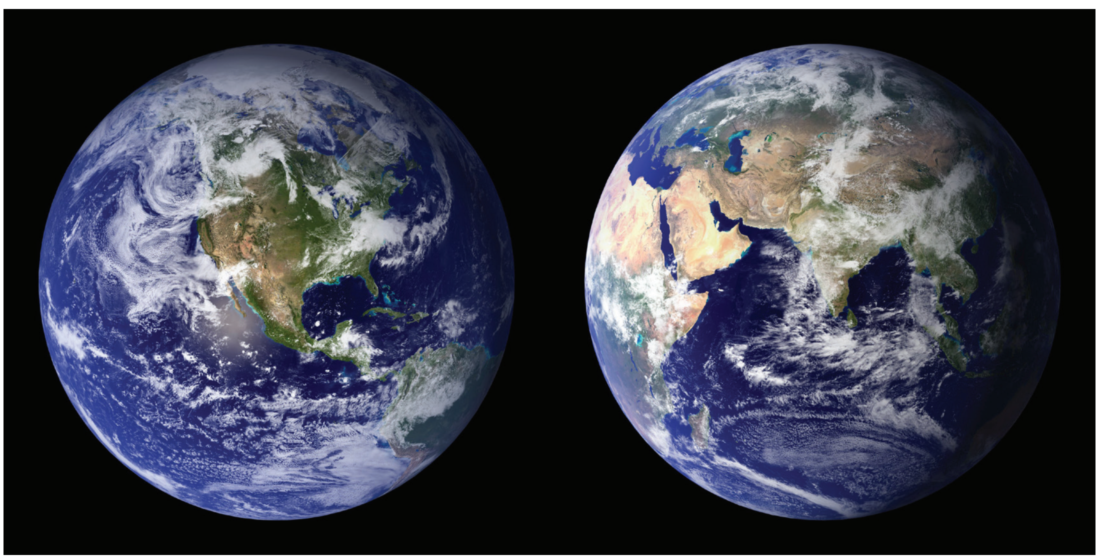
The **Teacher-Friendly** Guide™

to Climate Change



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On the front cover: the "Blue Marble." Composite images produced by NASA in 2001-2002.

On the back cover: Atmospheric CO_2 concentration at Mauna Loa Observatory from 1958 to 2014 (NOAA).

Chapter 9: Climate Change Adaptation

The Earth's average surface temperature has risen 0.8˚C (1.4˚ F) since 1880,[1] largely as a result of human-caused emissions of carbon dioxide (CO_2). These emissions spread evenly throughout the atmosphere and interact with the oceans, rocks, and plants and animals in a complex system we call the **carbon cycle**. Most of the CO_2 that we emit will remain in the Earth system—and continue to raise the Earth's temperature—for hundreds or thousands of years. According to the Intergovernmental Panel on Climate Change (IPCC, see Box 9.1),

> *Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2.*[2]

carbon cycle • *the exchange and recycling of carbon between the geosphere, hydrosphere, atmosphere, and biosphere.*

Even if we could instantly prevent any future CO_2 emissions—which we cannot do—we will have to deal with the ultimate impacts of the CO_2 that we have already emitted. These impacts are often described as being "in the pipeline," meaning that we are already committed to these changes and while we can't stop them, we can adapt to them. It is imperative that we continue to expand our mitigation efforts to limit the amount of human-caused global warming, but we also need to find ways to adapt to these climate impacts that are "in the pipeline." This chapter explores existing and proposed adaptation strategies

Box 9.1: The Intergovernmental Panel on Climate Change (IPCC)

The IPCC, founded in 1988 by the World Meteorological Organization and the United Nations Environment Programme, is a group of scientists from 195 countries who assess the state of the world's climate, climate science, impacts and risks of climate change, and options to respond to it. Over three thousand scientists are involved in writing and reviewing the IPCC's climate assessments approximately every six years, and these assessments are considered by many to be the authoritative source of information on climate change science. The assessments do not include policy suggestions, but they are intended to provide information to help government officials develop sound, research-based climate change policies.

See Chapter 7 on efforts to mitigate climate change.

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[1] This and other data on climate change can be found on a NASA website, Global Climate Change: Vital Signs of the Planet, http://climate.nasa.gov/.

[2] The IPCC publishes in-depth technical reports on climate change science, impacts, and mitigation. They also publish summaries for policymakers. The most recent summary of climate change science (as of this writing) can be found here: http://www.ipcc.ch/report/ar5/wg1/.

greenhouse effect • *the influence of GREENHOUSE GAS molecules in the Earth's atmosphere to retain heat (infrared radiation) radiating from the Earth's surface that would otherwise escape into space.*

storm surge • *a large volume of ocean water pushed onto land by offshore winds during a storm.*

for a variety of climate hazards and examines some of the challenges these strategies present.

1. How Much Does Adaptation Cost?

Many climate hazards come from processes that change very slowly over time, but are extremely difficult to stop. For example, as the atmosphere warms due to the **greenhouse effect**, so does the surface of the ocean. Surface water mixes slowly with the rest of the ocean, and it will take hundreds of years for the ocean to absorb and mix the additional heat we are introducing to the system. Warmer water takes up more volume than colder water, so the ocean is expanding and sea level is rising. Rise by 2100 due to this influence is expected to be between 15 and 30 centimeters (6 to 12 inches), depending on the level of future carbon emissions.[3]

For more on systems and ocean circulation, see Chapter 3: What is Climate?

