in time, as well; over the past 1100 years, human activity has led to the extinction of as many as 20% of all bird species… a tragic loss of biodiversity.

Harvard Biologist E.O. Wilson estimated in 1993 that the planet was losing 30,000 species per year – around three species per hour. In 2002, he predicted that if current rates continue, 50% of today's plant and animal species will be extinct within the current century – compared to hundreds of thousands or even millions of years for pre-human mass extinctions. A dramatic global decline in amphibian populations in less than 30 years headlines the recent rise in extinction. Herpetologists report that as many as 170 species have become extinct within that time, and at least one-third of remaining species are threatened. Costa Rica's Golden Toad (**Figure D** above), first described in 1966, was last seen in 1989 and has become a poster species for amphibian declines.

Why is Biodiversity Important? What are We Losing?

Why should humans care if biodiversity declines? Does it matter that we have 170 fewer amphibians, or that we are losing thousands of species each year, when the Earth holds millions of other species, and life has been through extinction before? The answer is a definitive yes! It matters to us even if we consider only the economic and spiritual benefits to humans. It matters to us because we do not even understand the myraid of indirect benefits – now recognized as **ecosystem services**– that we reap from other species. And, of course, it matters to other species as well.

Direct Economic Benefits of Biodiversity

- ***Food Supply***: **Monocultures** (large-scale cultivation of single varieties of single species) are extremely vulnerable to disease. A water mold caused the infamous Irish potato famine where potatoes had been bred from a single Incan variety. As recently as 1970, blight swept the corn belt where 80% of maize grown in the U.S. was a single type. According to the Food and Agricultural Organization of the United Nations, humans currently cultivate only 150 plant species, and just four provide over half of the food we eat. Just 15 animal species make up over 90% of our livestock.

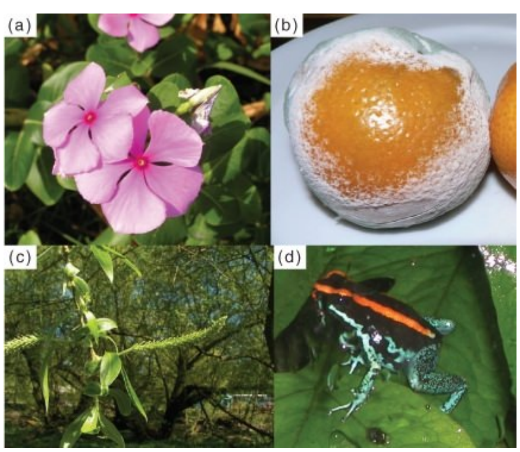
Potential for hybridization requires a diverse "bank" of wild, native species. Contemporary breeders increase genetic diversity by hybridizing crop species with wild species adapted to local climate and disease (**Figure** below).

Wild varieties of domesticated crops, such as this unusually shaped Latin American maize, hold the potential to enhance productivity, nutritional value, adaptation to local climates, and resistance to local diseases through hybridization. Loss of biodiversity limits our ability to increase the genetic diversity of crops.

- ***Clothing, Shelter, and Other Products***: As many as 40,000 species of plants, animals, and fungi provide us with many varied types of clothing, shelter and other products. These include timber, skins and furs, fibers, fragrances, papers, silks, dyes, poisons, adhesives, rubber, resins, rubber, and more.

- ***Energy***: In addition to these raw materials for industry, we use animals for energy and transportation, and biomass for heat and other fuels. Moreover, hydroelectric power depends on ecosystem structure: Chinese scientists calculated that the economic benefits of maintaining forest vegetation in the Yangtze River watershed "produced" more than twice the economic value of timber (had it been harvested) in annual power output.

- ***Medicine and Medical Models***: Since the first microorganisms competed for food, evolution has been producing chemicals for "warfare" and "defense" in bacteria, fungi, plants, and animals; **Figure** below shows several used by humans. According the American Museum of Natural History Center for Biodiversity Conservation (AMNH-CBC), 57% of the most important prescription drugs come from nature, yet only a fraction of species with medicinal potential have been studied.



A pharmacopoeia of the living world: The Rosy Periwinkle (A) is the source of two chemotherapy drugs effective against leukemias. The mold

Unique features of certain species have opened windows into how life works. For example, the Atlantic squid's giant axon revealed the basics of neurophysiology, and the horseshoe crab's (**Figure D** below) optic nerve and photoreceptors taught us how vision works. Other animals serve as disease models; as far as we know, other than humans, only armadillos suffer from leprosy, and only sea squirts form kidney stones.

- ***Efficient Designs: Inspiration for Technology***: **Biomimicry**, also known as biomimetics or **bionics**, uses organisms for engineering inspiration and human innovation. Rattlesnake heat-sensing pits, for example, suggested infrared sensors. Zimbabwe's Eastgate Centre **Figure** below incorporates air-conditioning principles from termite mounds. The 2006 Mercedes-Benz *Bionic* employs the body shape of the yellow box fish to combine high internal volume and efficient aerodynamics. Biomimetics professor Julian Vincent estimates that only 10% of current technology employs the highly efficient biological designs crafted by evolution and natural selection. Loss of biodiversity can be viewed as the loss of millions of years of evolutionary wisdom.

Bionics, or biomimicry, engineers structures based on biological designs made efficient by millions of years of evolution and natural selection. Above: The air-conditioning efficiency of a termite mound (left) inspired the design of the Eastgate Centre in Zimbabwe (right), which requires just 10% of the energy needed for conventional building of the same size. Below: The rigid exoskeleton and low-drag body shape of the tropical yellow box-fish (left) inspired the 2006 Mercedes-Benz

- ***Warnings of Toxins and Other Ecosystem Disruptions***: If you know how miners use canaries to detect poisonous gases underground, you will understand how widespread extirpation of peregrine falcons (**Figure E** below) warned us about the dangers of the pesticide DDT and food chain concentration of toxins.

Indirect Benefits of Biodiversity: Ecosystem Services

- ***Increasing Ecosystem Productivity***: Ecologist David Tilman compared grassland plots to show that increasing species diversity increased overall productivity (yield). Different plants utilize different resources, so a variety of plants may more completely use resources within an area. As noted above, diversity also reduces system vulnerability to pests and disease.

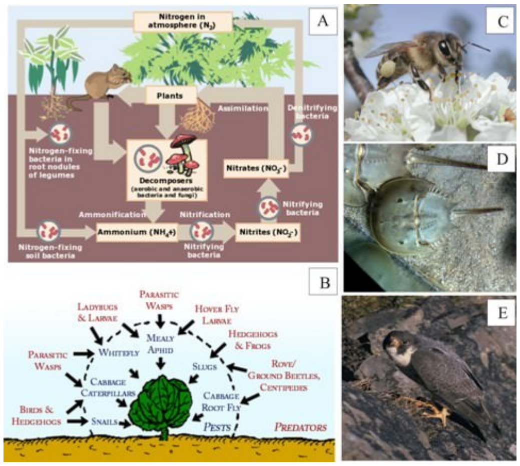
- ***Increasing Ecosystem Stability***: Tilman observed his grassland plots through several cycles of drought and documented a similar relationship between biodiversity and stability. Plots which were more diverse were more resistant to drought and later recovered more completely. Reducing ecosystem vulnerability to pests and disease may also be a factor in the relationship between diversity and stability. As you have learned before, diversity among individuals within a species increases the chance that at least some will survive environmental change; similarly, diversity among species within an ecosystem increases the chance that at least some species will survive environmental change.

- ***Maintaining the Atmosphere***: As you learned in the chapters on photosynthesis and respiration, plants and algae produce the O_2 which makes up 20% of the atmosphere essential to aerobic organisms, and remove CO_2 produced by respiration and burning fossil fuels. As Joseph Priestley expressed this service, plants "restore the air" which has been "injured by the burning of candles" or "infested with animal respiration." O_2 is also critical to life because it helps to maintain the ozone shield, protecting life from dangerous Ultra-Violet radiation.

- ***Maintaining Soils***: Soil microorganisms maintain nutrients in complex but critical chemical pathways. Vegetation and litter prevent erosion of soils which require thousands of years to form. Estimates suggest that erosion destroys as many as 3 million hectares of cropland annually, and that as much as one-fifth of the world's cropland is "desertified" through salination, acidification, or compacting.

- ***Maintaining Water Quality***: Water treatment plants rely in large part on microorganisms for water purification, and natural systems do the same. In nature, wetland, waterway, and watershed root systems combine with soil adsorption and filtration to accomplish water purification. When New York City decided to restore the Catskill watershed, their $1-1.5 billion investment in "natural capital" contrasted favorably with the $6-8 billion initial cost and $300 million annual operating cost of a new treatment plant.

- ***"Fixing" Nitrogen***: One of the most amazing aspects of biological systems on earth is their absolute need for nitrogen – to build the proteins and nucleic acids upon which life depends – and their nearly universal dependence on microorganisms to "fix" atmospheric N_2 gas and recycle the nitrogen of waste and death. Only after the bacterial "service" of processing nitrogen is it available in usable chemical form to plants, and through them, to animals (**Figure A** below).



Ecosystem services which depend on biodiversity include nitrogen fixation (A), pest control (B), pollination (C), medical models such as the horseshoe crab optic nerve and photoreceptors (D), and early warning about toxins, e.g. the peregrine falcon

- ***Nutrient Recycling and Waste Disposal***: Bacteria and nitrogen are not the only contributors to the waste management services of ecosystems. Fungi, protists, and scavengers help to decompose waste and dead organisms so that new life can reuse the available nutrients.

- ***Pollination***: The list of biotic pollinators, essential for sexual reproduction in many plants, is long including not only insects such as wasps, bees, ants, beetles, moths, butterflies, and flies, but also fruit bats and birds such as hummingbirds, sunbirds, spiderhunters, and honeyeaters. Although U.S. crops have relied on commercial honeybees (which are "migrated" to keep pace with maturing crops!), native pollinators in nearby forests or wild grasslands have been shown to improve the productivity of apples or almonds by 20%. The American Institute of Biological Sciences estimates that native insect pollination is worth $3.1 billion annually. Current alarm over honeybee colony collapse highlights the importance of biodiversity to the ecosystem service of pollination.

- ***Pest and Disease Control***: According to the AMNH-CBC, farmers spend $25 billion annually on pesticides, while predators in natural ecosystems (**Figure B** above) contribute 5 to 10 times that value in pest control. Costs associated with the use of chemical pesticides (such as water pollution) add to the value of natural pest control. Natural enemies are adapted to local environments and local pests, and do not threaten each other's survival (or ours!) as do broad-spectrum chemical pesticides. Preservation of natural enemies is associated with preservation of plant diversity, as well. Disrupted ecosystems can lead to increasing problems with disease. In Africa, deforestation has led to erosion and flooding, with consequent increases in mosquitoes and malaria.

Aesthetic Benefits of Biodiversity

- ***Cultural, Intellectual, and Spiritual Inspiration***: Music, art, poetry, dance, mythology, and cuisine all reflect and depend on the living species with whom we share the Earth. Our cultures reflect local and regional variations, and as such, biodiversity underlies our very identities. The beauty and tranquility of living ecosystems have inspired environmentalists (Rachel Carson, Aldo Leopold), spiritualists (Thomas Berry), and writers such as (Barry Lopez) throughout history. Recently, the increasing distance of human society from the natural world has raised concerns about our psychological and emotional health; E.O. Wilson has proposed that *biophilia* (love of the living world) is an increasingly ignored part of our human psyche, and Richard Louv believes that too many of our children suffer from "nature deficit disorder" caused by our increasing alienation from nature.

- ***Recreational Experiences***: Many people choose to use vacation and recreation time to explore natural ecosystems. Outdoor recreational activities – many of which are increasing in popularity – include hunting, fishing, hiking, camping, bird-, butterfly- and whale- watching, gardening, diving, and photography. Indoor hobbies such as aquariums also celebrate biodiversity. For Costa Rica, Ecuador, Nepal, Kenya, Madagascar, and Antarctica, ecotourism makes up a significant percentage of the gross national product. Ideally, ecotourism involves minimal environmental impact, conservation of bio- and cultural diversity, and employment of indigenous peoples.

Political and Social Benefits of Biodiversity

Some analysts relate biodiversity to political and social stability. Unequal access to food, clothing, water, and shelter provided by diverse ecosystems threatens social equity and stability. Land ownership and land use practices which threaten biodiversity often marginalize poorer people, forcing them into more ecologically sensitive areas and occupations. Poverty, famine, displacement, and migrations are problems related to loss of biodiversity which have already led to billions of dollars in relief costs and significant local armed conflict.

Intrinsic Value of Biodiversity

Many people value biodiversity for its inherent worth, believing that the existence of such a variety of genes, species, and ecosystems is reason enough for our respect. Intrinsic value goes beyond economic, aesthetic, environmental, and political benefits. For many people, intrinsic value alone imposes great responsibility on us to monitor our actions in order to avoid destroying the diversity of life.

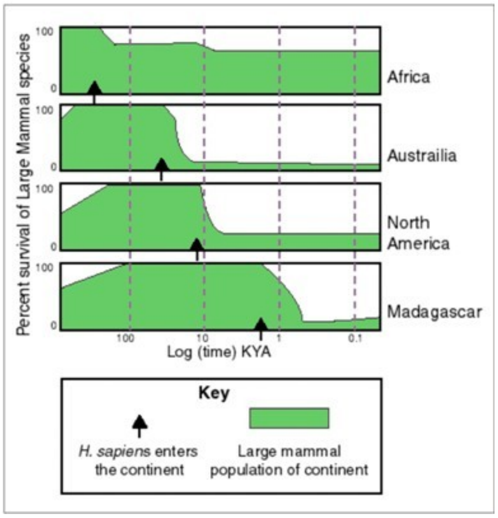
Why is biodiversity important? It supplies us with essential resources, raw materials, and designs which have direct economic value. It enhances the stability and productivity of ecosystems which in turn provide essential, under-appreciated services. These services, too, have great economic value, although we are only beginning to recognize their importance as we experience their loss. Biodiversity is critical for cultural identity, spiritual and intellectual inspiration, and our own re-creation. Biodiversity goes hand-in-hand with social and political stability. And for many people, biodiversity has inherent worth apart from its many benefits for us and our environment.

Biodiversity is critically important for us and for the Earth, and it is declining at an unprecedented rate. What is causing current extinctions? What can we – what can YOU – do to help?

Causes of the Sixth Extinction: Human Actions and the Environment

What are the causes of the Sixth Extinction? Many point to the Anthropocene, the new geological era brought about by Humans (see the Anthropocene chapter). There is nearly universal agreement that most result from human activities (**Table** below and **Figure** below). Although our activities have changed, we remain the single species most able to alter the Earth's genetic, species, and ecosystem biodiversity.

Continent/Island	Human Settlement (Years Before Present)	Extinctions Which Followed
Africa, Eurasia	Humans evolve here	relatively few extinctions
Indonesia	50,000	50% of large mammal species
Australia	40,000	55 species large mammals, reptiles, and birds
North and South America	10,000 – 12,500	70-80% of large mammals (at least 135 species) within 1000 years
Mediterranean Islands	10,000	large mammals and reptiles
West Indies	7,000	Mammals, birds, reptiles all 5 endemic mammals of Puerto Rico
Madagascar	2,000	virtually all large endemic land mammals, reptiles, and birds within 1500 years
Hawaiian Islands	1,500 (Polynesians) 250 (Europeans)	2/3 of native vertebrate species, 90% of bird species after European arrival, 20 more bird species
New Zealand	1,300	No mammals originally Frogs, lizards, and over 1/3 (40 species) of birds



Large animal extinctions followed the arrival of humans in many regions of the world, suggesting that human activities caused the extinctions.

Convincing evidence for human responsibility for Ice Age extinctions is outlined in **Figure** above. Comparing Ice Age to pre-human extinctions provides more evidence:

- Ice Age extinctions affected large animals disproportionately; pre-human extinctions affected all body sizes.
- Ice Age extinctions occurred at different times in different regions; pre-human extinctions were global and simultaneous.
- Recent extinctions follow human migration with regularity.
- The "syncopated" pattern does not fit climate change, and earlier interglacial periods did not see similar extinctions.

Although the data above has led to considerable agreement about human responsibility for the early Holocene extinctions, scientists still debate exactly how human activities caused extinctions. Hypotheses include:

1. **Overkill**: Animals outside Africa and Eurasia evolved in the absence of humans. Many did not fear humans and would have been easily killed, explaining the disproportionate numbers of large species affected.
2. **Cascade effects**: Extinctions of very large animals could have had major effects on ecosystems, including secondary extinctions. Loss of predators could have led to overpopulation and starvation of prey species. Loss of large herbivores would have affected their predators. Removal of even a single **keystone species** could have destabilized complex ecosystem interactions, leading to multiple extinctions.
3. **Disease**: Humans often brought along rats, birds, and other animals as they migrated to new regions. Animals in those new regions, however, would not have evolved resistance to the diseases they carried.

Avian malaria, for example, is still spreading through Hawaii, having already caused the extinctions of many bird species.

4. **Predation by exotic animals**: The rats, birds, and other animals accompanying humans brought not only disease but also new appetites to regions where animals had evolved without predators. Like humans, these animals found the "naïve" prey easy to capture.
5. **Habitat destruction**: Deforestation and agriculture accompanied humans, and the loss of habitat inevitably resulted in loss of species.

These effects of early human habitation foreshadow today's even greater threats to biodiversity. Overpopulation, industrialization, technology, cultural differences, and socioeconomic disparities compound the six major causes of today's Biodiversity Crisis. Most experts agree on the primary cause of extinction today:

Causes of Extinction #1: Habitat Loss

Habitat loss, degradation and fragmentation is universally accepted as the primary threat to biodiversity. Agriculture, forestry, mining, and urbanization have disturbed over half of Earth's vegetated land. Inevitably, species disappear and biodiversity declines.

Conversion for **agriculture** is a major reason for habitat loss. Within the past 100 years, the area of land cultivated worldwide has increased 74%; grazing land increased 113%. Agriculture has cost the United States 50% of its wetlands and 99% of its tallgrass prairies. Native prairie ecosystems (**Figure** below) – which comprise of thick, fertile soils, deep-rooted grasses, a colorful diversity of flowers, burrowing prairie dogs, owls and badgers, herds of bison and pronghorns, and booming prairie chickens, – are virtually extinct.

Habitat loss is the #1 cause of extinction today. In the U.S., over 99% of tallgrass prairies have been eliminated in favor of agriculture. Big bluestem grasses as tall as a human (center) and (clockwise from top) prairie chickens, prairie dogs, burrowing owls, yellow and purple coneflowers, blue grama grass, and bison make up part of the prairie community.

The largest cause of deforestation today is **slash-and-burn agriculture** (**Figure** below), used by over 200 million people in tropical forests throughout the world. Depletion of the surprisingly thin and nutrient-poor soil often results in abandonment within a few years, and subsequent erosion can lead to desertification. Half of Earth's mature tropical forests are gone; one-fifth of tropical rain forests disappeared between 1960 and 1990. At current rates of deforestation, all tropical forests will be gone by 2090.

Slash-and-burn agriculture is practiced by over 200 million people throughout the world; this photo was taken in Panama. Because of thin, nutrient-poor soils, plots are abandoned within just a few years. Experts predict that if current rates continue, all tropical forests will be gone by 2090.

Poverty, inequitable land distribution, and overpopulation combine in third world countries to add pressure to already stressed habitats. Use of firewood, charcoal, crop waste, and manure for cooking and other energy needs further degrade environments, threatening biodiversity through habitat loss.

Causes of Extinction #2: Exotic (Alien or Invasive) Species

Technology has made the human species the most mobile species of any which has ever lived. Both intentionally and inadvertently, humans have extended their mobility to a great number of other species, as well. Ships from Polynesian times (as long ago as 3500 BP) to the present have transported crop species and domesticated animals as well as stowaway rats and snakes. Recently, cargo ships have transported Zebra Mussels, Spiny Waterfleas, and Ruffe deep into the Great Lakes via ballast water. Europeans brought Purple Loosestrife and European Buckthorn to North America to beautify their gardens. Shakespeare enthusiast Eugene Schieffelin imported the now-ubiquitous European Starling to Central Park in the 1890s because he thought Americans should experience every bird mentioned in the works of Shakespeare. Australians imported the Cane Toad in an attempt to control the Cane Beetle, a native pest of sugar cane fields. The Brown Tree Snake (**Figure** below) may have hitchhiked in the wheel-wells of military aircraft to Guam – and subsequently extirpated most of the island's "naïve" vertebrate species.

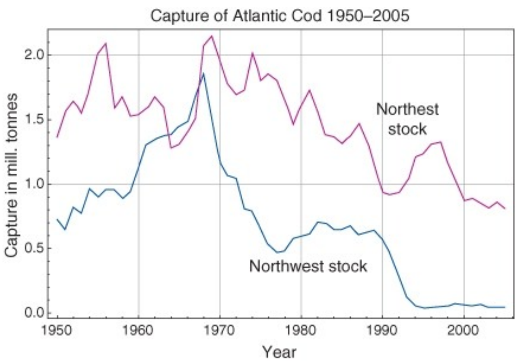
Many scientists consider exotic species to be the #2 cause of loss of biodiversity. One of the most infamous, the Brown Tree Snake (left), hitch-hiked on aircraft to Pacific Islands and caused the extinctions of many bird and mammal species which had evolved in the absence of predators. The Nile Perch (right) was intentionally introduced to Lake Victoria to compensate for overfishing of native species. The Perch itself overfished smaller species, resulting in the extinction of perhaps 200 species of cichlids.

Many of these **exotic** (non-native) **species**, away from the predation or competition of their native habitats, have unexpected and negative effects in new ecosystems. Freed from natural controls, introduced species can disrupt food chains, carry disease, out-compete natives for limited resources, or prey on native species directly – and lead to extinctions. Some hybridize with native species carefully tuned to local climate, predation, competition, and disease, resulting in **genetic pollution** which weakens natural adaptations. Others change the very nature of the habitats they invade; Zebra Mussels, for example, colonize most manmade and natural surfaces (including native mussels), filter-feeding so intensely that they increase water clarity and enrich bottom habitats with their waste.

Globalization and tourism are increasing the number of exotics which threaten biodiversity throughout the world, breaking down geographic barriers and threatening the wisdom of millions of years of evolution and natural selection. If current trends continue, our increasingly interconnected world will eventually be dominated by just a few fast-growing, highly adaptable, keenly competitive "super-species" rather than the rich diversity we have today. Some biologists, noting that invasive exotics closely resemble what we consider to be "weed" species, have concluded that the world's #1 weed species is – did you guess it? – none other than *Homo sapiens.*

Causes of Extinction #3: Overexploitation

The modern equivalent to overkill, **overexploitation** threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species. Practices such as clear-cutting old growth forests, strip mining, and driftnet fishing go beyond harvesting of single species or resources to degrade entire ecosystems. Technology-aided over-harvesting has reduced one of the richest fisheries in the world – the Grand Banks off the coast of Newfoundland – to an estimated 1% of what they were in 1977 (**Figure** below). In 2003 in the journal *Nature,* Canadian biologists published an analysis of data showing that "industrialized" fishing has reduced large predatory fish worldwide by 90%. Some species' stocks are so depleted that less desirable species are illegally sold under the names of more expensive ones; in 2004, University of North Carolina graduate students tested DNA from fish sold as "red snapper" from eight states and found that different species made up 77% of the fish tested! Overexploitation happens on the level of genes and ecosystems as well as individual species. Forest plantations, fish hatcheries and farms, and intensive agriculture reduce both species diversity and genetic diversity within species.



