potomac conservancy

RISING TO THE CHALLENGE

A NEW CLIMATE REALITY IN THE POTOMAC RIVER REGION

PUBLISHED 2021

SECTION 1

OUR CHANGING CLIMATE

GLOBAL CLIMATE CHANGE

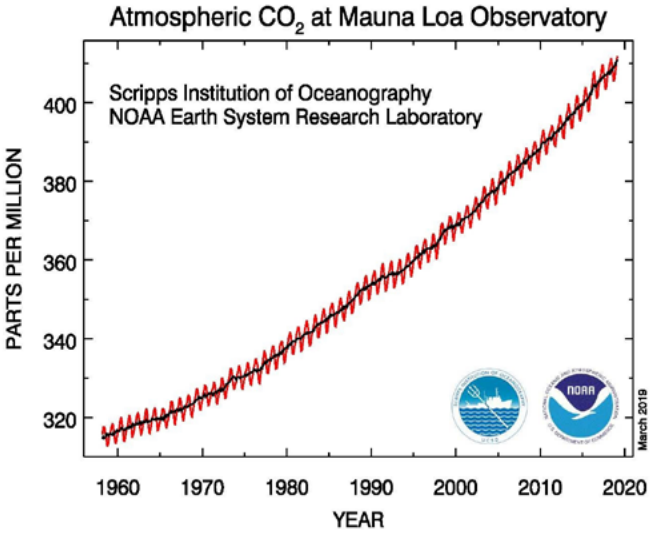
Global climate change has become the defining crisis of our time. Its effects are all around us, materializing in every corner of the globe. Rising seas are engulfing coastal communities, wildfires are burning hotter and fiercer in California and Australia, melting ice sheets are shrinking the surface area of Greenland and Antarctica, intensifying hurricanes and droughts are costing millions of dollars in damaged infrastructure, rising sea surface temperatures are starving coral reefs, increasing food and water insecurities are stressing local communities, and millions of people are being forced to relocate as they fight climate related risk and poverty (United Nations, n.d.).

GREENHOUSE EFFECT

While it's true that Earth's climate naturally cycles through ice ages and warm phases (over tens of thousands of years), the rapidity and degree to which the Earth has warmed in recent decades is unprecedented. According to the Intergovernmental Panel on Climate Change (IPCC) 2014 Fifth Assessment Report (The Intergovernmental Panel on Climate Change, 2014), "human influence on the climate system is clear" (The Intergovernmental Panel on Climate Change, 2014). **Billions of tons of carbon dioxide are spewed into our atmosphere each year as a result of modern industry and deforestation.** This gas persists for centuries – 300 to 1,000 years – in the atmosphere, meaning the addition of more and more carbon dioxide is only compounded over the decades (Buis, 2019).

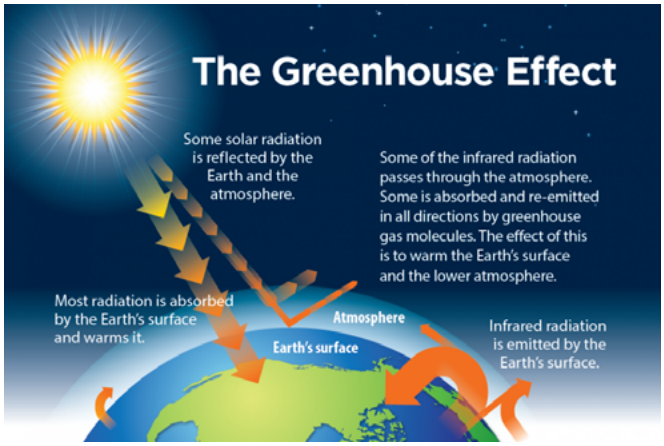
While carbon dioxide is the main culprit, other gasses like methane (released from natural gas fracking, from livestock and industrial agriculture practices, and the decay of organic waste put in landfills rather than composted) and nitrous oxide (released during fuel combustion and during the application of fossil-fuel based fertilizers or un-composted manure to fields) also add to the atmospheric soup of heat-trapping greenhouse gasses (U.S. Environmental Protection Agency, 2020a). Sulfur hexafluoride for instance, which is a byproduct of the electronics industry, is 22,000 times more effective at capturing heat energy than carbon dioxide, but does not remain in the atmosphere as long and is much less common (Helmenstine, 2020).