This presents a challenge to economists and policy makers who try to determine the cost of any particular adaptation strategy. For example, many large cities are located on ocean coasts and sit at or just above sea level. As these cities make plans for the upcoming decades they have to decide how they will deal with the sea level rise that is "in the pipeline." City infrastructure such as airports, sea ports, roads, bridges, and subway systems and people living in coastal cities will be affected by rising sea levels, and they will need to plan for how to adapt.

Cities can select a variety of potential strategies. They can build sea walls or levees, or enhance shorelines with plants and natural structures that can absorb water and break waves. They can develop building requirements that mandate new structures be built at higher elevations. They can develop plans to raise the elevation of sea ports and airports that are at risk. All of these options come with a cost—some much larger than others—but city planners also have to weigh these costs against the cost of inaction. If you are creating a city budget for the next year, future sea level rise may not seem like much of a threat. You may decide to do nothing and leave the sea level rise problem for future planners. You also may decide to build protective structures—at a high cost—and to justify these costs to the taxpaying public.

To make things even more difficult, many of these adaptation strategies and decisions have to be made in the face of uncertainty. How much will protective infrastructure cost? Who should pay for it? How high will the sea level rise? What type of **storm surge** should one prepare for? Are the frequency or severity of storm surges going to change in a warming climate? What should we do if sea levels start to rise quicker than we initially thought? What would happen if we did nothing?

[3] This cause of sea level is different than that caused by melting glaciers. The IPCC reports that from 1993 to 2010, thermal expansion contributed to sea level rise at a rate of 1.1 mm/yr, melting from glaciers contributed at a rate of 0.76 mm/yr, and melting of the Greenland and Antarctic ice sheets contributed at rates of 0.33 and 0.27 mm/yr, respectively. For melting glaciers there is a somewhat shorter time lag than for thermal expansion, and a feedback between a warmer atmosphere and glacial melting.

Every adaptation strategy has its own set of uncertainties and potential trade-offs. One example of a way to think about adaptation strategies and the potential costs and benefits comes from the US Department of Transportation:

> *Actions taken to adapt transportation systems to climate change have both costs and benefits. Costs can include increased construction cost associated with designing a bridge to be able to withstand more frequent and intense storms, training costs associated with process or equipment changes, or the increased cost of labor and materials if operation and maintenance activities change or occur more frequently. Costs can also include broader effects (whether positive or negative) on the economy and jobs.*
>
> *The benefits of adaptation are the adverse impacts that are avoided; the more effective adaptation is, the greater the benefits. Benefits could include savings from avoiding the need to repair/replace assets. Benefits could also include impacts on quality of life from reduced traffic delays, avoided risks to human safety, avoided disruption of the flow of goods, etc.*[4]

ecosystem services *• the numerous benefits that healthy ecosystems provide to people, such as food, medicine sources, raw materials, erosion control, waste decomposition, filtering pollutants out of air and water, and recreation opportunities.*

Costs assessments can be done from "bottom-up," where one constructs detailed inventories of systems and their components, and the costs of specific adaptation methods applied to them. Another approach is "top-down," where one uses aggregate data on a system and makes assumptions about the additional costs needed to apply adaptation techniques to the system. Benefits such as improvements to quality of life can be hard to quantify, but economists attempt to define and assign values to measurable quantities such as delays avoided, lives saved, health improved, jobs created, repairs deferred, and **ecosystem services** maintained. A cost-benefit analysis compares the costs and benefits of an action, with the goal of finding actions where the benefits outweigh the costs. This is a difficult exercise, because in addition to estimating monetary values of costs and benefits, one has to factor in the likelihood of the action being adopted and the time frame on which the costs and benefits will be realized (see *Box 9.2*).

2. Types of Adaptation Strategies

Table 9.1 lists examples of different types of adaptation strategies.[5] It does not address every possible hazard associated with climate change and is not meant to be comprehensive. Rather, it is meant to give examples of a range of strategies which communities, governments, and businesses can use to adapt to climate change. Some strategies are "win-win" or "no-regrets," that is, they have benefits beyond adapting to climate change and should probably be done anyway. Others can be seen as more drastic.

[4] These examples came from a 2013 US Department of Transportation report, Assessment of the Body of Knowledge on Incorporating Climate Change Adaptation Measures into Transportation Projects: Assessing Costs and Benefits of Adaptive Strategies.

[5] Examples of climate change adaptation strategies can be found on many federal and state websites. Examples in Table 9.1 were drawn mainly from Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S., Grabhorn, P., & (eds), Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation, Technical Report (2011), Albany, NY, New York State Energy Research and Development Authority (NYSERDA) and Denver Climate Resiliency Committee, City and County of Denver Climate Adaptation Plan (2014), Denver, CO Department of Environmental Health.

Climate Change Adaptation

Table 9.1: Example adaptation strategies.