Overexploitation of Atlantic cod threatens one of the world

Causes of Extinction #4: Global Climate Change

Our increasing reliance on fossil fuels is altering the Earth's atmosphere and climate. The effects include acid rain, breaks in the ozone layer shielding us from ultraviolet radiation, and greenhouse gases which raise the Earth's air and ocean temperatures and sea levels. Burning tropical rain forests compounds the effect, releasing carbon as CO_2 and eliminating the forest's ability to **sequester** carbon – remove carbon as CO_2 from the atmosphere – via photosynthesis. Inevitably, changing air and water temperatures, rainfall patterns, and salinity threaten species adapted to pre-warming conditions, and biodiversity declines globally. This concern is the topic of the Climate Change Lesson .

Causes of Extinction #5: Overpopulation

In 1960, Earth's human population stood at 3 billion. By 1999, we had grown to 6 billion. This unprecedented growth, together with developments in technology, has added immense pressure to resource and land use. Overpopulation compounds all of the aforementioned threats to biodiversity, and unequal distribution of resources extends the consequences to social and political instability. Human population growth continues (see the chapter on Biology of Populations). Growth rates vary – ominously, from a biodiversity perspective: the highest rates are in third world tropical countries where diversity is also highest. We have already seen how slash-and-burn agriculture and Lake Victoria fisheries connect socioeconomic changes to loss of biodiversity.

Causes of Extinction #6: Pollution

Pollution adds chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life. To a certain extent, pollution has not kept pace with population growth, at least in Europe and the US. Startling events such as the oil-and-debris-covered and lifeless Cuyahoga River catching fire in 1969 finally provoked the U.S. to stop viewing air and waterways as convenient dumping grounds for waste. Environmental legislation, including the establishment of the Environmental Protection Agency (EPA) has improved both water and air quality. Heeding the warning provided by the extirpation of the Peregrine Falcon from the Eastern U.S., scientists discovered that many synthetic chemicals concentrate as they move through the food chain (**biological magnification**), so that toxic effects are multiplied. DDT – the cause of the Peregrine's decline – was banned in the U.S., and regulation of pesticides was transferred from the Department of Agriculture to the EPA.

And yet, pollution continues to contribute to habitat degradation worldwide, especially in developing countries.

- **Air Pollution**: Knows no boundaries and growing concern about its effects on climate earn this topic two lessons later in this chapter. Acid rain, ozone depletion, and global warming each affect diversity.
- **Water Pollution**: Especially from threatens vital freshwater and marine resources in the US and throughout the world. Industrial and agricultural chemicals, waste, acid rain, and global warming threaten waters which are essential for all ecosystems. Threats to water resources are discussed in Lesson 2.
- **Soil Contamination**: Toxic industrial and municipal wastes, salts from irrigation, and pesticides from agriculture all degrade soils – the foundations of terrestrial ecosystems and their biodiversity. These and other threats to soils are discussed in Lesson 2, Natural Resources.

Outside the developed world, pollution controls lag behind those of the U.S. and Europe, and developing nations such as China are rapidly increasing levels of pollution. Many pollution problems remain in industrialized countries, as well: industry and technology add nuclear waste disposal, oil spills, thermal pollution from wastewater, light pollution of the night skies, acid rain, and more to the challenges facing Earth's biodiversity. Many will be discussed in the following lesson on Natural Resources, and you can certainly research more about those which interest or concern you. Our next task will be to switch from the doomsday report of problems and causes to a discussion of what WE – ordinary citizens – can do to help protect Earth's biodiversity.

End of Chapter Review

Chapter Summary

Like all species, humans depend on land, water, air, and living resources for food, energy, clothing, and **ecosystem services** such as nutrient recycling, waste disposal, and renewal of soil, freshwater, and clean air. Unlike other species, human technology supplements "natural" energy resources with fossil fuels and exploits both biotic and abiotic resources and produces wastes beyond the biosphere's capacity for renewal. Biodiversity encompasses all variation in living systems, including genetic, species, and ecosystem diversity.

Scientists do not know how many species currently inhabit the Earth; the vast majority of Bacteria and Archaea, Protists and Insects, are probably unknown. We discover new species of animals, plants, and fungi each year. About 1.8 million species have been identified, and most estimates of Earth's overall species biodiversity fall between 5 and 30 million. In general, biodiversity is highest near the equator, and decreases toward the poles. Biodiversity "hotspots" such as the California Floristic Province and unique habitats such as bogs occasionally disrupt the overall pattern. The fossil record and DNA analysis reveal a gradual increase in Earth's biodiversity after the first prokaryotes appeared roughly 4 billion years ago. Within the past 600 million years, a more detailed fossil record shows increasing biodiversity interrupted by five major extinctions in which at least 50% of species disappeared. According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event. Many scientists regard the Ice Age extinctions of large birds and mammals as the beginning of a continuum of extinctions caused by human activity which extends to the present. Dramatic losses of large mammal species follow a pattern of human dispersal across the globe from tens of thousands of years ago in Indonesia to just over 1,000 years ago in New Zealand, and over 20% of all bird species have become extinct within the past 1,100 years. Rates of extinction have accelerated in the past 50 years; current estimates include 3 species per hour and as many as 140,000 per year. In 2002, Harvard biologist E.O. Wilson predicted that if current rates of extinction continue, 50% of plant and animal species will be lost within the next 100 years – compared to hundreds of thousands or even millions of years for previous mass extinctions. Direct economic benefits include the potential to diversify our food supply, resources for clothing, shelter, energy, and medicines, a wealth of efficient designs which could inspire new technologies, models for medical research, and an early warning system for toxicity. Ecosystem services provided by biodiversity include ecosystem stability and productivity; maintaining and renewing soils, water supplies, and the atmosphere; nitrogen fixation and nutrient recycling; pollination, pest and disease control, and waste disposal. Less tangible but equally important are the cultural, aesthetic, and spiritual values and the importance of biodiversity to many modes of recreation. Finally, many people believe that biodiversity has intrinsic value, inherent in its existence. Human hunting, secondary effects on other species, disease carried and predation by exotic animals, and habitat destruction contributed to Ice Age extinctions. Habitat loss, including degradation and fragmentation, is the primary cause of extinction today; agriculture and deforestation continue to claim vegetated land and pollute both fresh and salt water seas.

Exotic species disrupt food chains and entire ecosystems to contribute to extinction. The modern equivalent to overkill, overexploitation of economically important species and ecosystems, threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species. Global climate change caused by the burning of fossil fuels disrupts weather patterns and, as it has throughout Earth's history, holds the potential to force the extinction of carefully adapted species. Pollution of land, air, and water poisons life and destroys ecosystems. Between 1960 and 1999, the Earth's human population increased from 3 billion to 6 billion people. Overpopulation combined with unequal distribution of resources dramatically intensifies pressures on biodiversity. Our daily activities and decisions can significantly help to protect biodiversity. After reducing consumption and reusing and recycling, careful consumption can help to conserve ecosystems. Local, seasonal products save energy costs for transportation. Durable and efficient products reduce long-term resource consumption.

Attributes

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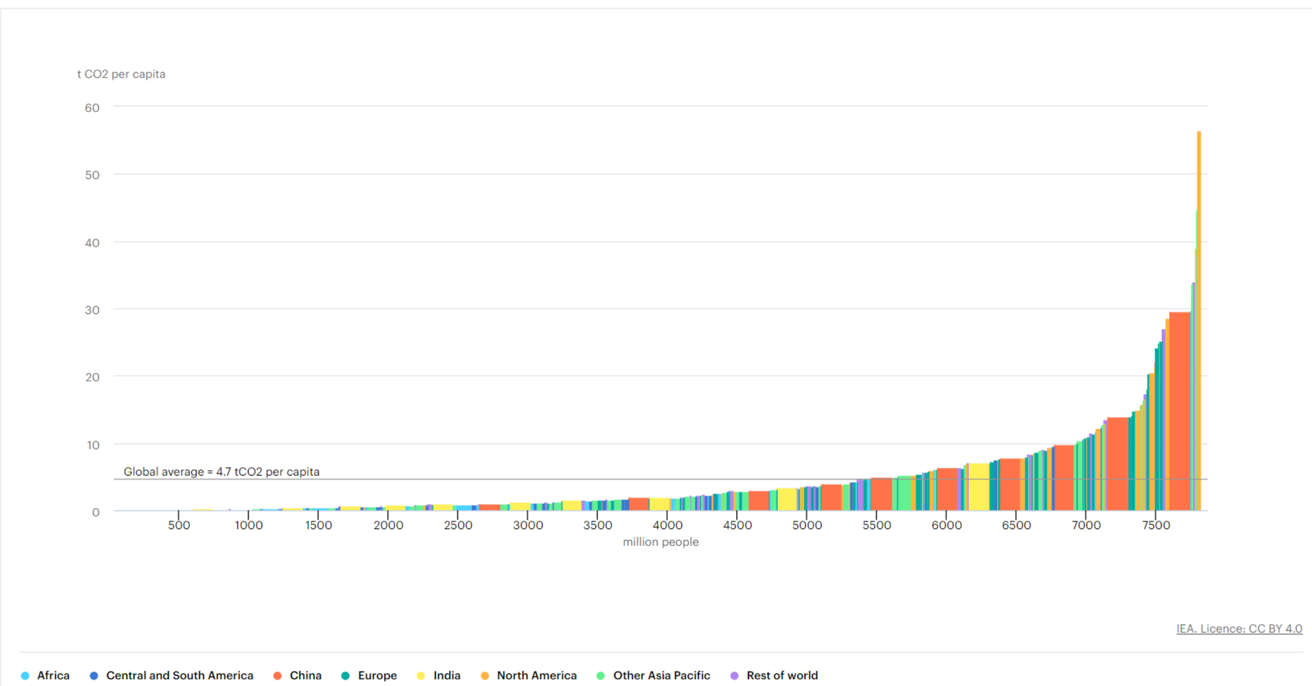
9.

CLIMATE CHANGE: ARE YOU PART OF THE PROBLEM OR PART OF THE SOLUTION?

Learning Objectives:

- What is climate change and how it is defined
- Understand the history behind climate change
- Describe the causes and consequences of climate change both regional and global
  - what are the major greenhouse gases(GHGs) and identify their sources and impacts
  - how is climate change effecting ecosystem and biodiversity
  - Be able to evaluate the impacts from various viewpoints and diverse groups
- Identify procedures of climate remediation and how to sequestrate carbon
- What tools are scientists using to study climate change

The world's top 1% of emitters produce over 1000 times more CO_2 than the bottom 1% with the US leading the way!



Source: IEA, *Energy-related CO2 emissions per capita by income decile by regions, 2021*, IEA, Paris https://www.iea.org/data-and-statistics/charts/energy-related-co2-emissions-per-capita-by-income-decile-by-regions-2021, IEA. Licence: CC BY 4.0

What is Climate Change?

According to the United Nations, climate change refers to long-term shifts in temperatures and weather patterns. Such shifts can be natural, due to changes in the sun's activity or large volcanic eruptions. But since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels like coal, oil and gas (United Nations Climate Action)

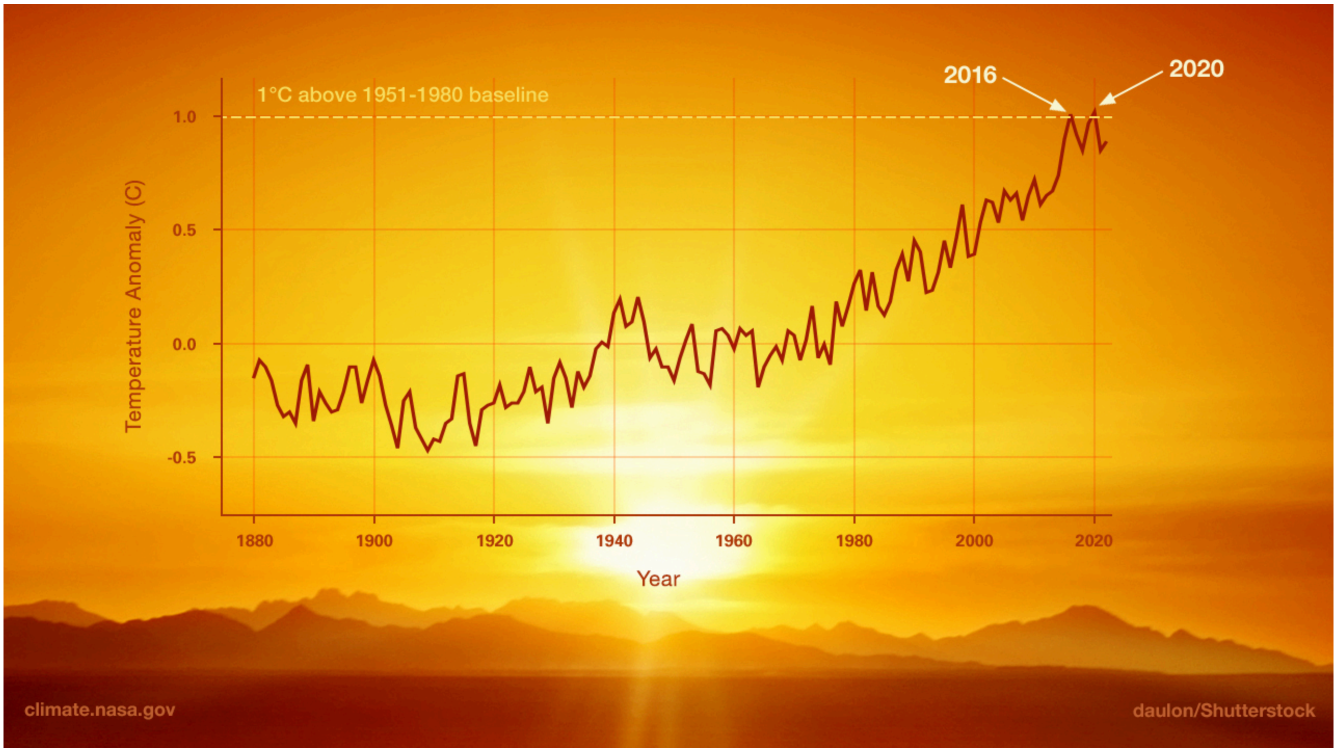
NASA defines climate change as; Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the term (NASA; What is Climate Change).

Climate change describes a change in the average conditions — such as temperature and rainfall — in a region over a long period of time. For example, 20,000 years ago, much of the United States was covered in glaciers. In the United States today, we have a warmer climate and fewer glaciers (NASA Kids)

Global climate change refers to the average long-term changes over the entire Earth. These include warming temperatures and changes in precipitation, as well as the effects of Earth's warming, such as:

- Rising sea levels
- Shrinking mountain glaciers
- Ice melting at a faster rate than usual in Greenland, Antarctica and the Arctic
- Changes in flower and plant blooming times.

Earth's climate has constantly been changing — even long before humans came into the picture. However, scientists have observed unusual changes recently. For example, Earth's average temperature has been increasing much more quickly than they would expect over the past 150 years. Climate change is one of the defining issues of our time. It is now more certain than ever, based on many lines of evidence, that humans are changing Earth's climate. The atmosphere and oceans have warmed, which has been accompanied by sea level rise, a strong
decline in Arctic sea ice, and other climate-related changes. The impacts of climate change on people and nature are increasingly apparent. Unprecedented flooding, heat waves, and wildfires have cost billions in damages. Habitats are undergoing rapid shifts in response to changing
temperatures and precipitation patterns.



This graph illustrates the change in global surface temperature relative to 1951-1980 average temperatures, with the year 2020 statistically tying with 2016 for hottest on record (Source: NASA's Goddard Institute for Space Studies).

The U.S. EPA defines climate change as: any significant change in the measures of climate lasting for an extended period of time (30yrs). In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer (www.epa.gov/climatechange/basices/)

As we see, the definitions addressing climate change are similar and interchangeable. The term climate change appeared in the scientific literature before the term global warming, and has been used more frequently in peer-reviewed articles for more than forty years. For example, the closely-related term climatic change was first used in a seminal 1956 paper by Gilbert N. Plass, whereas the term global warming wasn't used until 1975 by author Wallace Broecker.

What is Global Warming?

Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere. This term is not interchangeable with the term "climate change." (NASA). Global warming and climate change have different technical definitions, although they are often used interchangeably in popular media today.

Weather is a specific event for example, it rain today or its sunny and hot…it happens over a few hours, days or even weeks. It describes the short term state of the atmosphere. This includes such conditions as wind, air pressure, precipitation, humidity and temperature. Climate describes the typical, or average, atmospheric conditions. Weather and climate are different as the short term state is always changing but the long-term average is not. Climate is the average of weather.

The mass media, however, widely adopted the term global warming following James Hansen's widely reported testimony at a Senate hearing in 1988, in which he famously said: "***Global warming has reached a level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and observed warming.***[1]"

The Basics of Climate Change: Greenhouse gases affect Earth's energy balance and climate

The Sun serves as the primary energy source for Earth's climate. Some of the incoming sunlight is reflected directly back into space, especially by bright surfaces such as ice and clouds, and the rest is absorbed by the surface and the atmosphere. Much of this absorbed solar energy is re-emitted as heat (longwave or infrared radiation). The atmosphere in turn absorbs and re-radiates heat, some of which escapes to space. Any disturbance to this balance of incoming and outgoing energy will affect the climate. For example, small changes in the output of energy from the Sun will affect this balance directly.

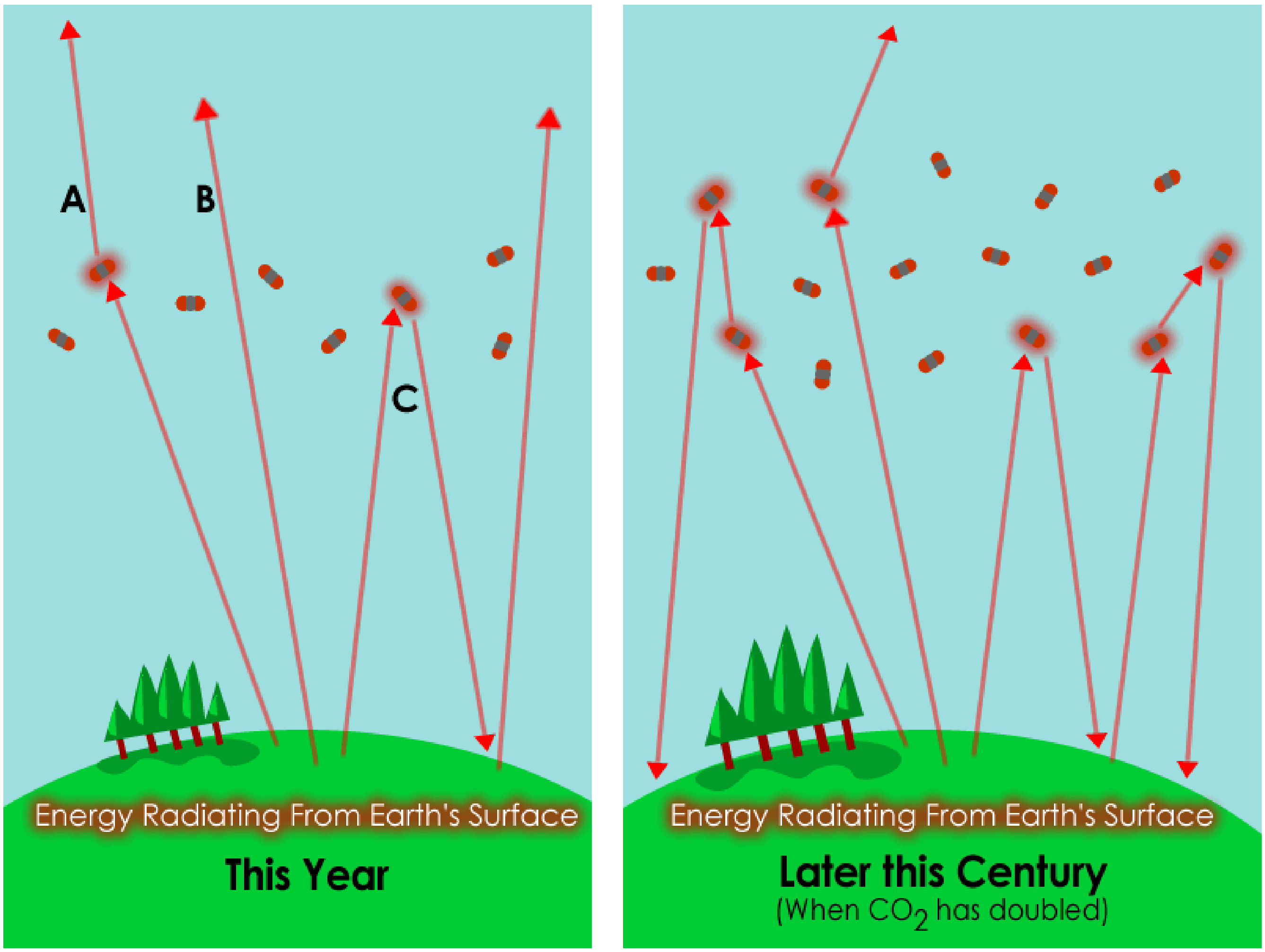
If all heat energy emitted from the surface passed through the atmosphere directly into space, Earth's average surface temperature would be tens of degrees colder than today. Greenhouse gases in the atmosphere, including water vapor, carbon dioxide, methane, and nitrous oxide, act to make the surface much warmer than this because they absorb and emit heat energy in all directions (including downwards), keeping Earth's surface and lower atmosphere warm . Without this greenhouse effect, life as we know it could not have evolved on our planet. Adding more greenhouse gases to the atmosphere makes it even more effective at preventing heat from escaping into space. When the energy leaving is less than the energy entering, Earth warms until a new balance is established.

Basics of Climate Change | US EPA

In the figure above, greenhouse gases in the atmosphere, including water vapor, carbon dioxide, methane, and nitrous oxide, absorb heat energy and emit it in all directions (including downwards), keeping Earth's surface and lower atmosphere warm. Adding more greenhouse gases to the atmosphere enhances the effect, making Earth's surface and lower atmosphere even warmer. Image based on a figure from US Environmental Protection Agency.

Greenhouse gases emitted by human activities alter Earth's energy balance and thus its climate. Humans also affect climate by changing the nature of the land surfaces (for example by clearing forests for farming) and through the emission of pollutants that affect the amount and type of particles in the atmosphere. Scientists have determined that, when all human and natural factors are considered, Earth's climate balance has been altered towards warming, with the biggest contributor being increases in CO2.

Even though only a tiny amount of the gases in Earth's atmosphere are greenhouse gases, they have a huge effect on climate. Sometime during this century, the amount of the greenhouse gas carbon dioxide in the atmosphere is expected to double. Other greenhouse gases like methane and nitrous oxide are increasing as well. The quantity of greenhouse gases is increasing as fossil fuels are burned, releasing the gases and other air pollutants into the atmosphere. Greenhouse gases also make their way to the atmosphere from other sources. Farm animals, for example, release methane gas as they digest food. As cement is made from limestone, it releases carbon dioxide.