Water vapor is one of the more "potent" greenhouse gasses because, like carbon dioxide, its atoms are able to vibrate in such a way that allows it to easily absorb heat energy. Unfortunately, as the Earth warms, the air will be able to hold more moisture, worsening the impact of water vapor as a greenhouse gas. According to an article by Columbia University's Earth Institute, "CO2 *carbon dioxide* makes up only about 0.04% of the atmosphere, and water vapor can vary from 0 to 4%. But while water vapor is the dominant greenhouse gas in our atmosphere, it has "windows" that allow some of the infrared energy to escape without being absorbed. In addition, water vapor is concentrated lower in the atmosphere, whereas CO2 mixes well all the way to about 50 kilometers up. The higher the greenhouse gas, the more effective it is at trapping heat from the Earth's surface" (Cho, 2019).



Concentrations of carbon dioxide in the atmosphere, in parts per million (ppm), have been steadily increasing over the course of sixty years. Credit: NOAA.

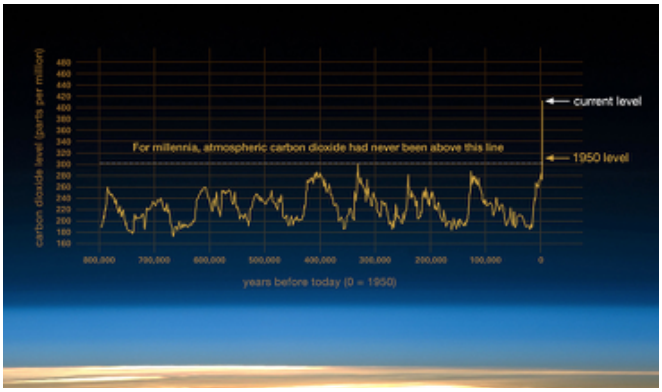
The concentration of carbon dioxide in Earth's atmosphere is currently at 412 ppm, a level that hasn't been exceeded in *three million years* – when temperatures and sea levels were much higher than today. This illustrates a 47% increase since the start of the industrial age in 1760, when levels were at 280 ppm. Incredibly, **scientists know that these increases in atmospheric carbon dioxide are, indeed, human-caused because carbon made by burning fossil fuels has a different isotopic ratio of heavy-to-light carbon atoms than carbon produced naturally by living plants** (Buis, 2019). One scientist from the National Physical Science Consortium, told Yale Climate Connections that, "we can't get away with saying that humans are not responsible for the carbon that's been added to the atmosphere. The isotopes don't lie, and they show it" (Harrington, 2018).



Radiative Forcing through the Greenhouse Effect. Credit: U.S. Environmental Protection Agency

How does it work? The sun's rays enter our atmosphere as shortwave radiation in the form of ultraviolet and visible light. Once that energy reaches the ground, it is absorbed and then reemitted as longwave radiation in the form of heat, or infrared rays. Incoming shortwave radiation easily passes between the gasses in our atmosphere, but the outgoing infrared (longwave) radiation gets absorbed. Carbon dioxide is an essential part of our atmosphere, as it keeps the planet warm enough for life. However, **the *density* of carbon dioxide has exponentially increased in the atmosphere since the industrial revolution, which began in 1750 as defined by the IPCC.** Since then, this human-induced increase in emissions is the primary cause of *positive* radiative forcing, whereby the ever-thickening blanket of carbon dioxide and other greenhouse gasses that trap heat energy cause our planet to be warmed more than is natural.

Radiative forcing, also known as climate forcing, is a measure that defines how much a given factor contributes to the downward direction of energy toward Earth's surface. This forcing is measured in watts per meter squared (W/m2) at the top of Earth's atmosphere. Scientists estimate that positive radiative forcing from rising concentrations of greenhouse gasses has added 1.6 W/m2 of energy to earth's atmosphere from 1750 to 2005. Radiative forcing can also be negative, where climate factors like high altitude clouds, reflective sea ice, and volcanic aerosols reflect sunlight and reduce the amount of energy being directed downward toward Earth's surface. However, the amount of positive radiative forcing now largely outweighs the amount of negative radiative forcing on the planet, and the result is a rapidly warming atmosphere. (OSS Foundation, n.d.; North Carolina State Climate Office, n.d.; Emanuel, n.d.; Mann, 2016).



The Keeling Curve. Credit: NASA

"The Keeling Curve links current carbon dioxide levels with those of the past. Data from historic ice core samples show a parallel between the rise and fall of carbon dioxide in the atmosphere and the timing of Earth's ice ages and warming trends" (Rafferty, 2018).