Adaptation Strategy: Relocate and retreat

Sea Level Rise
- Climate Hazard: *Coastal flooding, permanent inundation of coastal areas*
- Adaptation Strategy*: Relocate homes and infrastructure to higher elevations*

Heavy Downpours
- Climate Hazard: *Increasing flood risk*
- Adaptation Strategy*: Implement phased withdrawal of infrastructure from flood-prone areas*

Adaptation Strategy: Make changes in built infrastructure

Heat Waves
- Climate Hazard: *Decreasing dairy productivity due to heat stress in cows*
- Adaptation Strategy*: Alter livestock barns to increase cooling capacity*

Sea Level Rise
- Climate Hazard: *Coastal flooding and property damage*
- Adaptation Strategy*: Build structures to attenuate waves and storm surges*

Extreme Storms
- Climate Hazard: *Damage to power and communication lines*
- Adaptation Strategy*: Relocate lines underground where possible*

Adaptation Strategy: Renew and conserve natural systems

Sea Level Rise
- Climate Hazard: *Coastal erosion and loss of wetlands*
- Adaptation Strategy*: Renourish beaches and restore wetlands*

Heavy Downpours
- Climate Hazard: *Riverbank erosion and river flooding*
- Adaptation Strategy*: Stabilize riverbanks by planting deep-rooted, native plants*

Temperature Change
- Climate Hazard: *Shifts in range of animal species*
- Adaptation Strategy*: Maintain habitat connectivity and migration corridors*

Adaptation Strategy: Make land use changes

Sea Level Rise
- Climate Hazard: *Permanent inundation of coastal land*
- Adaptation Strategy*: Build up portions of low-lying cities*

Heavy Downpours
- Climate Hazard: *Increased flood risk and flood damage*
- Adaptation Strategy*: Buy out land or perform land swaps to encourage people to move out of flood-prone areas*

Adaptation Strategy: Modify management and operations

Temperature Change
- Climate Hazard: *Changing growing season and crop productivity*
- Adaptation Strategy*: Alter planting cycles, crop variety, and crop type*

Extreme Storms
- Climate Hazard: *Reduced bridge and roadway safety*
- Adaptation Strategy*: Plan to reduce/suspend traffic during extreme storm events*

Heat Waves
- Climate Hazard: *Heat-related illness and death*
- Adaptation Strategy*: Increase power supply for air conditioning, provide cooling centers for vulnerable populations*

Table 9.1: Continued.

Adaptation Strategy: Diversify to increase resilience

Temperature Change

Climate Hazard: *Reduced crop productivity at higher temperatures*

Adaptation Strategy*: Innovate and develop new crop types and farming methods*

Reduced Snowfall

Climate Hazard: *Loss of wintertime tourism (skiing, snowmobiling)*

Adaptation Strategy*: Shift and innovate other recreational and tourist activities*

Adaptation Strategy: Social innovation

Heat Waves

Climate Hazard: *Heat-related illness and death*

Adaptation Strategy*: Foster community networks that find and help at-risk populations*

Drought

Climate Hazard: *Stress on water supply*

Adaptation Strategy*: Influence consumer water conservation behavior with the use of smart meters and pricing*

Reduced Snowpack

Climate Hazard: *Reduced snowpack runoff and water supply*

Adaptation Strategy*: Encourage landscaping and gardening practices that use drought-resistant plants and eliminate need for irrigation*

Adaptation Strategy:Risk management

Extreme Weather

Climate Hazard: *Energy supply disruptions*

Adaptation Strategy*: Increase distributed electricity generation (electricity from multiple small sources)*

Extreme Storms

Climate Hazard: *Damage to transportation systems*

Adaptation Strategy*: Create mutual insurance pools to share risks*

Heat Waves

Climate Hazard: *Heat-related illness and death*

Adaptation Strategy*: Create systems to predict threats and alert at-risk populations*

Adaptation Strategy: Policy changes

Extreme Coastal Storms

Climate Hazard: *Damages to coastal property*

Adaptation Strategy*: Update building codes to promote storm-resistant structures*

Sea Level Rise

Climate Hazard: *Loss of coastal wetland habitat*

Adaptation Strategy*: Protect coastal wetlands with rolling easements (recognize nature's right-of-way to advance inland as sea level rises)*

Drought

Climate Hazard: *Lack of water for hydropower plants*

Adaptation Strategy*: Adjust reservoir release policies to ensure sufficient summer hydropower capacity*

tidal floods • *a flood occurring during high tides.*

nuisance flooding • *flooding which leads to inconveniences such as road closures and overflowing storm drains, but which does not cause severe damage.*

aquifers • *a water-bearing formation of gravel, permeable rock, or sand that is capable of providing water, in usable quantities, to springs or wells.*

storm surge • *a large volume of ocean water pushed onto land by offshore winds during a storm*

Box 9.2: Classroom exercise on cost-benefit assessment

A high school is in a region that is experiencing more intense heat waves, especially during June when classes are wrapping up and students are taking final exams. The school has inadequate cooling systems, and people are concerned about heat-related illness affecting the staff and students. Several students have already been taken to the hospital, suffering from heat stress.

The administration is considering several options to deal with extreme heat. Evaluate the costs and benefits of each option, and come up with a recommendation for what action(s) to take based on this analysis. You can add options that are not listed here.

Adaptation options:

1. Install a building-wide central air conditioning system
2. Install window air conditioners in classrooms, staff offices, the library, and the gym, but not elsewhere in the building
3. Provide ice water stations in the hallways for students to use in between classes
4. Shorten winter break and spring break so that school can end earlier in May, when heat waves are less likely
5. Start school two hours earlier, to avoid the afternoon heat
6. Avoid the afternoon heat by ending the school day earlier, but add school on Saturday to make up for the lost time

3. Adaptation to Different Climate Hazards

This section presents examples of adaptation responses to different hazards from a changing climate.