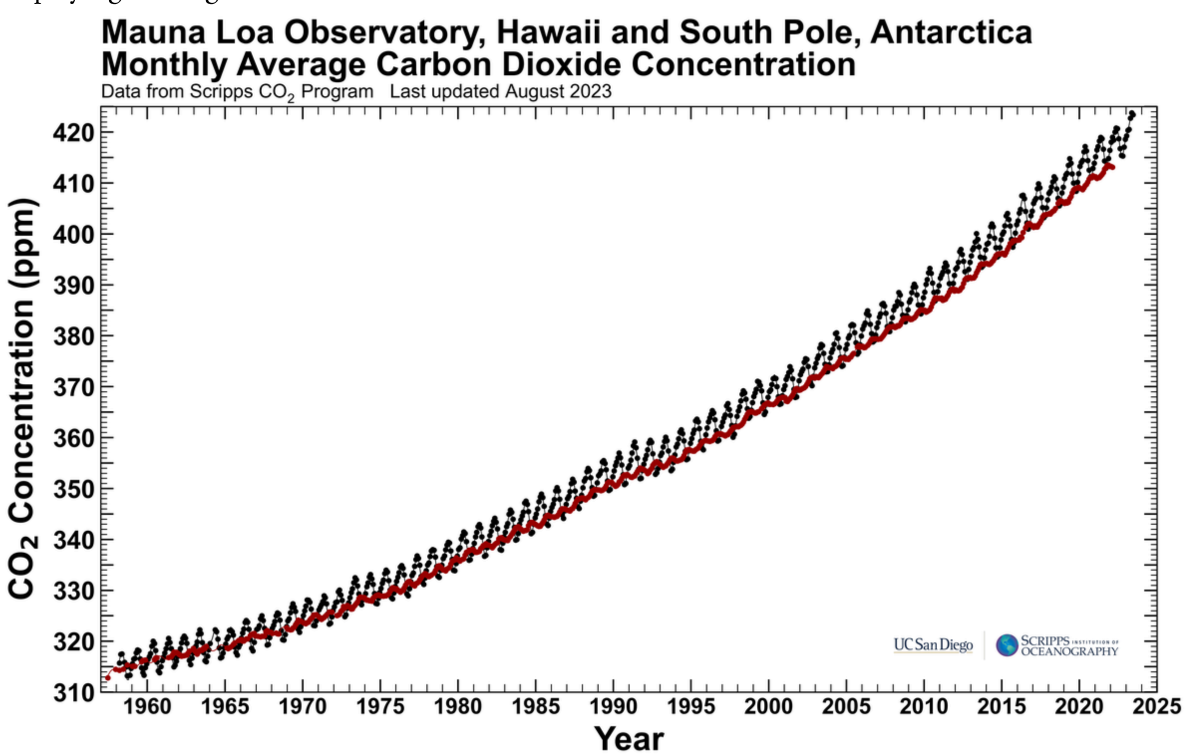
Above: (Left) The Earth's surface, warmed by the Sun, radiates heat into the atmosphere. Some heat is absorbed by greenhouse gases like carbon dioxide and then radiated to space (A). Some heat makes its way to space directly (B). Some heat is absorbed by greenhouse gases and then radiated back towards the Earth's surface (C). (Right) With more carbon dioxide in the atmosphere later this Century, more heat will be stopped by greenhouse gases, warming the planet. (Image: L.S.Gardiner/UCAR)

Why Greenhouse Gases Make the Planet Warmer

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=203#oembed-1

Are human activities adding to greenhouse gases in the atmosphere?

The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased significantly since the Industrial Revolution began. In the case of carbon dioxide, the average concentration measured at the Mauna Loa Observatory in Hawaii has risen from 316 parts per million (ppm = for every million molecules in the air, 316 of them were CO2) in 1959 (the first full year of data available) to more than 420 ppm in 2022 (See figure below). The same rates of increase have since been recorded at numerous other stations worldwide. Since preindustrial times, the atmospheric concentration of CO2 has increased by over 40%, methane has increased by more than 150%, and nitrous oxide has increased by roughly 20%. More than half of the increase in CO2 has occurred since 1970. Increases in all three gases contribute to warming of Earth, with the increase in CO2 playing the largest role.

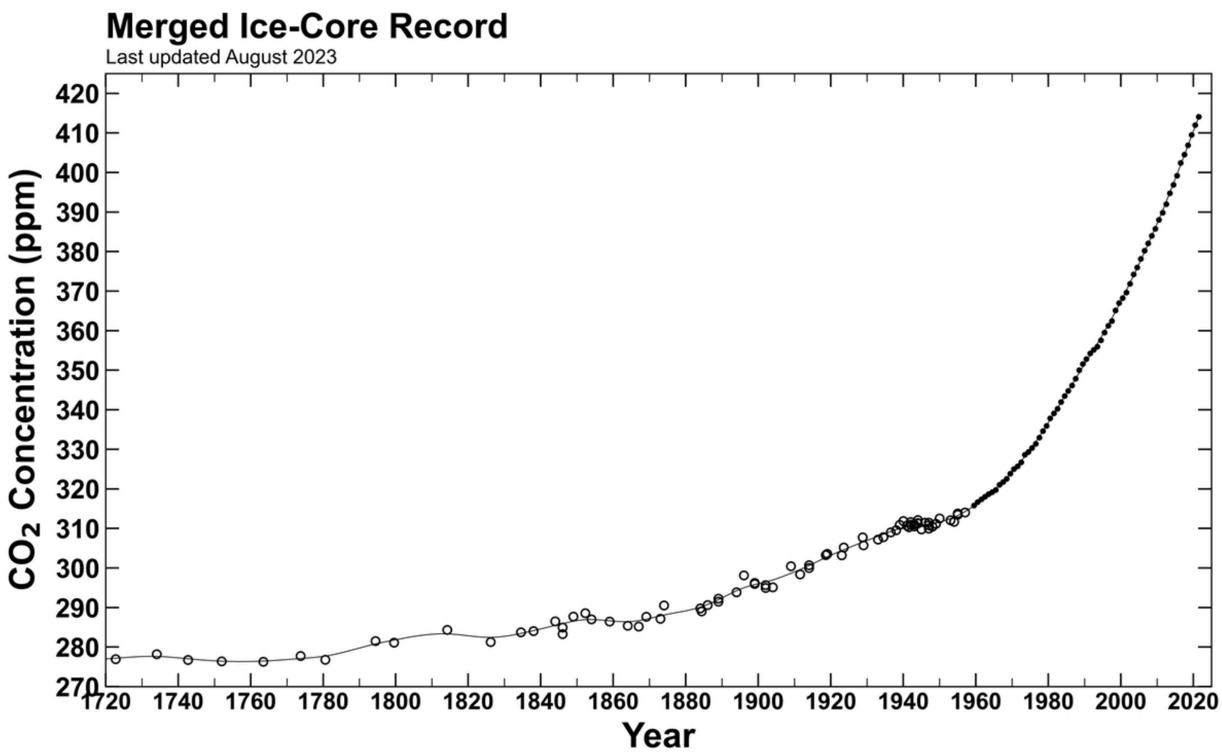


Black Curve: Monthly average atmospheric carbon dioxide concentration versus time at Mauna Loa Observatory, Hawaii (20 °N, 156 °W) where CO_2 concentration is in parts per million in the mole fraction (p.p.m.). Monthly data are shown as dots and connected with straight lines. The record is distinguished by its pronounced seasonal cycle.

Red Curve: Monthly average atmospheric carbon dioxide concentration versus time at the South Pole, Antarctica where CO_2 concentration is in parts per million in the mole fraction (p.p.m.). Monthly data points are shown as dots and connected approximately by a smooth curve.

Scientists have examined greenhouse gases in the context of the past. Analysis of air trapped inside ice that has been accumulating over time in Antarctica shows that the CO2 concentration began to increase significantly in the 19th century (see figure below), after staying

in the range of 260 to 280 ppm for the previous 10,000 years. Ice core records extending back 800,000 years show that during that time, CO2 concentrations remained within the range of 170 to 300 ppm throughout many "ice age" cycles — and no concentration above 300 ppm is seen in ice core records until the past 200 years.



Merged ice-core record of the time trend of the concentration of CO_2, in ppm, in air extracted from an Antarctic ice core combined with the trend based on direct atmospheric measurements.

Open Black Circles: Antarctic ice core record from Law Dome before 1958 (Macfarling Meure, C. et al., 2006: Law Dome CO2, CH4 and N2O ice core records extended to 2000 years BP. Geophysical Research Letters, 33.) Ice core data are rejected after 1958 which overlap direct measurements.

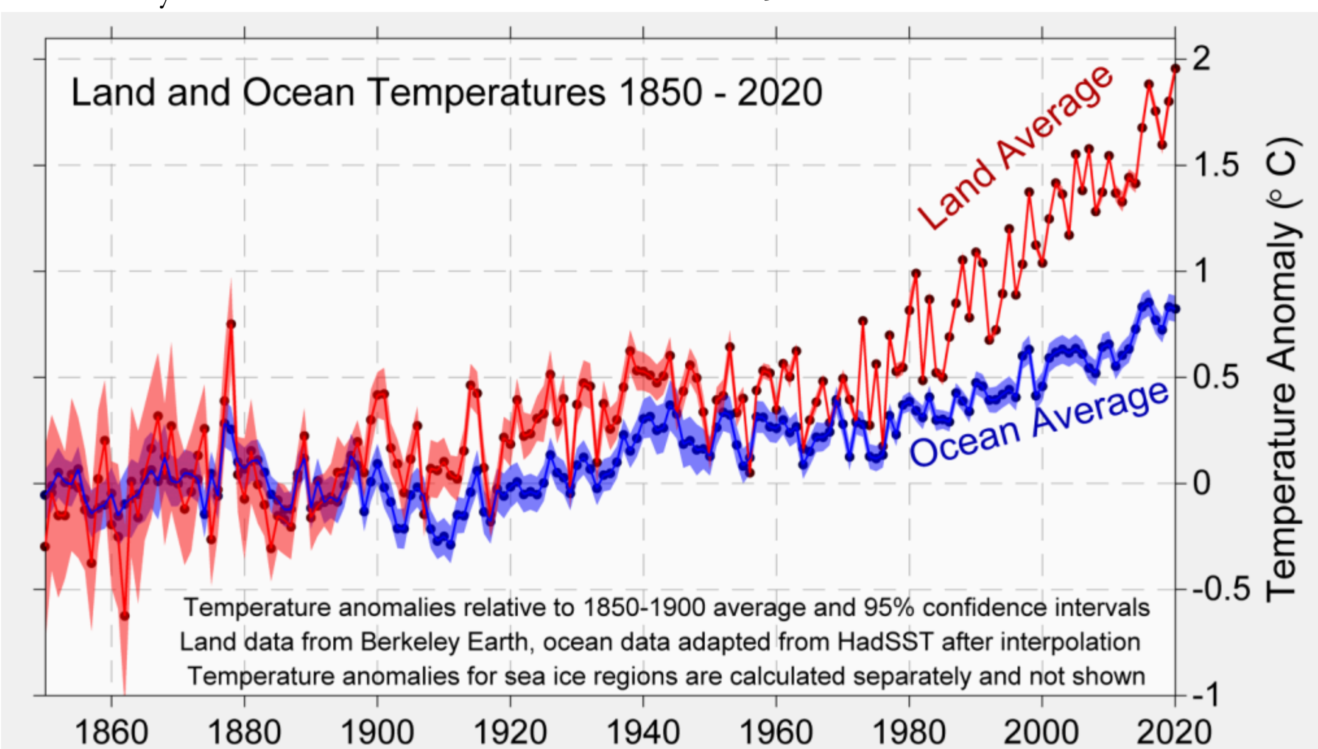
Closed Black Circles: Seasonally detrended arithmetic average of air measurements from Mauna Loa and the South Pole from the Scripps CO_2 program after and including 1958.

Source: https://scrippsco2.ucsd.edu/graphics_gallery/mauna_loa_and_south_pole/merged_ice_core_record.html

Measuring isotopes of carbon show in modern atmosphere a clear fingerprint of the addition of **old** carbon (depleted in natural radioactive ^{14}C) coming from the burning of fossil fuels (as opposed to "newer" carbon coming from living systems). The science shows that it is human activity (excluding land use changes) emitting an estimated 10 billion tonnes of CO_2 each year, and this is primarily from the burning of fossil fuels. This is more than enough to explain the noted increases in CO_2 concentrations. Along with this, and other information, it is clear and conclusively that humans are responsible for the elevated carbon dioxide levels in our atmosphere.

Climate records show a warming trend.

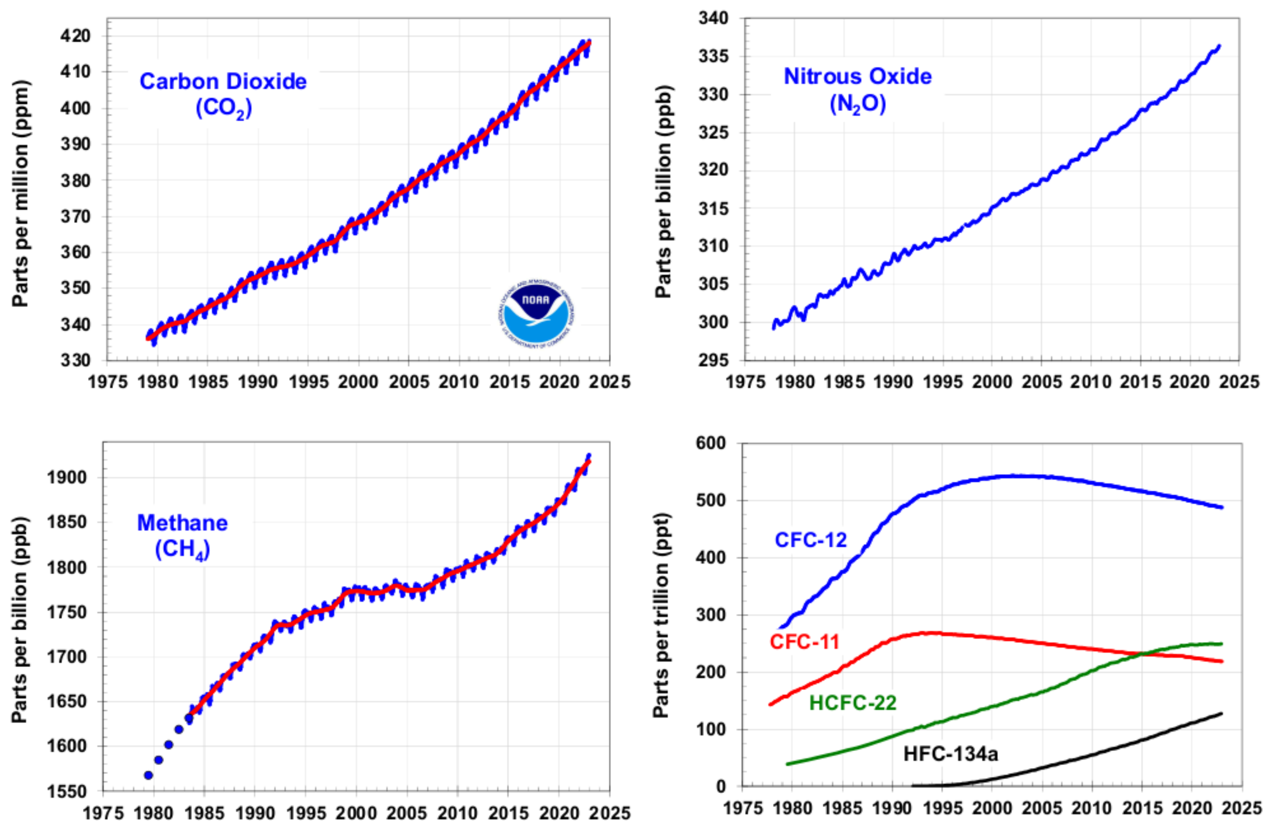
Estimating global average surface air temperature increase requires careful analysis of millions of measurements from around the world, including from land stations, ships, and satellites. Despite the many complications of synthesizing such data, multiple independent teams have concluded separately and unanimously that global average surface air temperature has risen by about 1 °C (1.8 °F See figure below) since 1900 . Although the record shows several pauses and accelerations in the increasing trend, each of the last four decades has been warmer than any other decade in the instrumental record since 1850.



Earth's global average surface temperature has risen, as shown in this plot of combined land and ocean measurements from 1850 to 2019 derived from
three independent analyses of the available data sets.

Going further back in time before accurate thermometers were widely available, temperatures can be reconstructed using climate-sensitive indicators "proxies" in materials such as tree rings, ice cores, and marine sediments. Comparisons of the thermometer record with these proxy measurements suggest that the time since the early 1980s has been the warmest 40-year period in at least eight centuries, and that global temperature is rising towards peak temperatures last seen 5,000 to 10,000 years ago in the warmest part of our current interglacial period.

Many other impacts associated with the warming trend have become evident in recent years. Arctic summer sea ice cover has shrunk dramatically. The heat content of the ocean as increased. Global average sea level has risen by approximately 16 cm (6 inches) since 1901, due both to the expansion of warmer ocean water and to the addition of melt waters from glaciers and ice sheets on land. Warming and precipitation changes are altering the geographical ranges of many plant and animal species and the timing of their life cycles. In addition to the effects on climate, some of the excess CO2 in the atmosphere is being
taken up by the ocean, changing its chemical composition (causing ocean acidification).



Global average abundances of the major, well-mixed, long-lived greenhouse gases – carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11 – from the NOAA global air sampling network since the beginning of 1979. These five gases account for about 96% of the direct radiative forcing by long-lived greenhouse gases since 1750. The remaining 4% is contributed by 15 other halogenated gases including HCFC-22 and HFC-134a, for which NOAA observations are also shown here. Methane data before 1983 are annual averages from D. Etheridge *[Etheridge et al., 1998]*, adjusted to the NOAA calibration scale *[Dlugokencky et al., 2005]*. https://gml.noaa.gov/aggi/aggi.html

Our Climate is complex and is shaped by many process

Based just on the physics of the amount of energy that CO2 absorbs and emits, a doubling of atmospheric CO2 concentration from pre-industrial levels (up to about 560 ppm) would by itself cause a global average temperature increase of about 1 °C (1.8 °F). In the overall climate system, however, things are more complex; warming leads to further effects (feedbacks) that either amplify or diminish the initial warming.

The most important feedbacks involve various forms of water. A warmer atmosphere generally contains more water vapor. Water vapor is a potent greenhouse gas, thus causing more warming; its short lifetime in the atmosphere keeps its increase largely in step with warming. Thus, water vapor is treated as an amplifier, and not a driver, of climate change. Higher temperatures in the polar regions melt sea ice and reduce seasonal snow cover, exposing a darker ocean and land surface that can absorb more heat, causing further warming. Another important but uncertain feedback concerns changes in clouds. Warming and increases in water vapor together may cause cloud cover to increase or decrease which can either amplify or dampen temperature change depending on the changes in the horizontal extent, altitude, and properties of clouds. The latest assessment of the science indicates that the overall net global
effect of cloud changes is likely to be to amplify warming.

The ocean moderates climate change. The ocean is a huge heat reservoir, but it is difficult to heat its full depth because warm water tends to stay near the surface. The rate at which heat is transferred to the deep ocean is therefore slow; it varies from year to year and from decade to decade, and it helps to determine the pace of warming at the surface. Observations of the sub-surface ocean are limited prior to about 1970, but since then, warming of the upper 700 m
(2,300 feet) is readily apparent, and deeper warming is also clearly observed since about 1990.

Surface temperatures and rainfall in most regions vary greatly from the global average because of geographical location, in particular latitude and continental position. Both the average values of temperature, rainfall, and their extremes (which generally have the largest impacts on natural systems and human infrastructure), are also strongly affected by local patterns of winds.

Estimating the effects of feedback processes, the pace of the warming, and regional climate change requires the use of mathematical models of the atmosphere, ocean, land, and ice (the cryosphere) built upon established laws of physics and the latest understanding of the physical, chemical and biological processes affecting climate, and run on powerful computers. Models vary in their projections of how much additional warming to expect (depending on the
type of model and on assumptions used in simulating certain climate processes, particularly cloud formation and ocean mixing), but all such models agree that the overall net effect of feedbacks is to amplify warming.

The climate is changing due to human activities

Rigorous analysis of all data and lines of evidence shows that most of the observed global warming over the past 50 years or so cannot be explained by natural causes and instead requires a significant role for the influence of human activities.

In order to separate the human influence on climate, scientists must consider many natural variations that affect temperature, precipitation, and other aspects of climate from local to global scale, on timescales from days to decades and longer. One natural variation is the El Niño Southern Oscillation (ENSO), an irregular alternation between warming and cooling (lasting about two to seven years) in the equatorial Pacific Ocean that causes significant
year-to-year regional and global shifts in temperature and rainfall patterns. Volcanic eruptions also alter climate, in part increasing the amount of small (aerosol) particles in the stratosphere that reflect or absorb sunlight, leading to a short-term surface cooling lasting typically about two to three years. Over hundreds of thousands of years, slow, recurring variations in Earth's orbit around the Sun, which alter the distribution of solar energy received by Earth, have been enough to trigger the ice age cycles of the past 800,000 years.

Fingerprinting is a powerful way of studying the causes of climate change. Different influences on climate lead to different patterns seen in climate records. This becomes obvious when scientists probe beyond changes in the average temperature of the planet and look more closely at geographical and temporal patterns of climate change. For example, an increase in the Sun's energy output will lead to a very different pattern of temperature change (across Earth's surface and vertically in the atmosphere) compared to that induced by an increase in CO2 concentration. Observed atmospheric temperature changes show a fingerprint much closer to that of a long-term CO2 increase than to that of a fluctuating Sun alone. Scientists routinely test whether purely natural changes in the Sun, volcanic activity, or internal climate variability could plausibly explain the patterns of change they have observed in many different aspects of the climate system. These analyses have shown that the observed climate changes of the past several decades cannot be explained just by natural factors.

What are some of the human causes of climate change?

In addition to emitting greenhouse gases, human activities have also altered Earth's energy balance through, for example:

- Changes in land use. Changes in the way people use land — for example, for forests, farms, or cities — can lead to both warming and cooling effects locally by changing the reflectivity of Earth's surfaces (affecting how much sunlight is sent back into space) and by changing how wet a region is.
- Emissions of pollutants (other than greenhouse gases). Some industrial and agricultural processes emit pollutants that produce aerosols (small droplets or particles suspended in the atmosphere). Most aerosols cool Earth by reflecting sunlight back to space. Some aerosols also affect the formation of clouds, which can have a warming or cooling effect depending on their type and location. Black carbon particles (or "soot") produced when fossil fuels or vegetation are burned generally have a warming effect because they absorb incoming solar radiation.
- Increases in near surface ozone from internal combustion engines, aerosols such as carbon black, mineral

dust and aviation-induced exhaust are acting to raise the surface temperature.

Greenhouse gas	Chemical formula or abbreviation	Lifetime in atmosphere	Global warming poten
Carbon dioxide	CO2	Variable	1
Methane	CH4	12 years	28-36
Nitrous oxide	N2O	114 years	298
Hydrofluorocarbons	Abbreviation: HFCs	1-270 years	12-14,800
Perfluorocarbons	Abbreviation: PFCs	2,600-50,000 years	7,390
Sulfur hexafluoride	SF6	3,200 years	22,800

Comparison of common greenhouse gases in the atmosphere.

The History of Climate Change

In 1640 carbon dioxide was discovered by Johann Baptista van Helmolt, Flemish alchemist, determined that air is a mixture of gases. He studied the gas given off when wood and other fuels were burned, which is carbon dioxide, determining that it is not healthy to breathe. In an experiment, he burned coal to see how much carbon dioxide it added to the air. In 1754 the first carbon dioxide detector was invented by Joseph Black, a medical student in Edinburgh, figured out that limewater can be used as a carbon dioxide (CO_2) detector. He observed that the normally clear liquid turned milky when exposed to “fixed air,” which is what he called CO_2. He started measuring the gas everywhere with his limewater, and found that it was released from mineral water, fermenting yeast, burning coal and oil, cremating corpses, and human exhalation. The limewater instrument was later improved by Lord Cavendish, and became known as the Cavendish Apparatus.