3.1 Rising Sea Level

Coastal communities sometimes experience flooding during high tides. These **tidal floods** (*Figure 9.1*) provide a view of the future with rising seas, when today's tidal floods become the future's everyday floods. In addition to **nuisance flooding**, a rising sea level can lead to coastal erosion, property damage, saltwater intrusion into freshwater **aquifers** and ecosystems, and permanent flooding of coastal land and infrastructure. When coastal storms with intense winds produce **storm surge**—a rising sea pushed onto land—higher sea levels lead to higher storm surge and more storm damage and risk to human lives.

Sea level rise affects billions of people worldwide. In 2010, 80% of the world's population lived within 60 miles of a coast. 75% of all large cities are located


Figure 9.1: Tidal flooding in the Brickell neighborhood of downtown Miami, FL in October, 2016.

on or near an ocean coast. In the US, Florida has the most cities at risk, but other American cities such as New York, Boston, Charleston, New Orleans, San Francisco, and many smaller cities are also vulnerable to sea level rise. Sea level rise also affects estuaries far upstream from the ocean. As sea level rises, salt water gets pushed further up into the freshwater region of an estuary, putting ecosystems and water resources for people at risk.

Strategies to protect coasts and communities from sea level rise include building structures that break or attenuate waves, maintaining and enhancing natural protective coastline features, setting restrictions and rules on whether and how coastal land can be developed, and relocating infrastructure and communities to higher ground. Building hard structures such as seawalls, levees, storm surge barriers, and breakwaters was common in the mid-20th century, but more recently organizations such as the Army Corps of Engineers have favored nature-based approaches such as building dunes and nourishing (i.e., adding sand to) beaches. Other nature-based approaches include maintaining and enhancing wetlands, coastal forests, barrier islands, and oyster reefs. These natural features help to prevent erosion, break waves offshore, and reduce the energy of incoming waves. They also serve other functions such as absorbing stormwater and providing habitat for commercially important fish and shellfish species. Some adaptation projects have used nature-based engineering, for example, they have created artificial oyster reefs or other structures that replicate natural ones (*Figure 9.2*).

Policies, regulations, building codes, and flood preparedness and insurance programs all play a role in adapting to rising seas. Communities can set restrictions on where buildings can be built, limiting development extremely close to the coast where beaches and buildings are at greatest risk (*Figure 9.3*). Communities can also create building codes that require new construction to be more storm-resistant, built on stilts, or made with the capacity to float. They can define “rolling easements” on property, which recognize that wetlands and beaches will migrate inland, regardless of whether properties will be eroded or flooded. Flood insurance rates for coastal properties can be set to reflect the reality of the risk in coastal zones, which is high. Finally, communities need to create effective flood and storm warning and preparedness programs, to keep residents safe in place or to evacuate them when necessary.

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Figure 9.2: Artificial oyster reefs parallel to the shoreline provide a way to slow the rate of coastal erosion by reducing incoming wave energy.

Figure 9.3: Beaches houses on the western side of Misquamicut Beach, Westerly, Rhode Island.

Some communities will need to consider relocation. This is already happening in places such as the village of Shishmaref, AK, where residents voted in 2016 to move their entire village away from a barrier island; in Staten Island, NY, where some residents left with no plans to return following devastation from Hurricane Sandy; and in Isle de Jean Charles, LA, where residents received the first ever grant of federal funding to help them relocate because of rising sea level brought on by climate change. Relocation can involve moving critical infrastructure such as hospitals, wastewater treatment plants, and bridges, but it can also involve moving entire communities or neighborhoods farther inland to higher ground. Other proposals have included building up low-lying areas of cities such as Norfolk, Virginia, which face the combined pressures of low elevation, rising seas, and naturally subsiding ground. The financial and social costs of relocation can be enormous, which is why mitigation—taking action to reduce the rate and magnitude of climate change, rather than relying entirely upon adaptation—is critical.

3.2 Heat Waves

Heat waves—defined as a series of consecutive days with exceptionally high air temperatures—can be deadly. During an intensely hot period in July of 1995, 733 people died from heat-related illness in Chicago. In 1993, a heat wave in Europe killed nearly 35,000 people, and in 2010, a heat wave in Moscow killed more than 10,000 people. Heat waves often disproportionately affect vulnerable populations: people who don't have enough income to pay for air conditioning at home, elderly people living alone who can't get themselves to cool locations, or people living in crime-ridden neighborhoods who are afraid to open windows.

Heat waves also stress ecosystems, livestock, and infrastructure. Dairy cows produce less milk and crop growth can slow during periods of intense heat, and paved roads can buckle. Energy systems are strained during heat waves when electricity demand for air conditioning rises, sometimes leading to **brownouts** and blackouts. These power disruptions in turn put strain on communications and emergency response systems. Heat waves combined with drought can increase the likelihood of wildfires. Under a warming climate the frequency and length of heat waves has increased in much of the US. This trend has already been noted in recent decades and is expected to continue.

Adaptation efforts to deal with extreme heat are underway, especially in urban areas where pollution, pavement, and the surfaces of buildings magnify localized warming in a phenomenon called the **urban heat island effect**. Strategies to reduce this effect often focus on reducing absorption of sunlight. Approaches include planting trees along city streets and in open spaces, and building living roofs—rooftops covered with living plants instead of asphalt or other materials (*Figure 9.4*). These techniques involving vegetation lead to measurable cooling. Plants can cool a roof or other surface by lightening the surface color (compared with dark asphalt), since light colors absorb less sunlight and radiate less heat than dark colors. A layer of plants can also provide insulation on a roof. Where living roofs are not feasible, painting roofs with reflective paint can help keep buildings cool. Using lighter colored paving materials for streets can also reduce local warming.

In addition, plants can cool the air through evapotranspiration. Evapotranspiration is a combination of evaporation of liquid water on plant leaves and in the soil around the plant and transpiration, the transfer of water from a plant's roots to its leaves and then to water vapor in the air. Evapotranspiration cools the air because it takes heat from the air to convert liquid water to water vapor.

Figure 9.4: Living roof on a building at the US Air Force Joint Base Andrews, MD.

brownout • *a situation where available electric power is limited but not eliminated.*

urban heat island effect • *a phenomenon in which an urban area experiences higher temperatures than do surrounding rural areas as a result of pollution, pavement, and the surfaces of buildings magnifying localized heating.*

green infrastructure • *structures that use plants, soil, and other natural features to perform functions such as providing shade, absorbing heat, blocking wind, or absorbing and filtering stormwater.*

In addition to making structural changes to keep cities cool, communities must develop effective heat warning systems to alert residents to the dangers of extreme heat, and put in place heat response plans to protect residents. These systems and plans must pay particular attention to vulnerable populations such as the elderly, low-income residents, and non-English speakers who may find it hard to get weather and safety information they can understand. The heat response plans might include actions such as using neighborhood social networks to check on elderly residents, opening air-conditioned cooling centers for the public, and providing maps and transportation to these centers.

Agricultural strategies to adapt to more frequent heat waves include using fans, sprinklers, and other cooling methods in livestock barns, and developing new crop varieties that can tolerate heat better. For activities such as transportation, telecommunications, and energy distribution, many of the adaptation strategies for extreme heat involve technological solutions. For example, power lines may need upgrading with wiring and transformers that work well at higher temperatures. Bridge and road materials may also need upgrading, and public transportation systems such as subways and buses may need more and better air conditioning. In addition, if large-scale systems that use energy can be made more energy efficient, it will reduce the strain on electrical systems during heat waves when demand is high.

3.3 Heavy Rainfall

Warmer air can hold more water vapor, so under a warming climate the average global amount of precipitation will increase—although this will not be evenly distributed. Some regions will get more rainfall, and some regions will get less, but heavy downpours have been increasing in most regions of the US, and are expected to continue to increase. *Figure 9.5* shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012. A large amount of rain falling in a short time can overwhelm stormwater management and sewer systems and lead to dangerous, destructive flooding and mudslides. It can also wash nutrients from farms and pollutants into sensitive ecosystems and drinking water reservoirs.

One way that cities are addressing the increased risk of heavy rainfall is through the use of **green infrastructure**. Conventional or “gray” ways of managing heavy rainfall in cities involve capturing the rain with gutters and storm sewers and moving it away through pipes to nearby streams, rivers, or lakes. Green infrastructure incorporates soil and plants, and uses them to absorb and filter rainwater. The absorption reduces the amount of stormwater that could potentially flood streets and neighborhoods, and any excess water is cleaner after being filtered.

One example of green infrastructure is a rain garden, typically a basin near a sidewalk or street containing decorative plants (*Figure 9.6*). The garden collects and absorbs rainwater, reducing pollution and preventing flooding. Building and maintaining a rain garden can be an excellent experiential education project for a school (see rain garden resources at the end of this chapter for guidance). A bioswale is a type of rain garden built as a channel along a street or parking lot. Bioswales absorb and filter water, and they also slow water down as it moves along the channel, reducing the risk of flooding. Paved areas such as parking

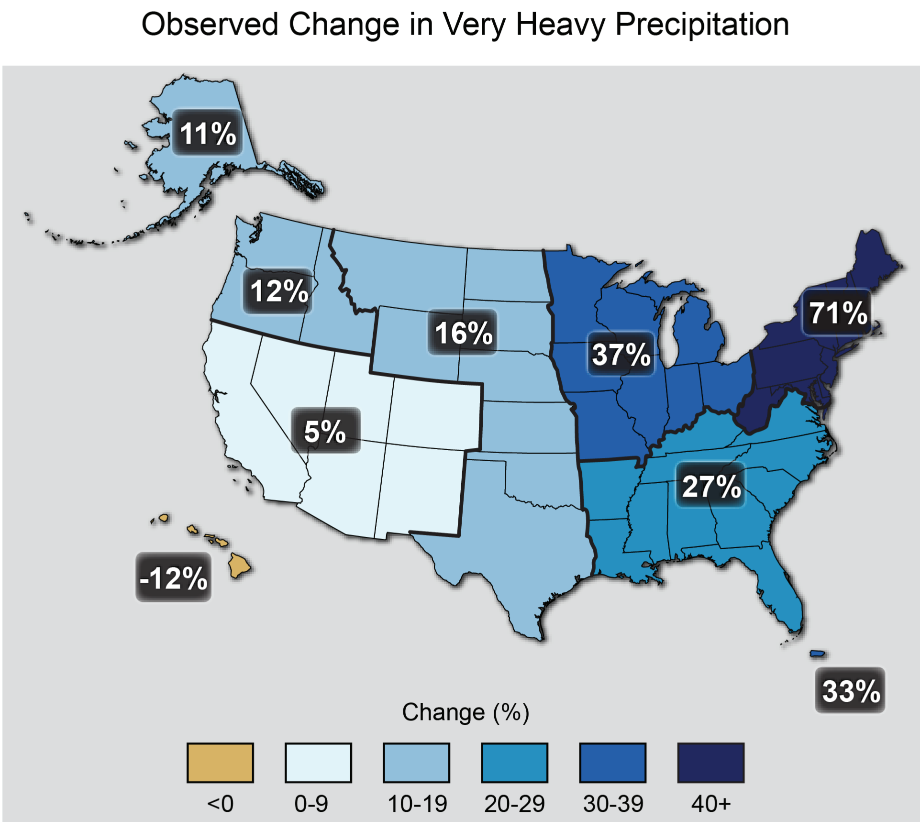

Figure 9.5: The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawai'i, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (See Teacher-Friendly Guide website for a full color version.)