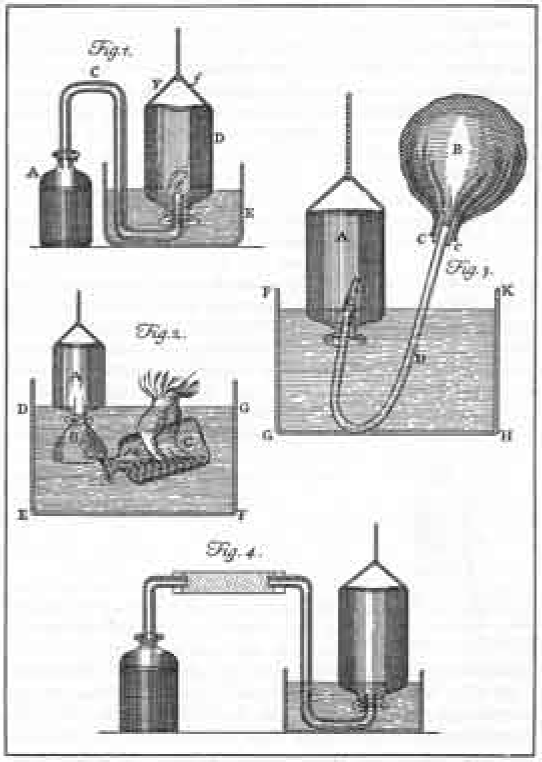
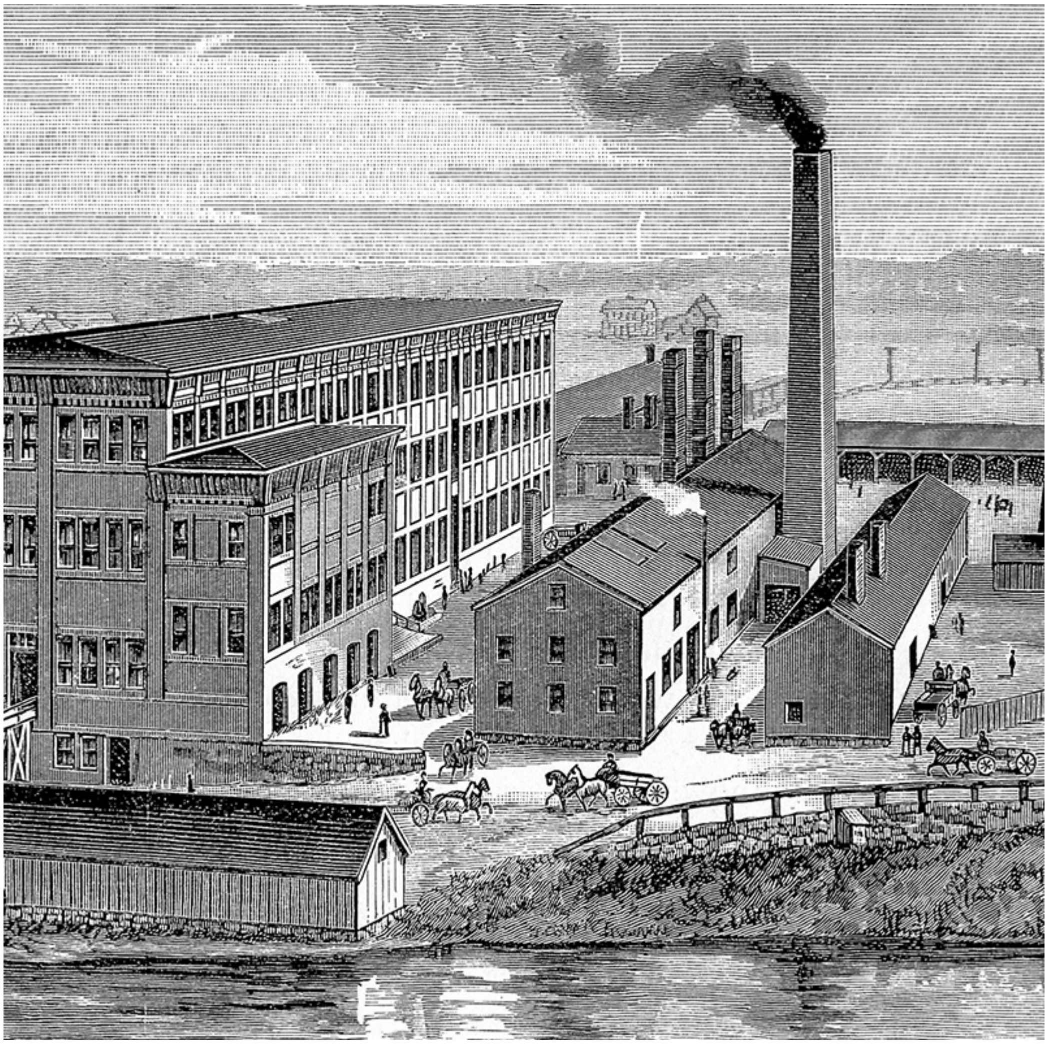


FIG. 48.—CAVENDISH'S APPARATUS FOR MANIPULATION OF GASES.

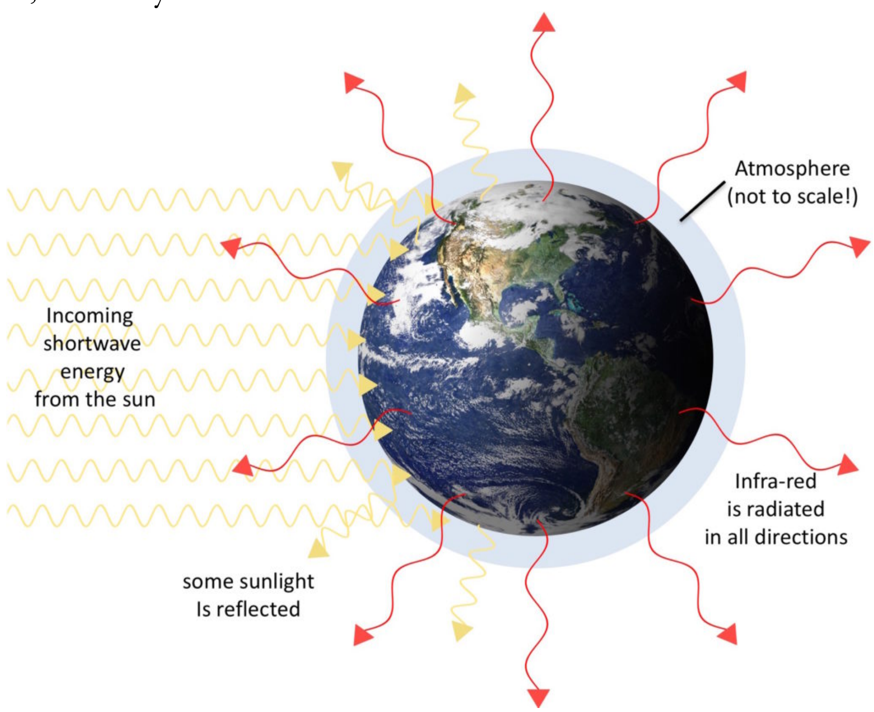
The limewater instrument that Cavendish used to study gases

Around 1760, we have the start of the Industrial Revolution. Since the start of the Industrial Revolution, the way people live and work has changed dramatically as manufacturing expanded. Over time, the amount of fossil fuels burned increased, which has increased the amount of carbon dioxide (CO_2) in the atmosphere . Before the Industrial Revolution, there was approximately 280 parts per million (ppm) of CO_2 in the air. Today, that amount is over 400 ppm!



In 1824 Jean-Baptiste-Joseph Fourier, a mathematician working for Napoleon, was the first to describe how Earth's atmosphere retains warmth on what would otherwise be a very cold planet.. To help explain the concept, he compared the atmosphere to the glass walls of a greenhouse. Fourier had studied the up-and-down cycles of temperature between day and night, and between summer and winter, and had measured how deep into the ground these heating and cooling cycles reach. It turns out they don't go very deep. At about 30 meters below the surface, temperatures remain constant all year round, showing no sign of daily or annual change. The temperature of any object is due to the balance of heat entering and leaving it. If more heat is entering, the object warms up, and if more heat is leaving, it cools down. For the planet as a whole, Fourier pointed out there are only three possible sources of heat: the sun, the Earth's core, and background heat from space. His measurements showed that the heat at the Earth's core no longer warms the surface, because the diffusion of heat through layers of rock is too slow to make a noticeable difference.

The solution lay in the behavior of 'dark heat', an idea that was new and mysterious to the scientists of the early nineteenth century. Today we call it infra-red radiation. Fourier referred to it as 'radiant heat' or 'dark rays' to distinguish it from 'light heat', or visible light. But really, they're just different parts of the electromagnetic spectrum. Any object that's warmer than its surroundings continually radiates some of its heat to those surroundings. If the object is hot enough, say a stove, you can feel this 'dark heat' if you put your hand near it, although it has to get pretty hot before we can feel the infra-red it gives off. As you heat up an object, the heat it radiates spreads up the spectrum from infra-red to visible light—it starts to glow red, and then, eventually white hot.



The surface temperature of the Earth is determined by the balance between the incoming heat from the sun (shortwave rays, mainly in the visible light and ultra-violet) and the outgoing infra-red, radiated in all directions from the Earth. The incoming short-wave rays passes through the atmosphere much more easily than the long-wave outgoing infra-red.

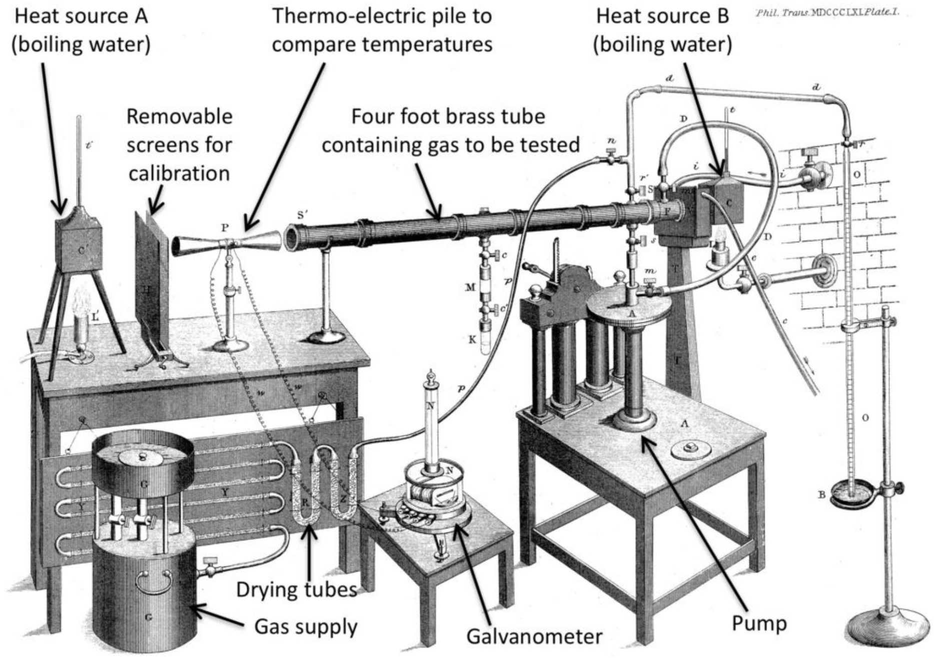
To explain the idea, Fourier used an analogy with the hotbox, a kind of solar oven, invented by the explorer Horace Bénédict de Saussure. The hotbox was a very well-insulated wooden box, painted black inside, with three layers of glass in the lid. De Saussure had demonstrated that the sun would heat the inside of the box to over 100°C, and that this temperature remains remarkably consistent, even at the top of Mont Blanc, where the outside air is much colder. The glass lets the sun's rays through, but slows the rate at which the heat can escape. Fourier argued that layers of air in the atmosphere play a similar role to the panes of glass in the hotbox, by trapping the outgoing heat; like the air in the hotbox, the planet would stay warmer than its surroundings. A century later, Fourier's theory came to be called the Greenhouse Effect, perhaps because a greenhouse is more familiar to most people than a hotbox.

Today, Fourier is perhaps best remembered for his work on the mathematics of such cycles, and the *Fourier transform*, a technique for discovering cyclic waveforms in complex data series, was named in his honor.

Later on in the 1800's hundreds, Eunice Foote, American scientist, discovered that carbon dioxide and water vapor cause air to warm in sunlight. In 1856, she presented her findings at the meeting of the American Association for the Advancement of Science (AAAS). "A paper was read before the late meeting of the

Scientific Association, by Prof. Henry for Mrs. Eunice Foot, detailing her experiments to determine the effects of the sun's rays on different gases," noted an 1856 article in Scientific America (which is no longer available).

1859; John Tyndall, British physicist, tested the gases in the atmosphere to find out which are responsible for the greenhouse effect. He found that nitrogen and oxygen, which make up almost all of the atmosphere, have no ability to trap heat, but that three gases present in smaller quantities do: carbon dioxide, ozone, and water vapor. Tyndall speculated that if the amounts of these gases dropped, it would chill the Earth.

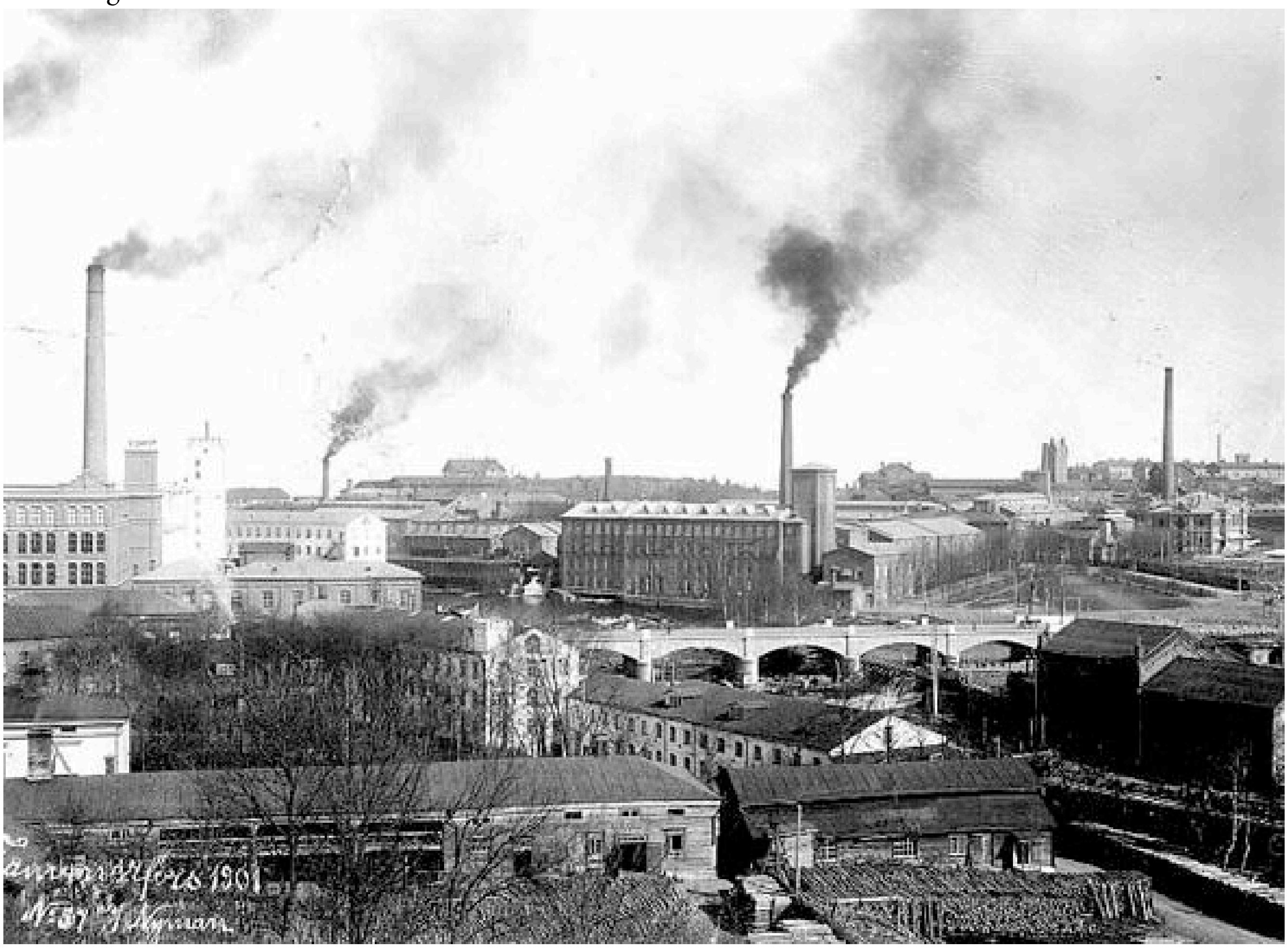


Tyndall's experimental equipment for testing the absorption properties of different gases. The brass tube was first evacuated, and the equipment calibrated by moving the screens until the temperature readings from the two heat sources were equal. Then the gas to be tested was pumped into the brass tube, and change in deflection of the galvanometer noted. (Figure adapted from Tyndall, 1861)

When Tyndall filled the tube with dry air, or oxygen, or nitrogen, there was very little change. But when he filled it with the hydrocarbon gas ethene, the temperature at the end of the tube dropped dramatically. This was so surprising that he first suspected something had gone wrong with the equipment—perhaps the gas had reacted with the salt, making the ends opaque? After re-testing every aspect of the equipment, he finally concluded that it was the ethene gas itself that was blocking the heat. He went on to test dozens of other gases and vapors, and found that more complex chemicals such as vapors of alcohols and oils were the strongest heat absorbers, while pure elements such as oxygen and nitrogen had the least effect.

Tyndall concluded that, because of its abundance in the atmosphere, water vapor is responsible for most of the heat trapping effect, with carbon dioxide second. Some of the other vapors he tested have a much stronger absorption effect, but are so rare in the atmosphere they contribute little to the overall effect. Tyndall clearly understood the implications of his experiments for the Earth's climate, arguing that it explains why, for example, temperatures in dry regions such as deserts drop overnight far more than in more humid regions. In the 1861 paper describing his experimental results, Tyndall argued that any change in the levels of water vapor and carbon dioxide, “must produce a change of climate”. He speculated that “Such changes in fact may have produced all the mutations of climate which the researches of geologists reveal”.

1896; Swedish chemist Svante Arrhenius recognized that burning coal could increase carbon dioxide and warm the climate. He estimated how much carbon dioxide the ocean could absorb. In an 1896 lecture, Arrhenius noted that it was not yet possible to calculate how fast temperature was rising. He also speculated that warming would be beneficial as people in the future “might live under a milder sky and in less barren surroundings.”



Factory smoke, 1901

1938; British coal engineer George Callendar compiled all carbon dioxide measurements made over the previous 100 years and found that the amount of CO_2 was increasing. He also found that temperatures were rising. His conclusion was that this was a good thing, that “the return of the deadly glaciers should be delayed indefinitely.”

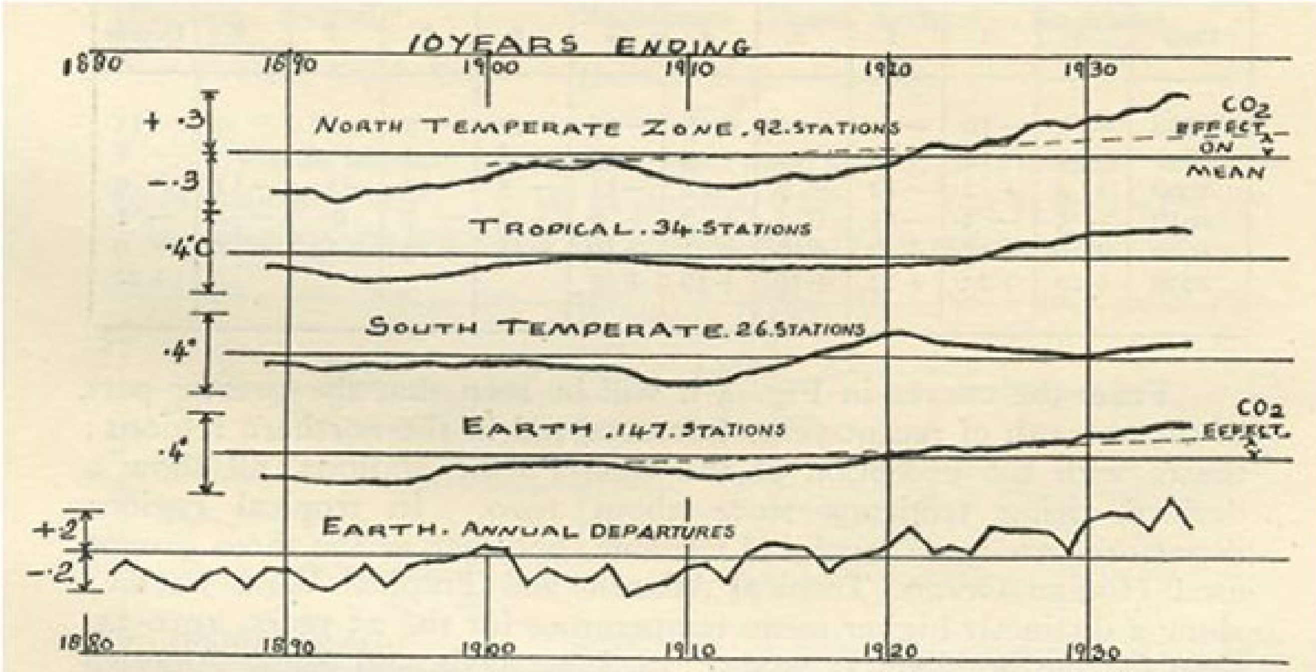


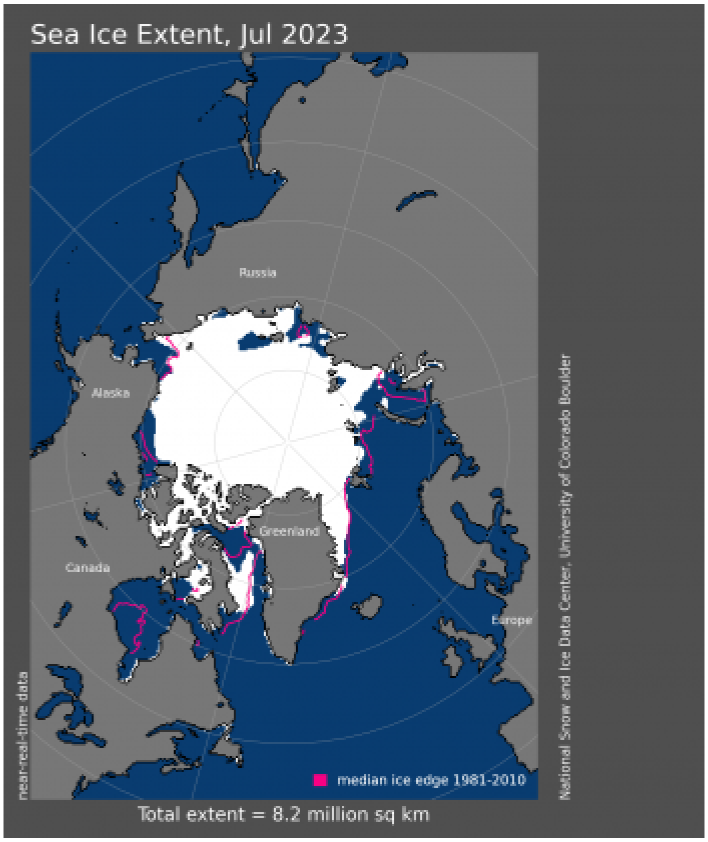
FIG. 4.—Temperature variations of the zones and of the earth. Ten-year moving departures from the mean, 1901-1930, °C.