lots can also be built to absorb stormwater, using permeable pavement instead of plants. This type of pavement has small holes that allow water to drain into the soil below (*Figure 9.7*).

Another solution to address heavy rainfall involves upgrading culverts. Culverts are pipes or channels that carry water underneath roads or railroad lines. Most drivers don't give a second thought to culverts, but when they are too small to handle water from a heavy downpour, flooding and severe erosion of the roadbed and surrounding area can occur. Many culverts around the country will need to be redesigned and rebuilt to an appropriate size for the increased heavy rains that climate change is expected to bring.

A final strategy to adapt to the increasing frequency of heavy rainfall is to relocate key infrastructure out of flood-prone areas, and to site new construction away from these areas. An important part of this strategy is having the best possible knowledge of the location of flood zones. The Federal Emergency Management Agency (FEMA) publishes and regularly updates flood hazard maps that can be used for managing floodplain development.

Figure 9.6: Rain garden in the High Point neighborhood in Seattle, WA.

Figure 9.7: Permeable pavement in an alley in Chicago, IL.

3.4 Drought

While many parts of the US have experienced drought in the past, the rising temperatures associated with global climate change will likely make droughts more severe. Warmer air leads to more evaporation from soils, lakes, and streams, and moisture loss from plants. These effects can stress agricultural production, ecosystems, and water resources for drinking water and energy production. The dry conditions from drought can also increase the risk of wildfires.

Adapting to more frequent and severe drought can involve monitoring and planning, restricting water use and grazing, improving and upgrading water supply and delivery infrastructure, developing and encouraging the use of drought-tolerant plants for gardens and crops, and educating the public and farmers on water conservation practices.

The National Drought Mitigation Center at the University of Nebraska-Lincoln, in partnership with the US government, produces weekly maps of drought conditions across the country (http://droughtmonitor.unl.edu). This monitoring, together with assessment of water sources and impacts of past droughts, can help communities plan for how to handle drought. Actions that communities can plan for include setting up a drought warning system, making arrangements for alternate water sources during drought events, and setting up irrigation schedules for farmland. An early warning system, for example, can help ranchers make decisions about grazing their cattle sustainably. Pastures may not grow during droughts, and with enough advance warning ranchers can plan to limit grazing, look for alternate sources of feed, or sell off parts of their herd in order to sustain their grazing land and livelihood.

Another important type of monitoring is checking water supply systems for leaks, to minimize wasted water (see *Box 9.3*). This falls under the broader goal of water conservation, which is a wise practice at all times and which can become critical during times of drought. Communities can conserve water by imposing restrictions—limiting water use to firefighting and other emergency or essential use—or through voluntary measures and education. Households can conserve water by eliminating lawn watering and planting gardens with drought-tolerant plants, buying low-water-use dishwashers and clothes washers and using them only when full, fixing leaks and drips promptly, building driveways with permeable pavement to allow rain to filter into the ground, and capturing and reusing rainwater or other household water. Farmers can conserve water by using planting practices that reduce erosion, slow water runoff, and maximize water absorption in soil, irrigating different areas at different times to spread the use of water over time and land area, and capturing rainwater.

Ecosystems also experience stress during times of drought, but people can take action to help plants and wildlife adapt. One example is by creating fish passages. When streams and rivers dry out because of drought, fish find it much more difficult to travel upstream to spawn. Even if they are able to spawn, low stream flows can threaten the viability of their eggs and young. Fisheries managers can help fish by building channels with sufficient stream flow to allow fish to pass, and by removing barriers such as dams.

Box 9.3: Exercise: essential and non-essential uses of water

Exercise: what are examples of essential and non-essential uses of water? Consider households, cities, farms, and non-agricultural businesses or industries (including energy producers). Have the students research the proportion of water use for residential, commercial, and agricultural purposes in their state.

One possible source for data is the US Environmental Protection Agency. See their websites on water use and state water facts: http://www3.epa.gov/watersense/our_water/water_use_today.html and http://www3.epa.gov/watersense/our_water/state_facts.html.

3.5 Extreme Weather

One of the consequences of climate change is an increase in the frequency and intensity of extreme weather events such as heat waves, drought, hurricanes, winter storms, and coastal storm surges. Some of these are driven by the ability of warmer air to hold more moisture while others are the result of climate change and the response of the interconnectivity of the atmosphere, the oceans, the biosphere, and the land. Extreme weather can be highly destructive and life threatening, and poses a difficult adaptation challenge.