From Callendar's 1938 paper, The Artificial Production of Carbon Dioxide and its Influence on Temperature

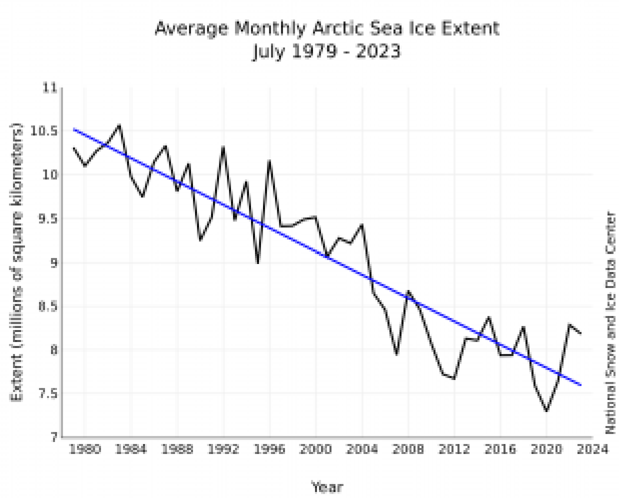
https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/j.1477-8696.1949.tb00952.x

1957; Roger Revelle, U.S. oceanographer, and Hans Suess, Austrian-born U.S. chemist, realized that carbon dioxide from industrial sources must be building up in the atmosphere, wrote in 1957: "Thus human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

Measurements since the 1950s indicate that the amount of sea ice in the Arctic has been declining. The Arctic is projected to have no summer ice cover by the middle of this century



Arctic sea ice extent for July 2023 was 8.18 million square kilometers (3.16 million square miles). The magenta line shows the 1981 to 2010 average extent for that month. Sea Ice Index data. Credit: National Snow and Ice Data Center https://nsidc.org/arcticseaicenews/



Monthly July ice extent for 1979 to 2023 shows a decline of 7.0 percent per decade. Credit: National Snow and Ice Data Center

1958; The Bell Telephone Science Hour addressed how our actions could be changing Earth's climate. "Even now, [we] may be unwittingly changing the world's climate through the waste products of [our] civilization," said the narrator. "Due to our release from factories and automobiles every year of more than six billion tons of carbon dioxide, which helps the air absorb heat from the Sun, our atmosphere seems to be getting warmer."

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=203#oembed-2

1958; Charles Keeling started making daily measurements of the amount of carbon dioxide in the air atop Mauna Loa in Hawaii. That first March day, he found 313 parts per million (ppm) of carbon dioxide in the air. The measurements, which are still made each day, reached 400 ppm on May 9, 2013, and continue to climb. Today, carbon dioxide levels are at 422 ppm and climbing (https://climate.nasa.gov/)

The Keeling Curve Hits 410 PPM

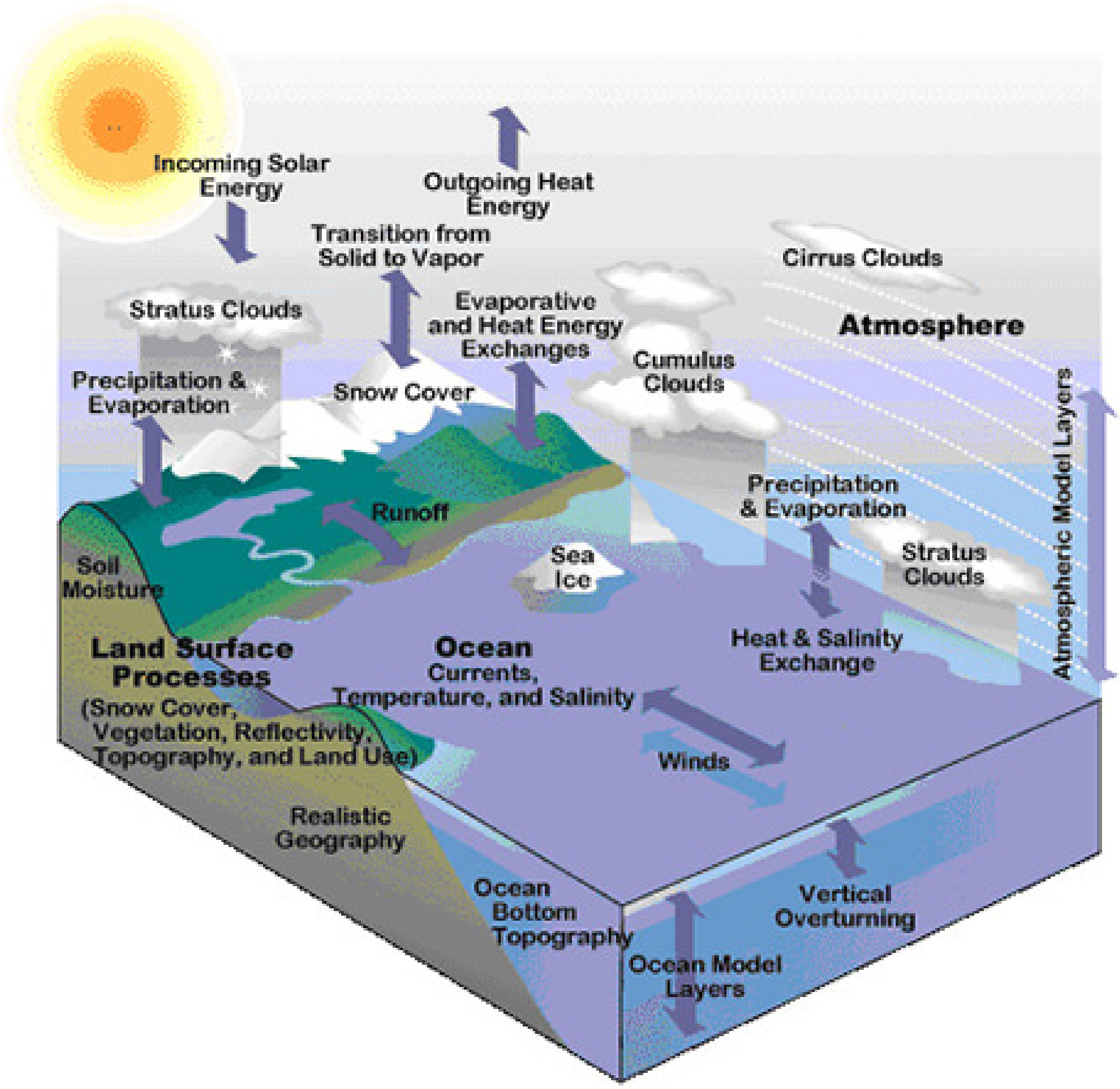
One or more interactive elements has been excluded from this version of the text. You can view them online here: https://rvcc.pressbooks.pub/envstudies/?p=203#oembed-3

1966: At Camp Century, Greenland, an ice core was extracted that showed 8,200 years of annual snow accumulation as thin layers in the ice. The thin layers of ice allowed scientists to reconstruct ancient climate using an ice core for the first time (source; https://nsidc.org/learn).

1988; NASA climate scientist James Hansen testified before the Senate Energy and Natural Resources Committee stating that climate was warming, greenhouse gases are responsible for the warming, and we are responsible for the growth in these gases.

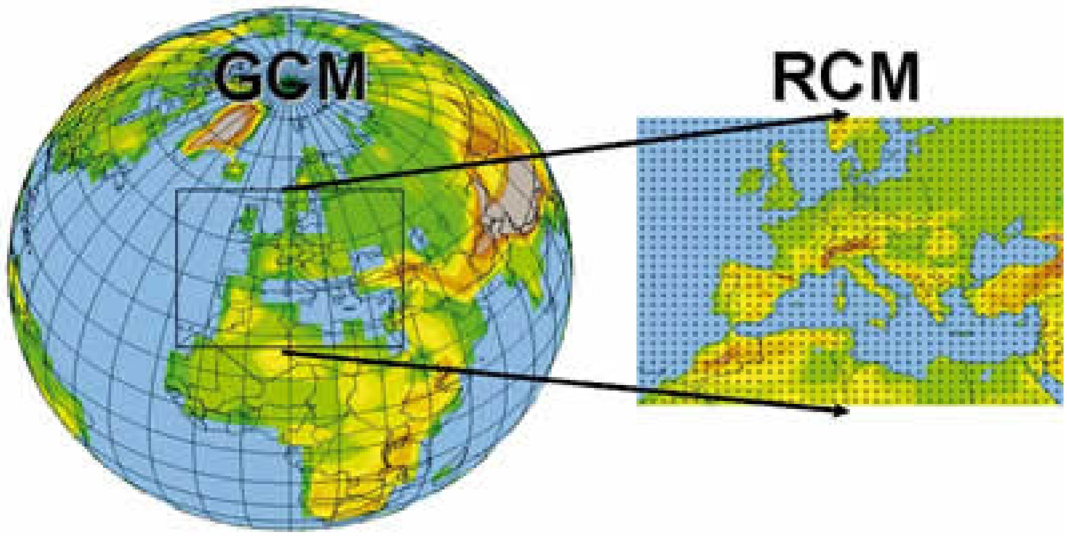
Also in 1988, the Intergovernmental Panel on Climate Change (IPCC) was formed. The IPCC was formed by the World Meteorological Organization and the United Nations to review the latest climate science every few years and help governments around the world understand what we know about climate change, its impacts, and efforts to adapt and mitigate.

1990s: New models were developed to include how the ocean, land, sea ice, and atmosphere interact to affect the climate. At the end of the decade, the National Center for Atmospheric Research ran a new model, the Community Climate System Model (CCSM), on its latest supercomputer to learn more about interactions in Earth's climate system.



Components of the Community Climate System Model (UCAR)

March 1, 1990: Robert Dickinson led a team to create a regional climate model for the western United States in 1989 and, in 1990, Filippo Giorgi simulated regional climate using a model nested in a general circulation model (GCM). Regional climate modeling has allowed predictions of how global climate change impacts local areas.

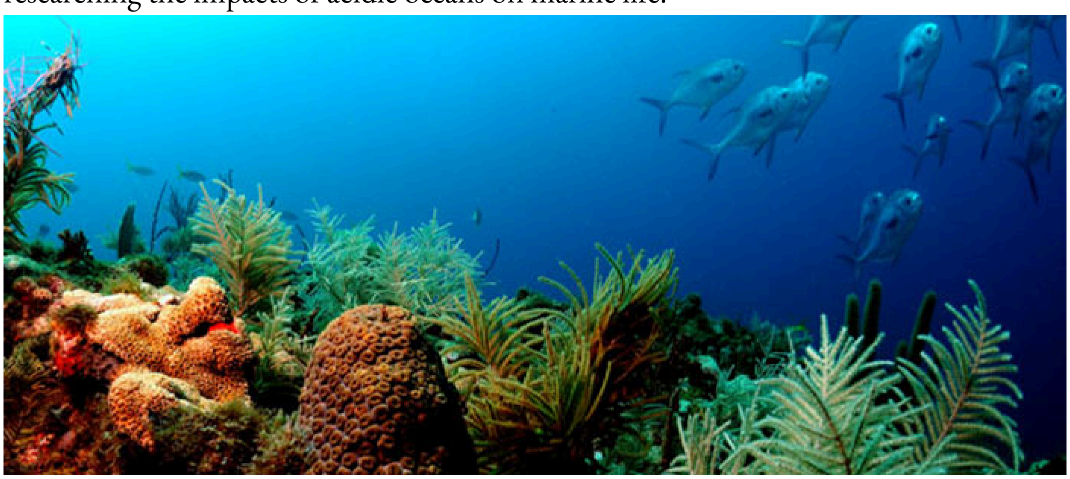


Giorgi, 2008, WMO

Diagram of a regional climate model within a GCM

April 1, 1990 Published in 1990, the IPCC's First Assessment Report stated that it was certain that "human activities are substantially increasing the atmospheric concentrations of greenhouse gases."According to the report, greenhouse gas increases had caused temperature to increase by 0.3° to 0.6° Celsius (0.5 – 1.1° Fahrenheit) over the past century and would cause global average temperature to warm about 1°C (1.8°F) by 2025 and 3°C (5.4°F) by 2100. Projections for regional temperature and precipitation changes were highly uncertain.

1992: U.S. scientists Stephen V. Smith and R.W. Buddemeier pointed out that more carbon dioxide (CO_2) in the ocean could be a problem for coral reefs. Later experiments confirmed their hypothesis that CO_2 makes seawater slightly acidic, which makes it difficult for corals and other animals to build reefs. Today at NCAR, scientist Joanie Kleypas (https://www2.cgd.ucar.edu/staff/kleypas/index.html) builds on their work, researching the impacts of acidic oceans on marine life.



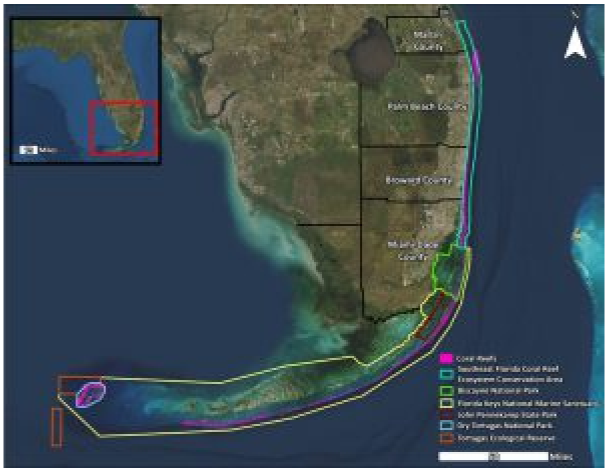
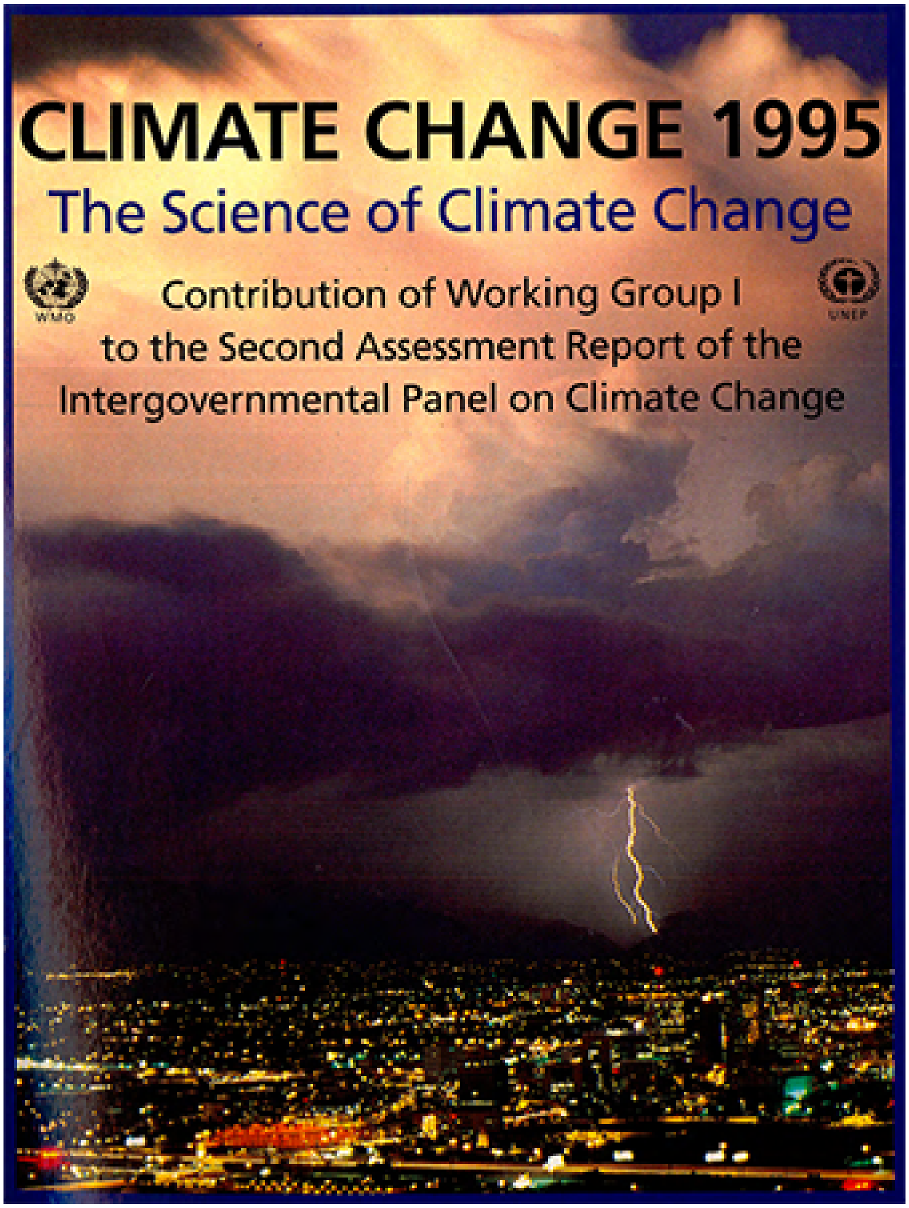


Image: Florida Department of Environmental Protection

From beautiful, extensive coral reefs and other marine life to mysterious shipwrecks, take a moment to explore and learn about the many resources that Florida Keys National Marine Sanctuary protects. Source: https://floridakeys.noaa.gov/explore.html

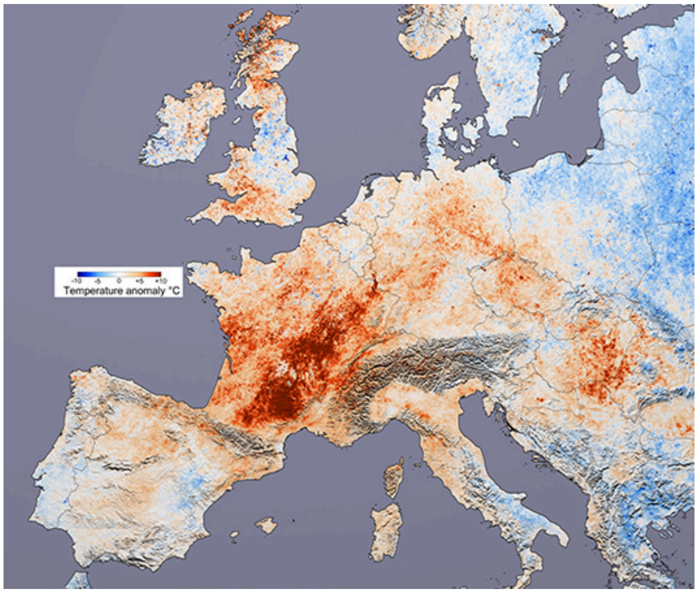
At the second World Climate Conference, held from October 29 to November 7, 1990 in its Ministerial Declaration, the Conference stated that climate change was a global problem of unique character for which a global response was required. It called for negotiations to begin on a framework convention without further delay. As the urgency for a stronger international action on the environment, including climate change, gained momentum, the General Assembly decided to convene in 1992 in Rio de Janeiro, Brazil, the United Nations Conference on Environment and Development. The Earth Summit, as it is also known, set a new framework for seeking international agreements to protect the integrity of the global environment in its Rio Declaration and Agenda 21, which reflected a global consensus on development and environmental cooperation. Chapter 9 of Agenda 21 dealt with the protection of the atmosphere, establishing the link between science, sustainable development, energy development and consumption, transportation, industrial development, stratospheric ozone depletion and transboundary atmospheric pollution. The most significant event during the Conference was the opening for signature of the United Nations Framework Convention on Climate Change (UNFCCC); by the end of 1992, 158 States had signed it. As the most important international action thus far on climate change, the Convention was to stabilize atmospheric concentrations of "greenhouse gases" at a level that would prevent dangerous anthropogenic interference with the climate system. It entered into force in 1994, and in March 1995, the first Conference of the Parties to the Convention adopted the Berlin Mandate, launching talks on a protocol or other legal instrument containing stronger commitments for developed countries and those in transition.

The cornerstone of the climate change action was, therefore, the adoption in Japan in December 1997 of the Kyoto Protocol to the UNFCCC, the most influential climate change action so far taken. It aimed to reduce the industrialized countries' overall emissions of carbon dioxide and other greenhouse gases by at least 5 per cent below the 1990 levels in the commitment period of 2008 to 2012. The Protocol, which opened for signature in March 1998, came into force on 16 February 2005, seven years after it was negotiated by over 160 nations.



Cover of the IPCC 2nd Assessment Report

2003: Researchers determined that climate change played a large role in the 2003 heatwave in Europe, which resulted in more than 30,000 deaths.