Adaptation strategies for drought, heat waves, and heavy rainfall are addressed in other sections of this chapter, so the focus of this section will be on storms that bring heavy winds, snow and ice, and storm surge. The more intense a hurricane, the higher the risk of damaging winds and storm surge. Storm surge occurs when offshore winds push a great volume of ocean water onto land. Sea level rise—another consequence of climate change due to warmer, expanding oceans and melting ice sheets—exacerbates the risk associated with storm surge because it means the sea is higher relative to land to begin with.

See *Box 6.5* in Chapter 6: Regional Climates for a discussion of climate change and extreme weather.

Adapting to storm surge is a difficult challenge for those who live on the coast, especially since storm surges can rise over 30 feet in an intense hurricane. Houses can be raised above the land surface by being built on piles (vertical structures), which allow water to flow beneath the house. The piles are built with deep foundations to prevent erosion of and damage to the piles. Communities can set regulations that require new buildings to be set back from flood-prone areas. They can also protect and revitalize natural features that provide buffers against storms surges, such as dunes and beach vegetation.

Adaptation strategies for high winds include using building practices that strengthen structures, designing building sites with high winds in mind (*Figure 9.8*), protecting power lines and other infrastructure, and providing education on safety in the face of severe winds. Building practices can be voluntary or made mandatory through building codes, and they include things like using extra nails when applying roof shingles, putting steel bracing around tall chimneys, and anchoring structures to permanent foundations. Site design considerations include incorporating natural wind breaks such as trees, designing features to

Figure 9.8: Hurricane clips, shown circled above, help anchor roofs to the main structure to prevent detachment due to severe wind. These clips can be found at many hardware stores, and are an inexpensive way to mitigate home damage from hurricanes. The home above kept its lid on during the severe winds brought by Hurricane Katrina, even though construction of the house had not been completed.

direct wind away from buildings, and using ventilation systems to control the flow of air in and out of buildings. Power and telecommunication lines can be placed underground for protection, and regular tree trimming can help prevent damage to over-ground lines.

Education plays a big role in making sure communities are prepared for storms with high winds. Examples from the Federal Emergency Management Agency (FEMA) include:

- informing residents of shelter locations and evacuation routes;
- educating homeowners on the benefits of wind retrofits such as shutters and hurricane clips;
- ensuring that school officials are aware of the best area of refuge in school buildings;
- instructing property owners on how to properly install temporary window coverings before a storm; and
- educating design professionals to include defense against strong winds as part of building design.

Winter storms can include high winds and storm surge (if along the coast), but they bring the additional hazards of snow, ice, and cold temperatures. A loss of power following a winter storm can lead to lack of heat for buildings, putting people at risk and causing water pipes to freeze and burst. Implementing and enforcing building codes can help reduce the risk of weak roofs that collapse under heavy snow, and can reduce heat loss through the use of insulation. Utilities lines can be protected from ice and snow damage through similar measures as described above for protection from high winds, and communities can install snow fences or rows of trees to prevent snow from drifting and building up on roads. As with other weather hazards, education is critical for preventing loss of life. People need to learn: how to drive on icy roads (and when to avoid driving); how to prevent death from carbon monoxide poisoning by venting generators to the outside, installing detectors, and not sitting in a snow-covered car with the engine on; and to check on elderly and other vulnerable neighbors who may have lost power.

Climate Change Adaptation

snowpack • *snow accumulated over time, often in mountainous areas that have a long cold season. When snowpack melts it feeds streams and rivers.*

3.6 Reduced Snowfall and Snowpack

Although climate change is expected to bring more intense winter storms, many parts of the country have experienced a reduction in overall snowfall and **snowpack**. Snowpack is an important water resource, and less snow in the winter means less meltwater in the spring, reducing the flow of streams and rivers and depleting water supplies. People depend on this water supply for household use and agriculture, and ecosystems depend on it to sustain fish and other wildlife populations. The snow itself is an important part of tourist industries such as skiing and snowmobiling, and trout fishing tourism depends on streams with cold meltwater from snowpack. In addition to less snowpack, climate change is expected to bring earlier springs and earlier flows of meltwater.

Adapting to changes in snowpack and snowmelt is largely a question of water management. Communities may need to expand or build additional reservoirs to store more water in preparation for times of low snowmelt. They may also need to work out arrangements with communities in other watersheds, to purchase water from elsewhere in times of great need. A critical part of adapting to dwindling water resources is to do a much better job of conserving water.

Tourist industries that depend on snowpack can take several steps to adapt to less snow. Ski resorts, for examples, can use snowmaking technology, alter and develop slopes so they require less snow, and diversify their businesses to offer other attractions. These practices come with costs, of course. The recreational trout fishing season may shift to earlier months when streams are cooler, and anglers may switch to fishing for warm-water species such as bass.

4. Equity and Social Justice Considerations

Decisions about responding to climate change cannot be based on science and economics alone. They need to incorporate considerations of humans' relationships and responsibilities to each other, and how groups of people who have more resources to take action can help other groups who have less. Countries vary over orders of magnitude in the total amount of CO_2 they've emitted in the past as a country, how much they emit now, and how much they emit per capita. One of the challenges in creating international agreements on carbon emissions, and in creating domestic support for such agreements, is in resolving the real-world economic implications of decisions that, in principle, might take these sorts of factors into account.