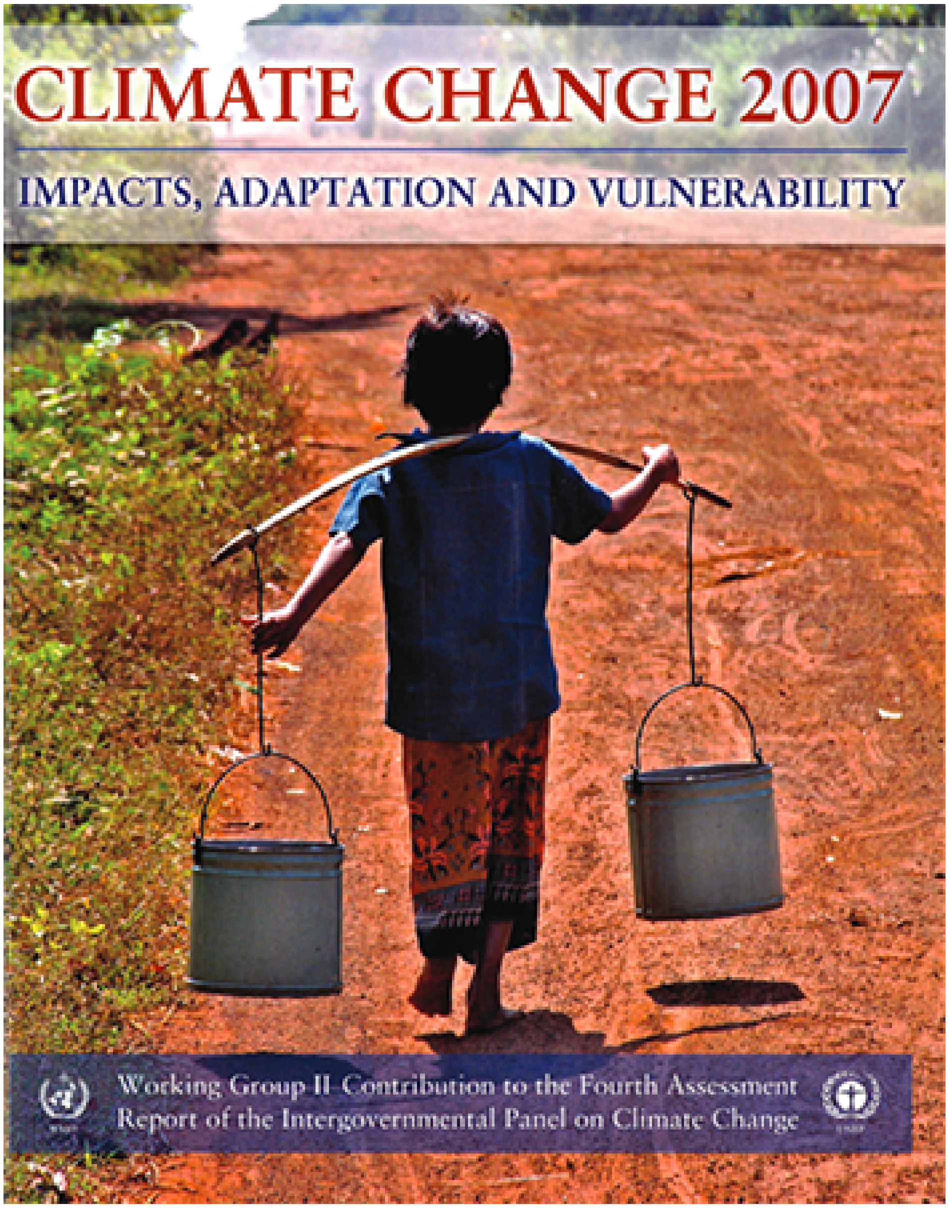
NASA Earth Observatory, Reto Stockli and Robert Simmon, with data from MODIS

Europe's 2003 extreme heat was concentrated in France

2006: The Stern Review described the economic impacts of climate change, finding that mitigating (reducing the amount of greenhouse gas emissions) and adapting (making changes to the way we live) would be much less expensive than the cost of trying to recover from the disastrous impacts of climate change in the future. Source: Stern Review on the Economics of Climate Change.

https://webarchive.nationalarchives.gov.uk/ukgwa/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm

2007: The IPCC Fourth Assessment Report noted that human-caused greenhouse gas emissions had increased 70% between 1970 and 2004 and the effects of climate change were becoming apparent. *"Warming of the climate system is unequivocal,"* wrote the authors of the 2007 report, "*as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."*[x]*"Anthropogenic [human-caused] warming could lead to some impacts that are abrupt or irreversible," they warned. "More extensive adaptation than is currently occurring is required to reduce vulnerability to climate change."*

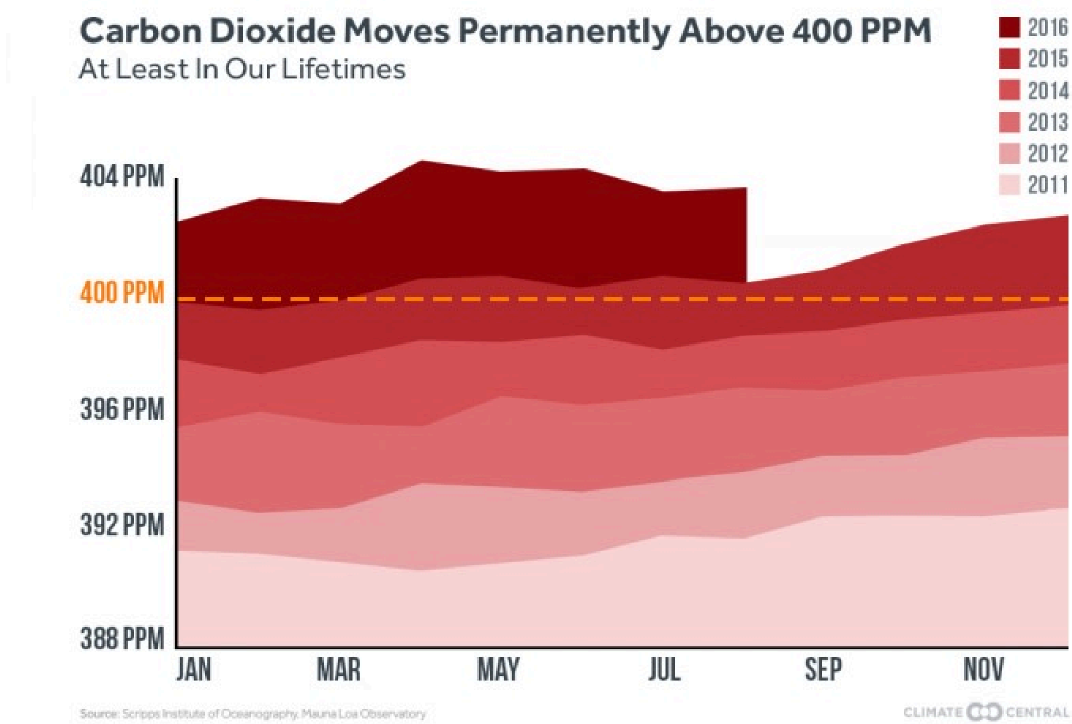


Cover of the IPCC 4th Assessment Report

2012: The Rising Voices program has brought indigenous knowledge and western science together to improve understanding of climate change and other types of science and to develop strategies for resilient and sustainable communities. *"We need to appreciate the experience and knowledge that has been transferred from generation to generation to generation in Native American communities."* – Bob GoughLearn more: Rising Voices at NCAR

2014: Emissions are the highest in modern times. The IPCC 5th Assessment Report noted that our influence on climate is clear and "recent anthropogenic emissions of greenhouse gases are the highest in history." The report's findings led to the Paris Climate Accord, in which nearly all of the world's countries (174 countries in total) committed to actions limiting warming to below 2° Celsius (3.6° Fahrenheit) in an effort to avoid the most catastrophic impacts. (The United States announced in 2017 that it would back out of the agreement.)

2016 the point of no return? Carbon dioxide stays above 400ppm year round. September is typically when carbon dioxide is at a minimum in its annual cycle. September 2016 was the first time that minimum level was over 400 parts per million. Before large-scale burning of fossil fuels, CO_2 levels were about 280 ppm.



Source: Climate Central https://www.climatecentral.org/news/world-passes-400-ppm-threshold-permanently-20738

2019: Biodiversity is Declining With Earth system models, scientists are now able to study how species and ecosystems around the world are likely to be affected by climate change and other human impacts. According to a 2019 United Nations report, climate change and other human impacts such as pollution and land use are threatening species worldwide. "*Around 1 million species already face extinction, many within decades, unless action is taken,*" according to the report.

2021: 2016 and 2020 tied as the warmest years on record, according to 2021 reports. Scientists studying long-term temperature records found that the 10 warmest years through 2020 all occurred since 2000. From NASA Goddard Institute for Space Studies Director Gavin Schmidt, "*…As the human impact on the climate increases, we have to expect that records will continue to be broken.*"

NASA Finds 2020 Tied for Hottest Year on Record

Globally, 2020 was the hottest year on record, effectively tying 2016, the previous record. Overall, Earth's average temperature has risen more than 2 degrees Fahrenheit since the 1880s. Temperatures are increasing due to human activities, specifically emissions of greenhouse gases, like carbon dioxide and methane. (Credits: NASA's Scientific Visualization Studio/Lori Perkins/Kathryn Mersmann)

2021 Tied for 6th Warmest Year in Continued Trend. NASA analysis shows, 2012 was tied for the sixth warmest year on NASA's record, stretching more than a century. Because the record is global, not every place on Earth experienced the sixth warmest year on record. Some places had record-high temperatures, and we saw record droughts, floods and fires around the globe.

Collectively, the past eight years are the warmest years since modern recordkeeping began in 1880. This annual temperature data makes up the global temperature record— which tells scientists the planet is warming.

According to NASA's temperature record, Earth in 2021 was about 1.9 degrees Fahrenheit (or about 1.1 degrees Celsius) warmer than the late 19th century average, the start of the industrial revolution.(Credit: NASA/GSFC/SVS/Kathryn Mersmann: https://www.giss.nasa.gov/research/news/20220113/

2022: Climate impacts are past the natural climate variability. According to the The Sixth Assessment Report from the IPCC highlights the impacts of human-induced climate change, including more frequent and intense extreme events. The changes have caused widespread adverse impacts and damages to nature and people, beyond what would be expected from natural climate variability (Source: IPCC Sixth Assessment Report https://www.ipcc.ch/report/ar6/wg2/resources/spm-headline-statements/

Consequences of Climate Change

We need to understand planet Earth so we can benefit humankind.

Carbon Dioxide = 422 ppm and rising

Methane = 1923.6 ppb and rising

Global Temperature = 1.1^0 C (2^0 F) Since preindustrial and increasing

Artic Sea Ice Minimum Extent = 12.6 % per decade and declining

Ocean Warming = 345 zettajoules since 1955 (The zettajoule is equal to one sextillion (10^{21}) joules, or units of heat energy. The amount of heat energy the ocean has absorbed over the past 6-plus decades is more than eight times the amount of energy humans used over that time for cooking, electricity, industry, heating, etc.).

Ice Sheets = 424 billion tons per year and declining

Sea Level = 4 inches since January 1993 and increasing

(Source: NASA Global Climate Change Vital Signs of the Planet. https://climate.nasa.gov/)

"Since systematic scientific assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact."

– INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE THE PANEL'S AR6 WORKING GROUP I (WGI) SUMMARY FOR POLICYMAKERS REPORT IS ONLINE AT HTTPS://WWW.IPCC.CH/REPORT/AR6/WG1/.

Communities:

The impacts of climate change are already being felt in communities across the country. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities. Future climate change is expected to further disrupt many areas of life, exacerbating existing challenges to prosperity posed by aging and deteriorating infrastructure, stressed ecosystems, and economic inequality. Impacts within and across regions will not be distributed equally. People who are already vulnerable, including lower-income and other marginalized communities, have lower capacity to prepare for and cope with extreme weather and climate-related events and are expected to experience greater impacts. Prioritizing adaptation actions for the most vulnerable populations would contribute to a more equitable future within and across communities. Global action to significantly cut greenhouse gas emissions can substantially reduce climate-related risks and increase opportunities for these populations in the longer term

Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth.

Economy:

Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century.

In the absence of significant global mitigation action and regional adaptation efforts, rising temperatures, sea level rise, and changes in extreme events are expected to increasingly disrupt and damage critical infrastructure and property, labor productivity, and the vitality of our communities. Regional economies and industries that depend on natural resources and favorable climate conditions, such as agriculture, tourism, and fisheries, are vulnerable to the growing impacts of climate change. Rising temperatures are projected to reduce the efficiency of power generation while increasing energy demands, resulting in higher electricity costs. The impacts of climate change beyond our borders are expected to increasingly affect our trade and economy, including import and export prices and U.S. businesses with overseas operations and supply chains. Some aspects of our economy may see slight near-term improvements in a modestly warmer world. However, the continued warming that is projected to occur without substantial and sustained reductions in global greenhouse gas emissions is expected to cause substantial net damage to the U.S. economy throughout this century, especially in the absence of increased adaptation efforts. With continued growth in emissions at historic rates, annual losses in some economic sectors are projected to reach hundreds of billions of dollars by the end of the century—more than the current gross domestic product (GDP) of many U.S. states.

Interconnected Impacts:

Climate change affects the natural, built, and social systems we rely on individually and through their connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts that are often difficult to predict, threatening essential services within and beyond the Nation's borders.

Climate change presents added risks to interconnected systems that are already exposed to a range of stressors such as aging and deteriorating infrastructure, land-use changes, and population growth. Extreme weather and climate-related impacts on one system can result in increased risks or failures in other critical systems, including water resources, food production and distribution, energy and transportation, public health, international trade, and national security. The full extent of climate change risks to interconnected systems, many of which span regional and national boundaries, is often greater than the sum of risks to individual sectors. Failure to anticipate interconnected impacts can lead to missed opportunities for effectively managing the risks of climate change and can also lead to management responses that increase risks to other sectors and regions. Joint planning with stakeholders across sectors, regions, and jurisdictions can help identify critical risks arising from interaction among systems ahead of time.

Water:

> *The quality and quantity of water available for use by people and ecosystems across the country are being affected by climate change, increasing risks and costs to agriculture, energy production, industry, recreation, and the environment.*

Rising air and water temperatures and changes in precipitation are intensifying droughts, increasing heavy downpours, reducing snowpack, and causing declines in surface water quality, with varying impacts across regions. Future warming will add to the stress on water supplies and adversely impact the availability of water in parts of the United States. Changes in the relative amounts and timing of snow and rainfall are leading to mismatches between water availability and needs in some regions, posing threats to, for example, the future reliability of hydropower production in the Southwest and the Northwest. Groundwater depletion is exacerbating drought risk in many parts of the United States, particularly in the Southwest and Southern Great Plains. Dependable and safe water supplies for U.S. Caribbean, Hawai'i, and U.S.-Affiliated Pacific Island communities are threatened by drought, flooding, and saltwater contamination due to sea level rise. Most U.S. power plants rely on a steady supply of water for cooling, and operations are expected to be affected by changes in water availability and temperature increases. Aging and deteriorating water infrastructure, typically designed for past environmental conditions, compounds the climate risk faced by society. Water management strategies that account for changing climate conditions can help reduce present and future risks to water security, but implementation of such practices remains limited.

Health:

> *Impacts from climate change on extreme weather and climate-related events, air quality, and the transmission of disease through insects and pests, food, and water increasingly threaten the health and well-being of the American people, particularly populations that are already vulnerable.*

Changes in temperature and precipitation are increasing air quality and health risks from wildfire and ground-level ozone pollution. Rising air and water temperatures and more intense extreme events are expected to increase exposure to waterborne and foodborne diseases, affecting food and water safety. With continued warming, cold-related deaths are projected to decrease and heat-related deaths are projected to increase; in most regions, increases in heat-related deaths are expected to outpace reductions in cold-related deaths. The frequency and severity of allergic illnesses, including asthma and hay fever, are expected to increase as a result of a changing climate. Climate change is also projected to alter the geographic range and distribution of disease-carrying insects and pests, exposing more people to ticks that carry Lyme disease and mosquitoes that transmit viruses such as Zika, West Nile, and dengue, with varying impacts across regions. Communities in the Southeast, for example, are particularly vulnerable to the combined health impacts from vector-borne disease, heat, and flooding. Extreme weather and climate-related events can have lasting mental health consequences in affected communities, particularly if they result in degradation of livelihoods or community relocation. Populations including older adults, children, low-income communities, and some communities of color are often disproportionately affected by, and less resilient to, the health impacts of climate change. Adaptation and mitigation policies and programs that help individuals, communities, and states prepare for the risks of a changing climate reduce the number of injuries, illnesses, and deaths from climate-related health outcomes.

Indigenous Peoples:

> *Climate change increasingly threatens Indigenous communities' livelihoods, economies, health, and cultural identities by disrupting interconnected social, physical, and ecological systems.*

Many Indigenous peoples are reliant on natural resources for their economic, cultural, and physical well-being and are often uniquely affected by climate change. The impacts of climate change on water, land, coastal areas, and other natural resources, as well as infrastructure and related services, are expected to increasingly disrupt Indigenous peoples' livelihoods and economies, including agriculture and agroforestry, fishing, recreation, and tourism. Adverse impacts on subsistence activities have already been observed. As climate changes continue, adverse impacts on culturally significant species and resources are expected to result in negative physical and mental health effects. Throughout the United States, climate-related impacts are causing some Indigenous peoples to consider or actively pursue community relocation as an adaptation strategy, presenting challenges associated with maintaining cultural and community continuity. While economic, political, and infrastructure limitations may affect these communities' ability to adapt, tightly knit social and cultural networks present opportunities to build community capacity and increase resilience. Many Indigenous peoples are taking steps to adapt to climate change impacts structured around self-determination and traditional knowledge, and some tribes are pursuing mitigation actions through development of renewable energy on tribal lands.

Ecosystems and Ecosystem Services:

> *Ecosystems and the benefits they provide to society are being altered by climate change, and these impacts are projected to continue. Without substantial and sustained reductions in global greenhouse gas emissions, transformative impacts on some ecosystems will occur; some coral reef and sea ice ecosystems are already experiencing such transformational changes.*

Many benefits provided by ecosystems and the environment, such as clean air and water, protection from coastal flooding, wood and fiber, crop pollination, hunting and fishing, tourism, cultural identities, and more will continue to be degraded by the impacts of climate change. Increasing wildfire frequency, changes in insect and disease outbreaks, and other stressors are expected to decrease the ability of U.S. forests to support economic activity, recreation, and subsistence activities. Climate change has already had observable impacts on biodiversity, ecosystems, and the benefits they provide to society. These impacts include the migration of native species to new areas and the spread of invasive species. Such changes are projected to continue, and without substantial and sustained reductions in global greenhouse gas emissions, extinctions and transformative impacts on some ecosystems cannot be avoided in the long term. Valued aspects of regional heritage and quality of life tied to ecosystems, wildlife, and outdoor recreation will change with the climate, and as a result, future generations can expect to experience and interact with the natural environment in ways that are different from today. Adaptation strategies, including prescribed burning to reduce fuel for wildfire, creation of safe havens for important species, and control of invasive species, are being implemented to address emerging impacts of climate change. While some targeted response actions are underway, many impacts, including losses of unique coral reef and sea ice ecosystems, can only be avoided by significantly reducing global emissions of carbon dioxide and other greenhouse gases.

Agriculture:

> *Rising temperatures, extreme heat, drought, wildfire on rangelands, and heavy downpours are expected to increasingly disrupt agricultural productivity in the United States. Expected increases in challenges to livestock health, declines in crop yields and quality, and changes in extreme events in the United States and abroad threaten rural livelihoods, sustainable food security, and price stability.*

Climate change presents numerous challenges to sustaining and enhancing crop productivity, livestock health, and the economic vitality of rural communities. While some regions (such as the Northern Great Plains) may see conditions conducive to expanded or alternative crop productivity over the next few decades, overall, yields from major U.S. crops are expected to decline as a consequence of increases in temperatures and possibly changes in water availability, soil erosion, and disease and pest outbreaks. Increases in temperatures during the growing season in the Midwest are projected to be the largest contributing factor to declines in the productivity of U.S. agriculture. Projected increases in extreme heat conditions are expected to lead to further heat stress for livestock, which can result in large economic losses for producers. Climate change is also expected to lead to large-scale shifts in the availability and prices of many agricultural products across the world, with corresponding impacts on U.S. agricultural producers and the U.S. economy. These changes threaten future gains in commodity crop production and put rural livelihoods at risk. Numerous adaptation strategies are available to cope with adverse impacts of climate variability and change on agricultural production. These include altering what is produced, modifying the inputs used for production, adopting new technologies, and adjusting management strategies. However, these strategies have limits under severe climate change impacts and would require sufficient long- and short-term investment in changing practices.

Infrastructure:

> *Our Nation's aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to degrade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being.*

Climate change and extreme weather events are expected to increasingly disrupt our Nation's energy and transportation systems, threatening more frequent and longer-lasting power outages, fuel shortages, and service disruptions, with cascading impacts on other critical sectors. Infrastructure currently designed for historical climate conditions is more vulnerable to future weather extremes and climate change. The continued increase in the frequency and extent of high-tide flooding due to sea level rise threatens America's trillion-dollar coastal property market and public infrastructure, with cascading impacts to the larger economy. In Alaska, rising temperatures and erosion are causing damage to buildings and coastal infrastructure that will be costly to repair or replace, particularly in rural areas; these impacts are expected to grow without adaptation. Expected increases in the severity and frequency of heavy precipitation events will affect inland infrastructure in every region, including access to roads, the viability of bridges, and the safety of pipelines. Flooding from heavy rainfall, storm surge, and rising high tides is expected to compound existing issues with aging infrastructure in the Northeast. Increased drought risk will threaten oil and gas drilling and refining, as well as electricity generation from power plants that rely on surface water for cooling. Forward-looking infrastructure design, planning, and operational measures and standards can reduce exposure and vulnerability to the impacts of climate change and reduce energy use while providing additional near-term benefits, including reductions in greenhouse gas emissions.

Oceans & Coasts:

> *Coastal communities and the ecosystems that support them are increasingly threatened by the impacts of climate change. Without significant reductions in global greenhouse gas emissions and regional adaptation measures, many coastal regions will be transformed by the latter part of this century, with impacts affecting other regions and sectors. Even in a future with lower greenhouse gas emissions, many communities are expected to suffer financial impacts as chronic high-tide flooding leads to higher costs and lower property values.*

Rising water temperatures, ocean acidification, retreating arctic sea ice, sea level rise, high-tide flooding, coastal erosion, higher storm surge, and heavier precipitation events threaten our oceans and coasts. These effects are projected to continue, putting ocean and marine species at risk, decreasing the productivity of certain fisheries, and threatening communities that rely on marine ecosystems for livelihoods and recreation, with particular impacts on fishing communities in Hawai‘i and the U.S.-Affiliated Pacific Islands, the U.S. Caribbean, and the Gulf of Mexico. Lasting damage to coastal property and infrastructure driven by sea level rise and storm surge is expected to lead to financial losses for individuals, businesses, and communities, with the Atlantic and Gulf Coasts facing above-average risks. Impacts on coastal energy and transportation infrastructure driven by sea level rise and storm surge have the potential for cascading costs and disruptions across the country. Even if significant emissions reductions occur, many of the effects from sea level rise over this century—and particularly through mid-century—are already locked in due to historical emissions, and many communities are already dealing with the consequences. Actions to plan for and adapt to more frequent, widespread, and severe coastal flooding, such as shoreline protection and conservation of coastal ecosystems, would decrease direct losses and cascading impacts on other sectors and parts of the country. More than half of the damages to coastal property are estimated to be avoidable through well-timed adaptation measures. Substantial and sustained reductions in global greenhouse gas emissions would also significantly reduce projected risks to fisheries and communities that rely on them.

Tourism and Recreation:

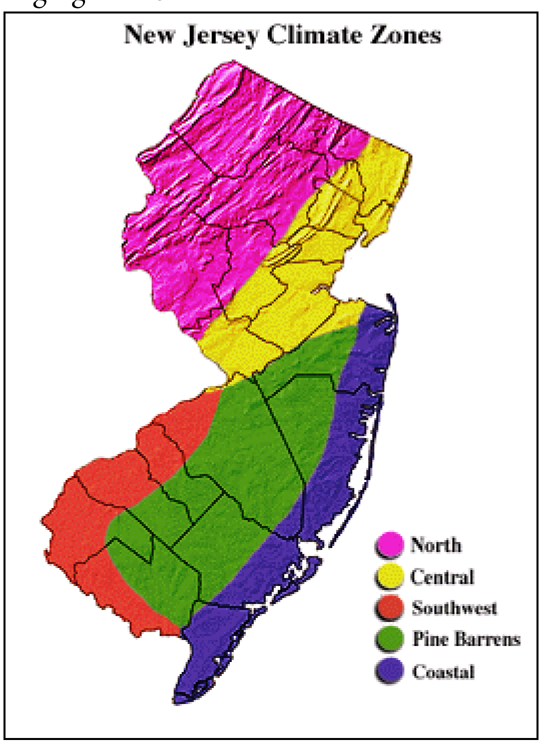
> *Outdoor recreation, tourist economies, and quality of life are reliant on benefits provided by our natural environment that will be degraded by the impacts of climate change in many ways.*

Climate change poses risks to seasonal and outdoor economies in communities across the United States, including impacts on economies centered around coral reef-based recreation, winter recreation, and inland water-based recreation. In turn, this affects the well-being of the people who make their living supporting these economies, including rural, coastal, and Indigenous communities. Projected increases in wildfire smoke events are expected to impair outdoor recreational activities and visibility in wilderness areas. Declines in snow and ice cover caused by warmer winter temperatures are expected to negatively impact the winter recreation industry in the Northwest, Northern Great Plains, and the Northeast. Some fish, birds, and mammals are expected to shift where they live as a result of climate change, with implications for hunting, fishing, and other wildlife-related activities. These and other climate-related impacts are expected to result in decreased tourism revenue in some places and, for some communities, loss of identity. While some new opportunities may emerge from these ecosystem changes, cultural identities and economic and recreational opportunities based around historical use of and interaction with species or natural resources in many areas are at risk. Proactive management strategies, such as the use of projected stream temperatures to set priorities for fish conservation, can help reduce disruptions to tourist economies and recreation.