Box 9.4: Classroom discussion topic: global environmental justice

In 2011, the five countries that emitted the most CO_2 were:[6]

		percent of global CO_2 emissions
1.	China	28%
2.	United States	16%
3.	European Union	10%
4.	India	6%
5.	Russia	6%

In metric tons of CO_2 emitted per person in 2011, the top five ranked countries were:[7]

		metric tons of CO_2 emitted per person
1.	Saudi Arabia	19.65
2.	Australia	18.02
3.	United States	17.62
4.	Canada	16.24
5.	Russia	12.55

China's and India's per capita CO_2 emissions were 6.52 and 1.45 metric tons per person, respectively.

Potential discussion questions:

1. Given these numbers, what are the responsibilities of different countries for taking action to adapt to and mitigate climate change?

2. Should wealthier nations such as the US pay to help poorer nations respond to climate change? If so, what is a country's balance between spending money to protect its own people and cities and spending money to help people elsewhere?

3. Do developed countries such as the US and Canada bear greater responsibility to address climate change since the current warming comes largely from CO_2 they have emitted in the past, or is China's responsibility greater since it is the largest emitter (total, not per capita)? Note that recent studies suggest China's carbon emissions are slowing down.

4. What are individuals' responsibilities to address climate change? An interesting question to consider is one posed by philosopher Dale Jamieson.[8] He describes a person taking a long airplane flight, which results in a large amount of carbon emissions. These carbon emissions contribute to warming which can lead to extreme weather events that kill people. One could argue then that taking airplane flights can amount to committing murder, but very few people flying on airplanes feel like they are murderers. How does our sense of morality fit with our actions that are causing climate change?

[6] For details see https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data#Country.

[7] The Union of Concerned Scientists presents data for these countries and more here: http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html#.WJt4aDsrLIU. The original data source is the US Energy Information Administration.

[8] See, for example, Jamieson's book Reason in a Dark Time (Oxford University Press, 2014).

Climate Change Adaptation

Resources

General Adaptation Resources

The US Climate Resilience Toolkit provides a wealth of case studies, tools, maps, and other resources on adaptation to climate change: https://toolkit.climate.gov.

To help identify adaptation efforts across the country, the Georgetown Climate Center has created a map though which one can find state and local adaptation plans: http://www.georgetownclimate.org/adaptation/plans.html.

In 2013 FEMA published a report that outlines actions communities can take to reduce the risk from natural hazards and disasters, many of which are exacerbated by climate change. The report, *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*, can be found here: https://www.fema.gov/ar/media-library/assets/documents/30627.

Adapting to Sea Level Rise

The US Army Corps of Engineers has written a report that provides an overview of different types of approaches to making coastal areas more resilient to climate change impacts. The report is titled *Coastal Risk Reduction and Resilience: Using the Full Array of Measures* and is available here: http://www.corpsclimate.us/ccacrrr.cfm.

After Hurricane Sandy the US Department of Housing and Urban Development launched a design competition called Rebuild by Design to find innovative ways to rebuild coasts that would make them more resilient to future storms. Information about the winning designs and the future of the Rebuild by Design initiative can be found here: http://www.rebuildbydesign.org/.

Restore America's Estuaries, a non-profit conservation organization, has produced a video that explains the concept and benefits of living shorelines for protecting coasts: https://vimeo.com/140113632.

Adapting to Extreme Heat

This US Environmental Protection Agency webpage provides a concise overview of the ways in which plants can help keep cities cooler: http://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands.

Talking Trees: An Urban Forestry Toolkit for Local Governments provides overviews, details, and case studies on the benefits of planting trees in cities. https://www.nyclimatescience.org/catalog/n255?DocId=vitroIndividual:http://www.nyclimatescience.org/individual/n255.

Many cities and counties have plans for excessive or extreme heat, including warning systems, information on how to avoid heat illness, maps of cooling center locations, and information about water and power conservation. Some examples can be found at:

- https://www1.nyc.gov/site/em/ready/extreme-heat.page (New York City)
- https://www.cityofchicago.org/city/en/depts/fss/provdrs/emerg/svcs/city_cooling_centers.html (Chicago)
- https://beta.phila.gov/services/safety-emergency-preparedness/natural-hazards/excessive-heat/ (Philadelphia)
- https://www.stlouis-mo.gov/government/departments/health/news/heat-advisory-until-8-pm-tuesday.cfm (St. Louis)
- http://www.ci.minneapolis.mn.us/health/preparedness/extremeheat (Minneapolis)
- http://lacoa.org/ht_extreme%20heat.htm (Los Angeles)

Adapting to Heavy Rainfall Events

The internet contains many excellent resources on how to design, install, maintain a rain garden. These are just a few examples:

- http://www.12000raingardens.org/build-a-rain-garden/schools/
- http://www.raingardennetwork.com/benefits-of-planting-rain-gardens/
- http://nemo.uconn.edu/raingardens/
- http://water.rutgers.edu/Rain_Gardens/RGWebsite/RainGardenManualofNJ.html

The US EPA has an informative website on managing stormwater with green infrastructure: https://www.epa.gov/green-infrastructure.

The University of Idaho has a webpage with information about the benefits, history, and technical details of green roofs: https://webpages.uidaho.edu/larc380/new380/pages/greenRoof.html.

The Nature Conservancy produced a video on the role of well-designed culverts in adapting to climate change, both for protecting fish and human communities: https://www.youtube.com/watch?v=vWtVFsOOFW8.

The Chicago Green Alley Handbook gives examples of ways in which small urban streets can be redesigned to handle the impacts of climate change: http://www.chicagoclimateaction.org/filebin/pdf/greenalleyhandbook.pdf.