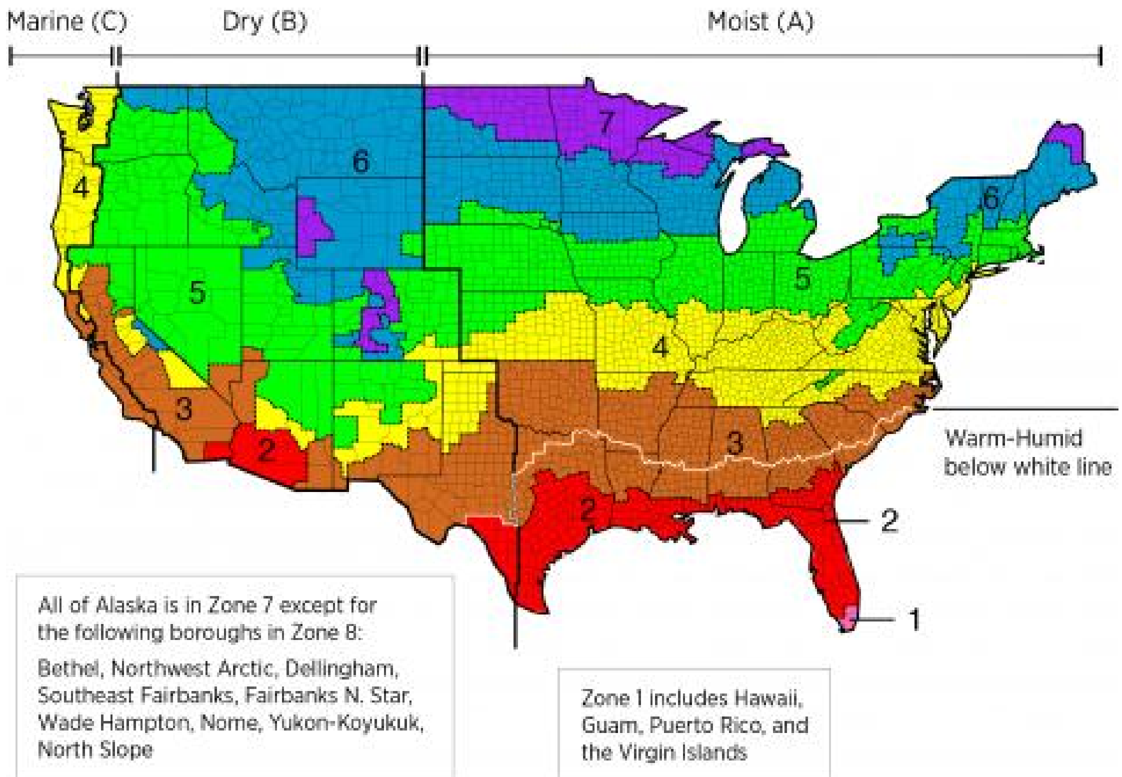
The Northeast: i.e. "New Jersey"

Annual average temperature have risen more than 3.5^{o} F in the Garden State since the beginning of the 20th century. If emission keep on the projected path, NJ will see continuing warming trends during this century. Heat waves will be more frequent and more intense. Cold waves are projected to me less intense.

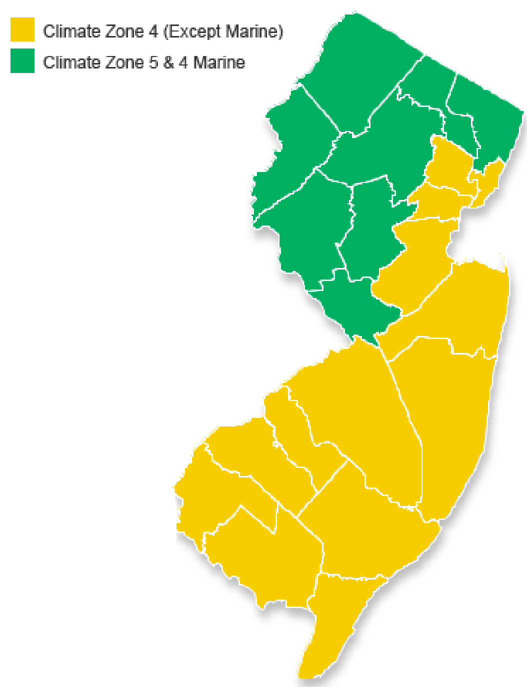
New Jersey's geographic position in the mid-latitudes often places it near the jet stream, particularly in the late fall, winter, and spring, giving the state its characteristic varied weather. Precipitation is frequent because low-pressure storms associated with the jet stream commonly affect the state. In addition, New Jersey's location on the eastern coast of North America exposes it to the cold winter and warm summer air masses of the continental interior and the moderate and moist air masses of the western Atlantic Ocean. In winter, the contrast between the frigid air masses of the continental interior and the relatively warm Atlantic provides the energy for occasional intense storms known as nor'easters. As a result of these influences, **New Jersey's climate is characterized by moderately cold and occasionally snowy winters and warm, humid summers.** There is a west-to-east contrast of temperatures, with cooler temperatures in the higher elevations of the northwest and warmer temperatures in the east near the coast. Temperature differences from the northwest to southeast are most noticeable in the winter. The northern elevated highlands and valleys experience colder temperatures and more annual average precipitation than the rest of the state. Average minimum temperatures in January range from 15° to 20°F in the northwest to 25° to 30°F along the coast. A similar temperature gradient exists for average maximum temperatures in July—cooler summertime temperatures of 80° to 85°F occur in the northwestern corner and temperatures between 85° and 90°F occur in the rest of the state. The statewide annual average precipitation is 47.6 inches. There is a north-south precipitation gradient as well, with the north-central portion of the state averaging around 50 inches of precipitation and the coastal region averaging 40–45 inches.



New Jersey is located about halfway between the Equator and the North Pole, on the eastern coast of the United States. Its geographic location results in the State being influenced by wet, dry, hot, and cold airstreams, making for daily weather that is highly variable



The map above shows the 7 different climate zones of the United States. The lower 2/3 of New Jersey is in climate zone 4 while the upper regions are in climate zone 5. Source: 2012 International Energy Conservation Code (IECC) International Code Council



Temperatures in New Jersey have risen more than 3.5°F since the beginning of the 20th century (See figure below). All of the 10 hottest calendar years on record for the state have occurred since 1990, and six have occurred since 2010. The year 2012 was the warmest on record at 3.0°F above average, and 2020 was the second warmest on record at 2.6°F above average. The number of very hot days has been varied (Figure 2a). The number of warm nights in New Jersey has consistently been above the long-term average since the early 2000s, with the highest 5-year average occurring during the 2010–2014 period (Figure 3). The number of very cold nights has been below average since the early 1990s (Figure 2b). Over the past 25 years, there have been many more unusually warm months than unusually cold months in New Jersey. During the 2000–2020 interval, there were no top 5 coldest months, but there were 38 top 5 warmest months.

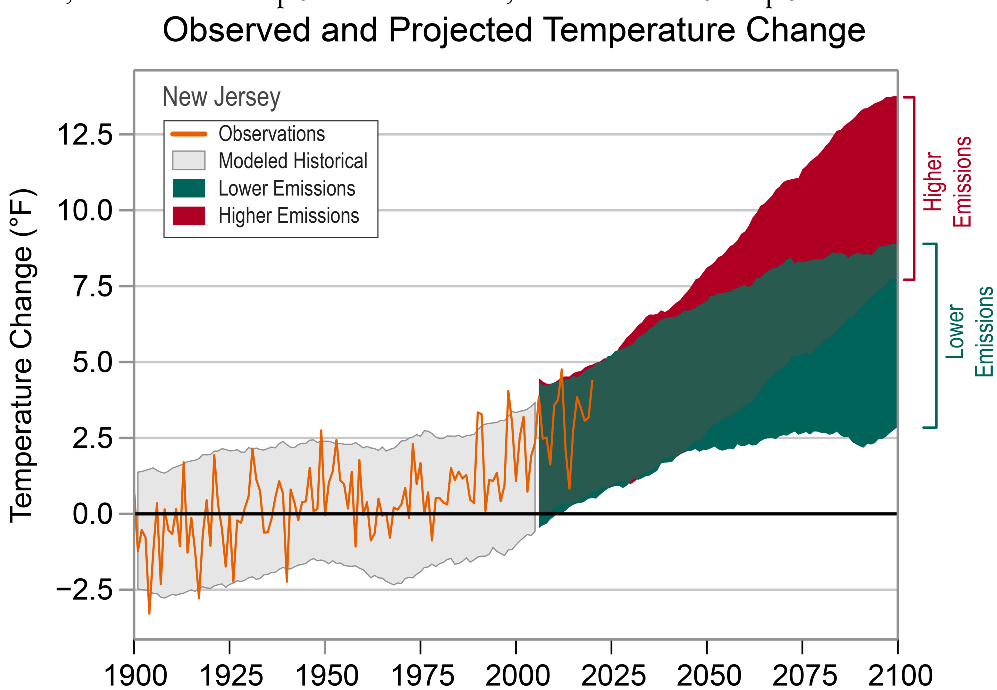
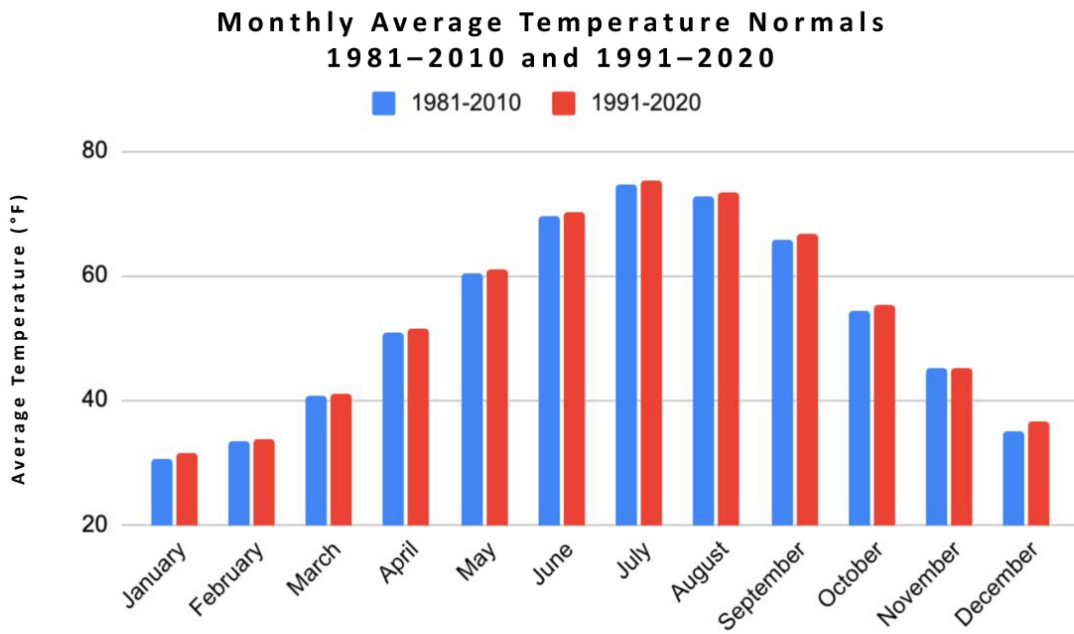
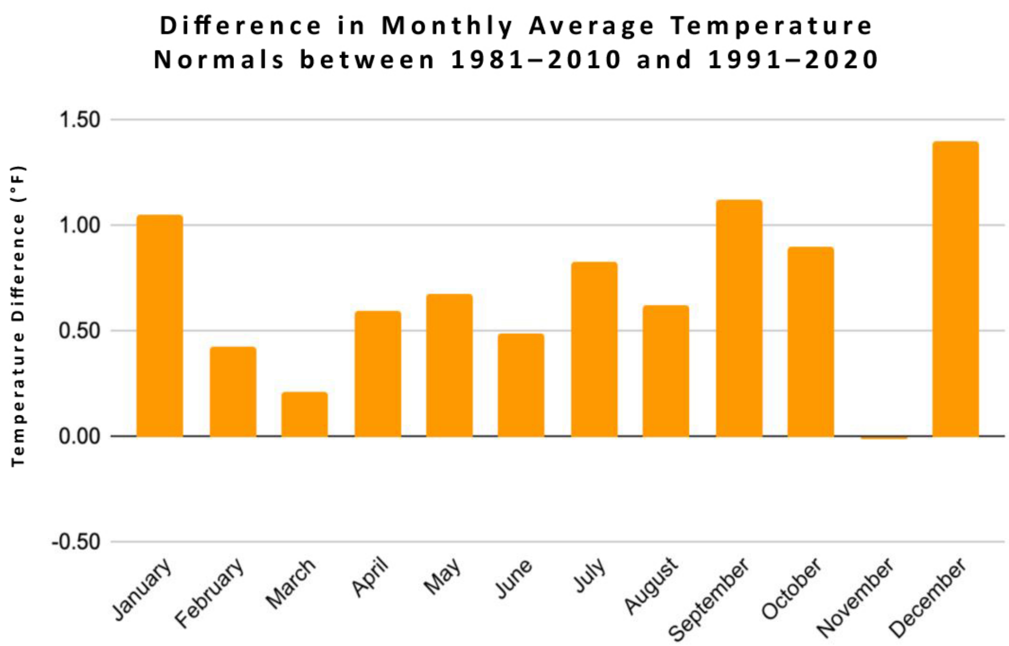


Figure 1

The New Jersey annual average temperature for the 1991–2020 normals period of 53.56 °F is 0.70 °F warmer than the 1981–2010 normal of 52.86 °F. The monthly temperature differences between the two normals periods ranges from zero in November to as much as 1.4 °F in December.



The monthly normals for the two periods are plotted alongside each other in the figure above



Monthly differences in average temperature normals between the 1981–2010 and 1991–2020 periods. Positive values indicate the more recent 30-year interval is warmer than the prior one. From viewing both perspectives of average temperature, the warm season —May to October — is consistently warming. The cool season, November to April, also warms but shows more month-to-month fluctuations than the warm season. Source Comparing the 1981–2010 and 1991–2020 Normals October 21, 2022 – 4:44pm — Erica Langer https://www.njweather.org/content/comparing-1981%E2%80%932010-and-1991%E2%80%932020-normals

Total annual precipitation for New Jersey has been about 3.7 inches above average over the last 16 years (Figure 2c). The driest conditions were in the 1960s, and near normal to wet conditions have occurred since the 1970s. The wettest consecutive 5 years was the 1971–1975 interval, and the driest was the 1962–1966 interval. The number of 2-inch extreme precipitation events was well above average during 2005–2014 but has been slightly below average since then. During 2010–2014, the state experienced the greatest number of 2-inch extreme precipitation events, about 50% above the long-term average. Summer precipitation has been above the long-term average during this century, with the highest 5-year average occurring during the 2010–2014 period. The state can also experience short-term droughts, such as in 2002, 2010, and 2016–2017 and the summer of 2022.

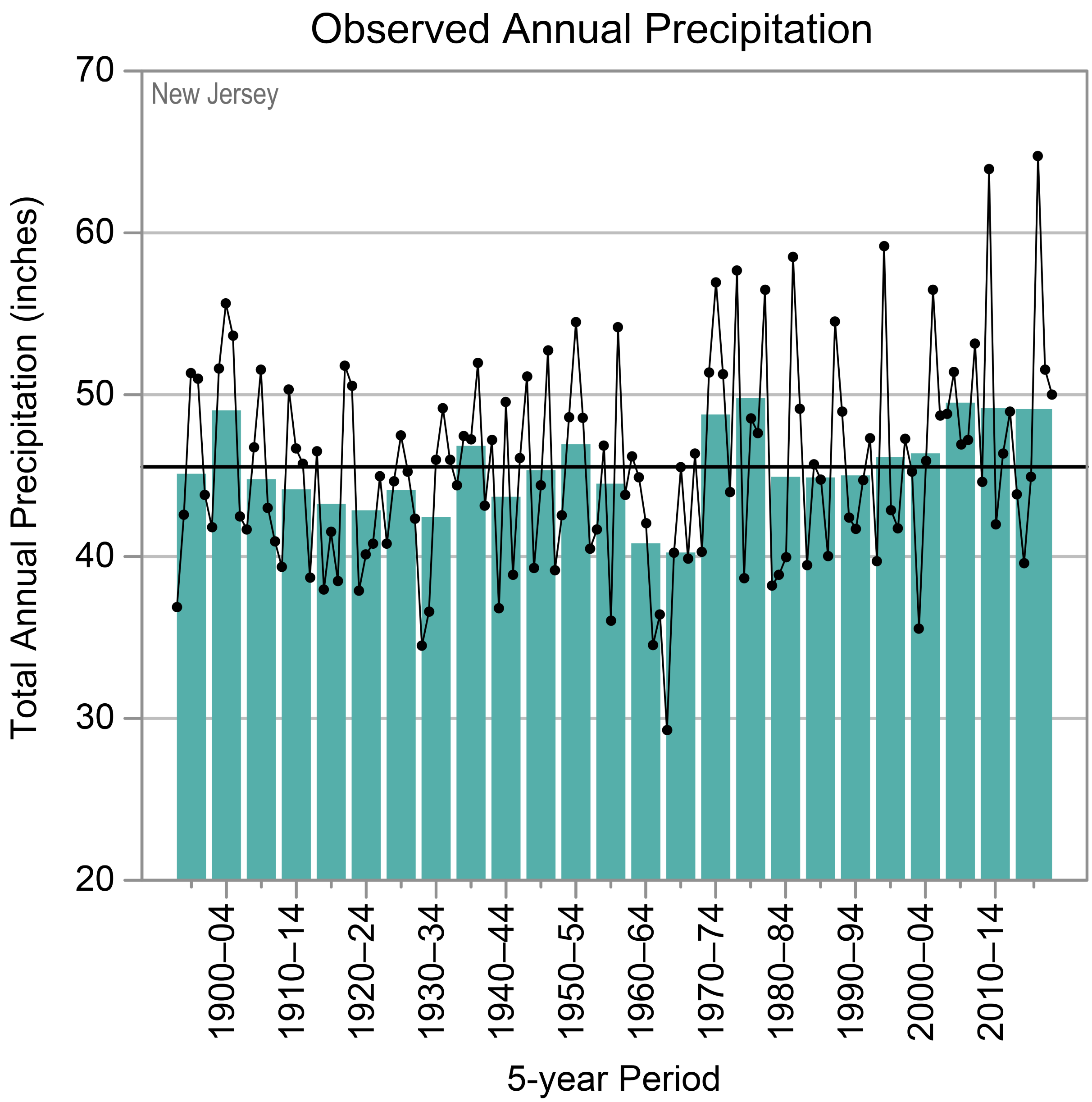


Figure 2c

Extreme weather events typically experienced in the state include coastal nor'easters, snowstorms, spring and summer thunderstorms, flooding rains, heat and cold waves, tropical storms, and on rare occasions, hurricanes. The state's coastline is highly vulnerable to damage from coastal storms, which include nor'easters, tropical storms, and hurricanes. Damaging nor'easters are most common between October and April, and those tracking over or near the coast can bring strong winds and heavy precipitation. **Annually, the state experiences at least one coastal storm, but some years have seen as many as 5 to 10 storm events.** The most extreme and destructive event to affect New Jersey in recent years was Superstorm Sandy in 2012. The powerful storm surge, the most destructive element of Sandy, reached 9–10 feet above normal in some areas along the coast. This was caused by strong winds and an unusual west-northwestward track. New Jersey experienced extensive damage from severe winds and coastal flooding, with an estimated $29.4 billion in repair, response, and restoration costs. February 2010 brought three winter storms to the state, causing Atlantic City to have their snowiest month on record. The blizzard of 2016 brought high winds and heavy snow; Bayville, NJ, had gusts of 72 mph and many beaches experienced moderate to major erosion.

Under a higher emissions pathway, historically unprecedented warming is projected during this century (Figure 1). Even under a lower emissions pathway, temperatures are projected to most likely exceed historical record levels by the middle of this century. However, a large range of temperature increases is projected under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records (Figure 1 above). Increases in the number of extremely hot days and decreases in the number of extremely cold days are projected to accompany the overall warming. According to a state-level analysis, by the middle of this century an estimated 70% of summers in this region are anticipated to be hotter than what we now recognize as the warmest summer on record.

Winter and spring precipitation and extreme precipitation events are projected to increase in this century (Figure 5). The projections of increasing precipitation and heavy precipitation events are true for a large area of the Northern Hemisphere in the northern middle latitudes. This may result in increased coastal and inland flooding risks throughout the state.

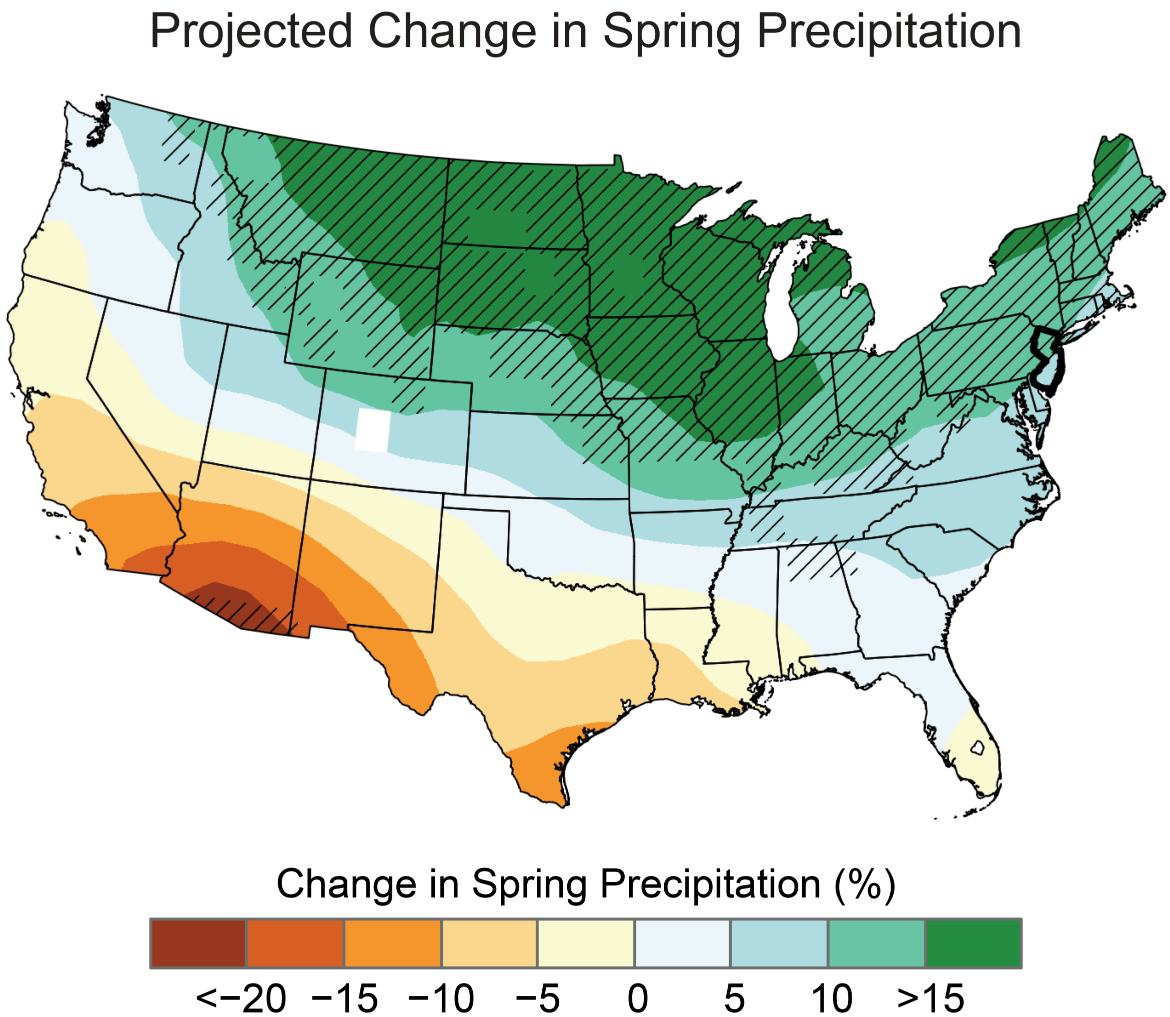


Figure 5: Projected changes in total spring (March–May) precipitation (%) for the middle of the 21st century compared to the late 20th century under a higher emissions pathway. The whited-out area indicates that the climate models are uncertain about the direction of change. Hatching represents areas where the majority of climate models indicate a statistically significant change. New Jersey is part of a large area of projected increases in spring precipitation in the northeastern and central United States. Source: CISESS and NEMAC. Data: CMIP5.

Since 1900, global average sea level has risen by about 7–8 inches. It is projected to rise another 1–8 feet, with a likely range of 1–4 feet, by 2100 as a result of both past and future emissions from human activities (Figure 6). Even greater rises are projected along the New Jersey coast because of land subsidence. Sea level along the coast of New Jersey has also risen faster than the global average. Observations beginning in 1911 show sea level has risen at an average rate of 1.6 inches per decade, about double the global rate, over the period of record at Atlantic City. Sea level rise has caused an increase in tidal floods associated with nuisance-level impacts. Nuisance floods are events in which water levels exceed the local threshold (set by NOAA's National Weather Service) for minor impacts. These events can damage infrastructure, cause road closures, and overwhelm storm drains. As sea level has risen along the New Jersey coastline, the number of tidal flood days (all days exceeding the nuisance-level threshold) has also increased, with the greatest number occurring in 2017 (Figure 7). Coastal flooding caused by sea level rise has important future cross-sector implications for public health, water resources, and coastal ecosystems.

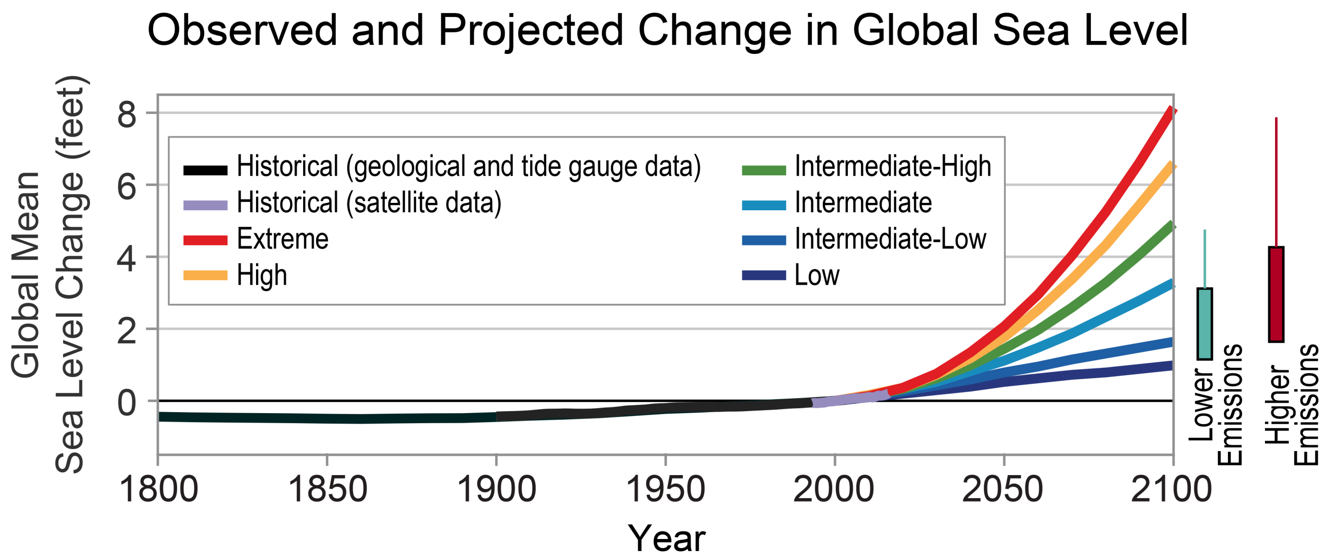


Figure 6: Global mean sea level (GMSL) change from 1800 to 2100. Projections include the six U.S. Interagency Sea Level Rise Task Force GMSL scenarios (Low, navy blue; Intermediate-Low, royal blue; Intermediate, cyan; Intermediate-High, green; High, orange; and Extreme, red curves) relative to historical geological, tide gauge, and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines) and the very likely ranges in 2100 under both lower and higher emissions futures (teal and dark red boxes). Global sea level rise projections range from 1 to 8 feet by 2100, with a likely range of 1 to 4 feet. Source: adapted from Sweet et al. 2017.

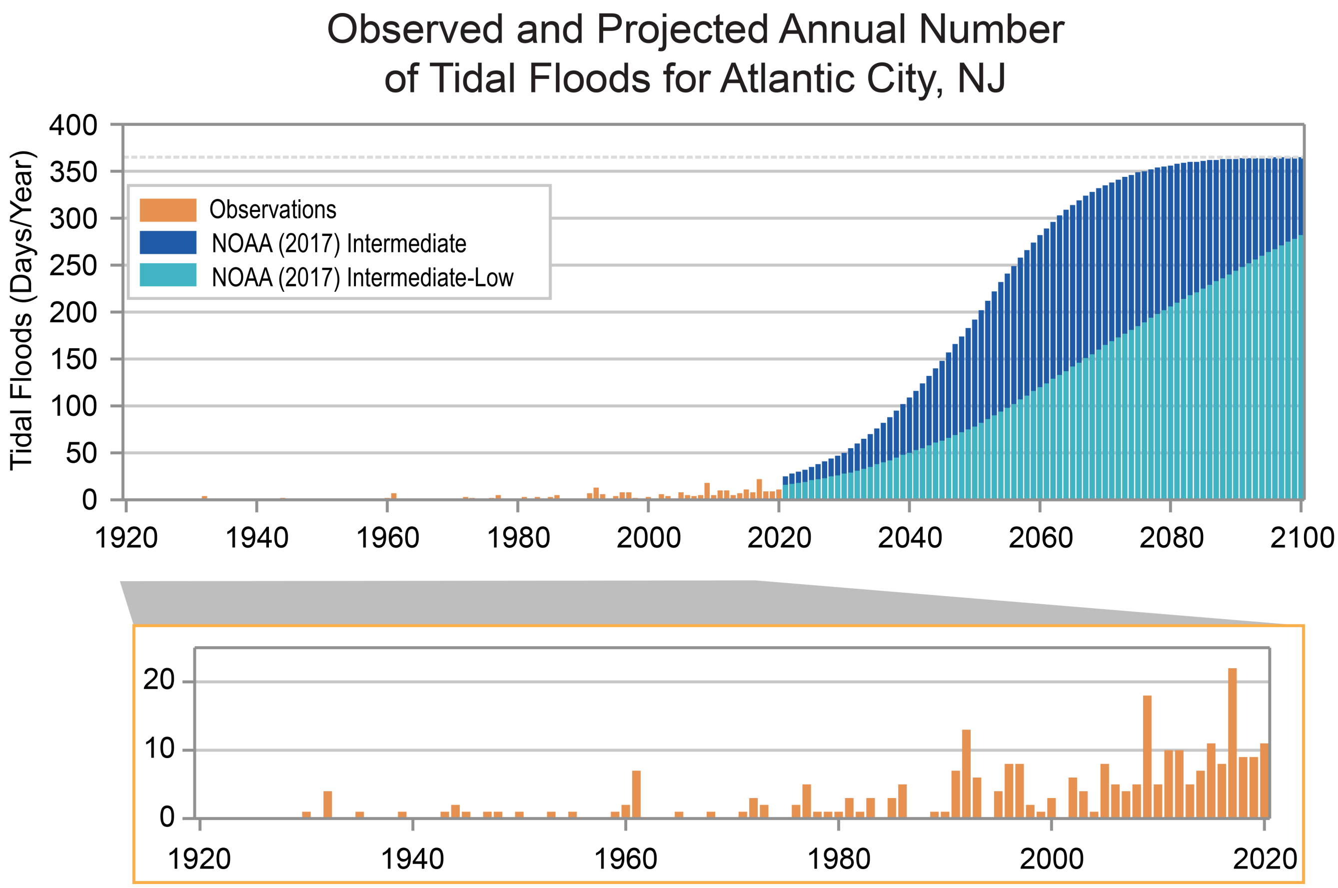


Figure 7: Number of tidal flood days per year at Atlantic City, NJ, for the observed record (1923–2020; orange bars) and projections for 2 NOAA (2017) sea level rise scenarios (2021–2100): Intermediate (dark blue bars) and Intermediate-Low (light blue bars). The NOAA (2017) scenarios are based on local projections of the GMSL scenarios shown in Figure 6. Sea level rise has caused a gradual increase in tidal floods associated with nuisance-level impacts. The greatest number of tidal flood days (all days exceeding the nuisance-level threshold) occurred in 2017 at Atlantic City. Projected increases are large even under a the Intermediate-Low scenario. Under the Intermediate scenario, tidal flooding is projected to occur nearly every day of the year by the end of the century. Additional information on tidal flooding observations and scenarios is available at https://statesummaries.ncics.org/technicaldetails. Sources: CISESS and NOAA NOS.

Climate Change Solutions:

According to the UN environmental programme (https://www.unep.org/interactive/six-sector-solution-climate-change/) UNEP's six sector solution can reduce 29-32 GT CO_2e and will limit temperature rise to 1.5^{0}C...here is the roadmap for the key 6 sectors:

Buildings and Cities

- Retrofit public buildings
- Promote the installation of heat pumps, solar cells and heat storage technology

- Incentivize the installation of central cooling and heating and the use of energy efficient lighting and appliances
- Set carbon-neutral building standards for new construction
- Mainstream sustainable building within urban and rural planning
- Incentivize mini-grid solutions, district heating and cooling and waste to energy systems
- Plan cities for strategic density and mixed use of buildings and urban fabric, so that neighborhoods have the services they need at the local scale
- Integrate grey, blue and green infrastructure to manage resources and runoff with minimal impact to the environment
- Invest in physical and market infrastructure to better link rural and urban producers and consumers
- Develop smart systems to integrate buildings, mobility and energy systems, including traffic management, distributed EV-charging and integrated planning processes

Energy:

- Commit to more ambitious Nationally Determined Contributions and energy transition strategies
- Set national and sub-national decarbonization and net-zero carbon targets
- Halt policies that support the fossil fuel industry, including excessive subsidies
- Introduce policies that incentivize renewable energy and promote energy efficiency

- Monitor and reduce your company's energy usage and strive for energy efficiency
- Embrace the opportunities that a transition to renewable energy will create across your supply chains
- Divest holdings in fossil fuel companies
- Set decarbonization and net-zero carbon targets
- Urge your politicians to propose and vote for ambitious policies for renewable energy and energy efficiency
- Push for and support policies for renewable energy and energy efficiency
- Speak up at work to make renewable energy and reduction a collective issue
- Advocate for renewable energy and energy efficiency in your organization
- Talk to friends about the need for renewable energy and energy efficiency
- Attend or arrange events or communities in support for renewable energy and energy efficiency
- Join a local or national organization supporting renewable energy and energy efficiency
- Understand how much energy you use and try to consume less of it
- Use energy that comes from renewable sources if possible
- Divest from investments or pension funds investing in fossil fuels
- If possible, choose utilities and operators committed to decarbonization and energy efficiency

Industry:

- Impose and strengthen energy efficiency standards
- Price carbon — this will facilitate the drawdown of carbon-intensive technologies and promote more sustainable alternatives
- Promote the use of efficient and renewable heating and cooling
- Incentivize and mandate less emissions of greenhouse gases, including cutting methane leaks

- Scale up research and development to create new options for low-carbon industrial processes
- Audit the energy use and resource efficiency of your operations to identify cost-effective high-impact reductions
- Understand your exposure to climate risk and take precautions
- Embrace the opportunities associated with renewable energy and resource efficiency
- Be a leader in sustainable industrial practices

Agriculture, Food & Waste:

- Measure food loss, create waste baselines and implement strategies to reduce food waste
- Set and promote science-based targets to increase the availability and uptake of plant-rich diets, increase sustainable production and minimize food waste
- Inform consumers and producers about food choices and how to reduce food loss waste across the supply chain
- Align national diet recommendations with climate goals
- Promote and support climate-smart and sustainable agriculture practices

- Measure and report company food loss and waste
- Adopt a corporate commitment to halve food loss and waste by 2030
- Work with suppliers and clients to find solutions that reduce food loss and waste across the supply chain, targeting waste hotspots like weak links in the cold chain
- Review packaging, provide clear storage and freezing guidance, eliminate 'display until' dates and clarify best before/use-by dates
- Avoid 'Buy One Get One Free' food promotions if they are likely to cause customers to buy more than they can eat
- Repurpose extra-ripe foods in-store
- Integrate corporate food loss and waste strategies across your company, including by making it easier for consumers and employees to limit their food waste
- Set up processes for surplus food rescue to transfer healthy, uneaten food to services who can distribute

it to those in need

- Urge your politicians to propose ambitious policies for waste reduction and nature-based agriculture
- Push for and support policies for waste reduction and nature-based agriculture
- Speak up at work to make waste reduction a collective issue
- Advocate for waste reduction and nature-based agriculture in your organization
- Talk to friends about the need for waste reduction and nature-based agriculture
- Attend or arrange events or communities for waste reduction and nature-based agriculture
- Shift towards a more plant-rich diet
- Plan meals, write shopping lists, use portion-sizing tools for rice and pasta and cook with leftovers
- Buy only what you can eat or save
- Embrace 'ugly' fruit and vegetables
- Store food to maximize freshness, including by freezing food when appropriate if possible
- Share excess with services who can distribute it to the needy
- Compost food scraps
- Ask grocery stores, restaurants and hotels to tackle food loss and champion those who lead the way
- Eat seasonally and locally when possible

Nature based Solutions:

- Halve tropical deforestation by 2025 and stop net deforestation by 2030 globally
- Stop policies and subsidies that incentivize deforestation and peatlands degradation and promote their restoration
- The UN Decade on Ecosystem Restoration is a rallying call for the protection and revival of ecosystems all around the world, for the benefit of people and nature. It runs through 2030, which is also the deadline for the Sustainable Development Goals and the timeline scientists have identified as the last chance to prevent catastrophic climate change.
- Restore 150 million hectares of forests and other landscapes by 2020 and 350 million hectares by 2030 – the two primary goals of the Bonn Challenge
- Systematically monitor and evaluate the progress of conservation and restoration efforts
- Work with suppliers to find collaborative solutions to minimize ecosystem impacts across the supply chain
- Invest in landscape conservation and restoration as part of net-zero emission efforts; investments must meet high social and environmental standards
- Promote investments in deforestation and peatlands drainage-free supply chains.
- Join a local or national organization supporting forest and peatlands habitat conservation and restoration

- Adopt a diet that reduces forest habitat loss, peatlands drainage and degradation by shopping locally and in season and purchasing products with deforestation-free and peatlands drainage-free ingredients, when possible.
- Whenever possible, neutralize your carbon footprint through investments in natural carbon sinks, such as forests and peatlands.

- Work with suppliers to find collaborative solutions to minimize ecosystem impacts across the supply chain
- Invest in landscape conservation and restoration as part of net-zero emission efforts; investments must meet high social and environmental standards
- Promote investments in deforestation-free supply chains.
- Consider overlaps between making your supply chain climate resilient and restoring forests and ecosystems – and make it happen.

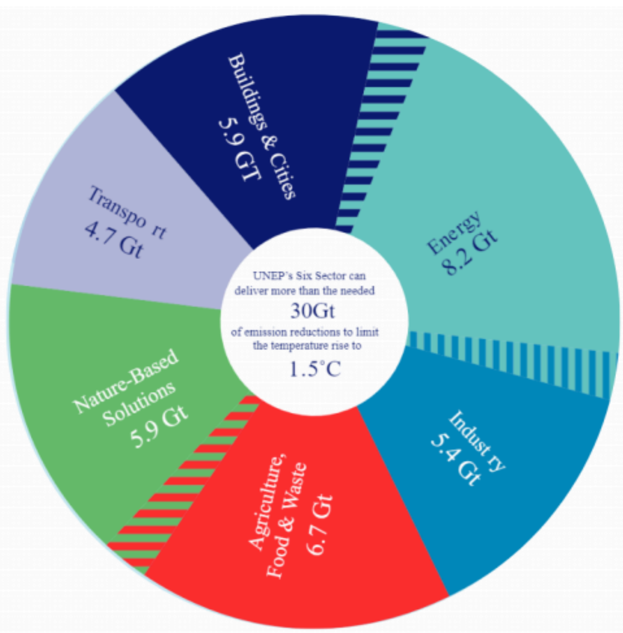
- Urge your politicians to propose ambitious regulation against deforestation and for nature restoration
- Push for and support policies against deforestation and for nature restoration
- Speak up at work against deforestation and for nature restoration
- Advocate against deforestation and for nature restoration in your organization
- Talk to friends about the need for nature restoration
- Attend or arrange events or communities against deforestation and for nature restoration
- Join a local or national organization supporting forest habitat conservation and restoration
- Adopt a diet that reduces forest habitat loss and degradation by shopping locally and in season and purchasing products with deforestation-free ingredients, when possible
- Whenever possible, neutralize your carbon footprint through investments in natural carbon sinks, such as forests

Transportation:

    - Switch fleets to electric vehicles
    - Incentivize a transition to zero-emission transportation, including for cars, taxis, buses, trucks and trains
    - Invest in and remove barriers to non-motorized mobility infrastructure, like protected bicycle lanes or paths for pedestrians

Promote the significant public health benefits of low-carbon policies, including increased public transportation and non-motorized mobility

- Switch fleets to electric vehicles
- Arrange for flexible and staggered working arrangements
- Switch to rail for the transportation of raw materials
- Embrace video conferencing for meetings and conferences
- Urge your politicians to propose support electrification of the transport sector
- Push for and support e-mobility and public transportation
- Speak up at work to make the needs for electric vehicles a collective issue
- Advocate for e-mobility and non-emission transport in your organization
- Talk to friends about the need for e-mobility and non-emission transport
- Attend or arrange events or communities for e-mobility and non-emission transport
- Buy electric vehicles and cars that use cleaner fuels
- Choose rail over air and travel as little as possible
- Reduce your commute by working from home
- Hold meetings over videoconference
- Walk and cycle
- Use public and shared transport
- Support local government initiatives to introduce better mass transit and non-motorized mobility infrastructure
- Join bike-, scooter- or car-sharing service



Infographic by UNEP (https://tinyurl.com/2bhwbecu)
Note from UNEP: All data has been extrapolated from UNEP's flagship 2020 edition of the Emissions Gap Report. The interactive story is currently being updated to reflect the reports latest data.

ACT NOW

Act for Our Common Future

Embrace the possible. That's the call of the 17 Sustainable Development Goals, a blueprint for a better world. We don't have to wait for the future we want—we can create it right now. Everyone can join the global movement for change.

ActNow is the United Nations campaign to inspire people to act for the Sustainable Development Goals.

https://www.un.org/actnow

Summary:

Our climate is changing because the Earth is warming. People have increased the amount of carbon dioxide in the air by 40 percent since the late 1700s. Other heat trapping greenhouse gases are also increasing. These gases have warmed the surface and lower atmosphere of our planet about one degree during the last 50 years. Evaporation increases as the atmosphere warms, which increases humidity, average rainfall, and the frequency of heavy rainstorms in many places—but contributes to drought in others.

Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. These changes have a broad range of observed effects that are synonymous with the term. Climate change describes a change in the average conditions — such as temperature and rainfall — in a region over a long period of time. Global warming is the long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere.

Our star; The Sun, serves as the primary energy source for Earth's climate. Some of the incoming sunlight is reflected directly back into space, especially by bright surfaces such as ice and clouds and the rest are absorbed by the surface and the atmosphere. The Earth has a natural greenhouse effect due to trace amounts of water vapor (H2O), carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) in the atmosphere. The natural greenhouse effect is caused by the natural amounts of greenhouse gases, and is vital to life. In the absence of the natural greenhouse effect the surface of the Earth would be approximately 33 °C cooler. The enhanced greenhouse effect refers to the additional radiative forcing resulting from increased concentrations of greenhouse gases induced by human activities i.e. the burning of fossil fuels. The main greenhouse gases whose concentrations are rising are carbon dioxide, methane, nitrous oxide, hydro chlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and ozone in the lower atmosphere.

Many other impacts associated with the warming trend have become evident in recent years. Arctic summer sea ice cover has shrunk dramatically. The heat content of the ocean as increased. Global average sea level has risen by approximately 16 cm (6 inches) since 1901, due both to the expansion of warmer ocean water and to the addition of melt waters from glaciers and ice sheets on land. Warming and precipitation changes are altering the geographical ranges of many plant and animal species and the timing of their life cycles. In addition to the effects on climate, some of the excess CO2 in the atmosphere is being taken up by the ocean, changing its chemical composition (causing ocean acidification).

Rigorous analysis of all data and lines of evidence shows that most of the observed global warming over the past 50 years or so cannot be explained by natural causes and instead requires a significant role for the influence of human activities. In order to distinguish the human influence on climate, scientists must consider many natural variations that affect temperature, precipitation, and other aspects of climate from local to global scale, on timescales from days to decades and longer.

In 1640 carbon dioxide was discovered by Johann Baptista van Helmolt, Flemish alchemist, determined that air is a mixture of gases. Around 1760, we have the start of the Industrial Revolution. Since the start of the Industrial Revolution, the way people live and work has changed dramatically as manufacturing expanded. Before the Industrial Revolution, there was approximately 280 parts per million (ppm) of CO2 in the air. Today, that amount is over 400 ppm. In the 1800's hundreds Eunice Foote, American scientist, discovered that carbon dioxide and water vapor cause air to warm in sunlight. Swedish chemist Svante Arrhenius recognized that burning coal could increase carbon dioxide and warm the climate. He estimated how much carbon dioxide the ocean could absorb. Roger Revelle, U.S. oceanographer, and Hans Suess, Austrian-born U.S. chemist, realize that carbon dioxide from industrial sources must be building up in the atmosphere. Measurements since the 1950s indicate that the amount of sea ice in the Arctic has been declining. The Arctic is projected to have no summer ice cover by the middle of this century. In 1958; Charles Keeling started making daily measurements of the amount of carbon dioxide in the air atop Mauna Loa in Hawaii. That first March day, he found 313 parts per million (ppm) of carbon dioxide in the air.

1988 Intergovernmental Panel on Climate Change (IPCC) was formed. The IPCC was formed by the World Meteorological Organization and the United Nations to review the latest climate science every few years and help governments around the world understand what we know about climate change, its impacts, and efforts to adapt and mitigate. At the second World Climate Conference in 1990 in its Ministerial Declaration, the Conference stated that climate change was a global problem of unique character for which a global response was required.

The General Assembly decided to convene in 1992 in Rio de Janeiro, Brazil, the United Nations Conference on Environment and Development. The Earth Summit, as it is also known, set a new framework for seeking international agreements to protect the integrity of the global environment in its Rio Declaration and Agenda 21, which reflected a global consensus on development and environmental cooperation. Chapter 9 of Agenda 21 dealt with the protection of the atmosphere, establishing the link between science, sustainable development, energy development and consumption, transportation, industrial development, stratospheric ozone depletion and transboundary atmospheric pollution.

September 2016 was the first time that minimum level was over 400 parts per million. Before large-scale burning of fossil fuels, CO2 levels were about 280 ppm. Globally, 2020 was the hottest year on record, effectively tying 2016, and the previous record. Overall, Earth's average temperature has risen more than 2 degrees Fahrenheit since the 1880s. The past eight years are the warmest years since modern recordkeeping began in 1880. This annual temperature data makes up the global temperature record— which tells scientists the planet is warming.

Climate Change will impact our communities,, economy, the interconnected systems, our water, health, Indigenous people, ecosystem and everything we get from nature, our food supply, infrastructure, our shore lines as well as tourism and recreation. We have the solutions and we need to apply these solutions so humans can continue to exist on planet Earth.

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