The United Nations (UN) Paris Agreement, adopted in December, 2015, and ratified by over 150 countries, is based on the primary goal of "... keeping a global temperature rise this century well below 2 degrees Celsius... and to pursue efforts to limit the temperature increase even further

to 1.5 degrees Celsius." Meeting this goal requires each country that has signed to develop a nationally determined contribution (NDC) to help reach global peak greenhouse gas levels by reducing emissions as soon as possible. The Intergovernmental Panel on Climate Change (IPCC)'s Special Report on Global Warming (SR15), published in October 2018, states with high confidence that global warming is expected to reach 1.5°C (2.7°F) between 2030 and 2052, should temperatures continue to rise at the current rate. As of February, 2021, the UN's NDC Synthesis Report indicated the status of nations' current contributions currently falls short of reaching the Paris Agreement goals, which according to the IPCC, require a 45% reduction in emissions below 2010 levels by 2030. (Intergovernmental Panel on Climate Change, 2018; United Nations Framework Convention on Climate Change, 2018; United Nations Framework Convention on Climate Change, 2021).

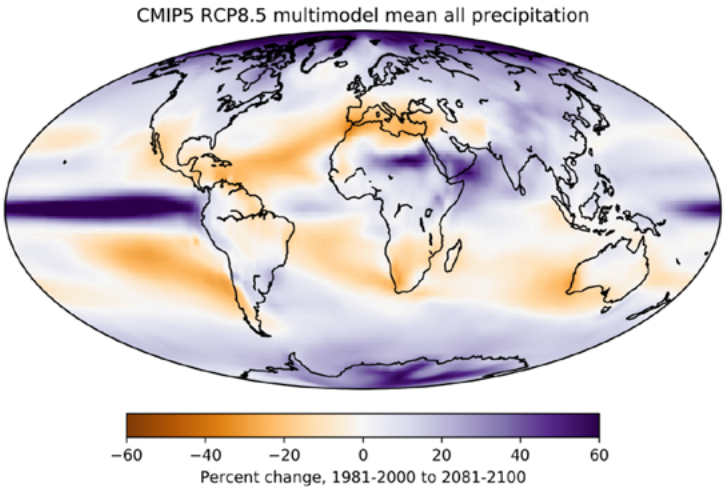
GLOBAL TEMPERATURE TRENDS

Earth's average global temperature has risen 1.2 °C (approximately 2°F) since 1880, when data became sufficiently widespread enough to calculate global temperatures with reasonable accuracy. The majority of this warming has happened since 1975. Although 1°C (1.8°F) might not sound like much, it takes a great deal of heat energy to warm every ocean, land mass, and the atmosphere by that amount. For perspective, a simple 1-2°C (1.8-3.6°F) drop from the 14th through the 19th century dipped the Earth into the Little Ice Age, while a 5°C (9°F) drop 20,000 years ago submerged North America under a deep layer of ice (Buis, 2019; Hausfather, 2020).

The IPCC's Fifth Assessment Report (The Intergovernmental Panel on Climate Change, 2014) states that, "recent warming of the climate system is unequivocal, and since the 1950s, many of the observed increases are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (The Intergovernmental Panel on Climate Change, 2014). **Yet the warming effects of climate change are not uniform across the globe.** For instance, the Arctic is warming twice as fast as the rest of the planet due to shifts in global energy transport and the loss of reflective sea ice (Levy, n.d.). And some areas like the United Kingdom are even predicted to become cooler. The latter occurs because the large influx of freshwater from Greenland's meltwater is beginning to slow massive ocean currents, weakening the transport of warm water from the tropics to the United Kingdom via the Gulf Stream (Fecht, 2020).

GLOBAL PRECIPITATION TRENDS

While climate models agree on Earth's overall warming trends, regional precipitation changes are much harder to predict because rainfall is inherently variable and occurs on much smaller spatial scales than temperature swings. For many areas of the world, climate models disagree on whether there will be more or less rain and snow in the future. Still, there are some regions, including southern Africa and the Mediterranean, where most models suggest rain will decrease. Likewise, rainfall is expected to increase in the high-latitudes and in South Asia (Hausfather, 2018a).



Credit: Carbon Brief

Overall, a warming world means that there will be greater evaporation and reduced snowpack globally, increasing the length and intensity of droughts, even when rainfall is not necessarily reduced. However, warmer air holds more moisture. The Clausius-Clapeyron equation states that for each 1°C (1.8°F) of temperature rise, the air can hold 7% more moisture. This means that water vapor will accumulate in the air longer than before; so, **although it may not rain as often, when it does rain, there will be a heavier pour.** But, like temperature, this increased capacity for holding water vapor will not result in uniform precipitation increases across Earth's surface. **Generally, in the mid and high-latitudes, wet areas are projected to become wetter while dry areas become dryer.** Moreover, the north and south poles will see heavy increases in precipitation as the air in the poles warms faster than the global average (Hausfather, 2018a).

CLIMATE VERSUS WEATHER

It is important to point out that climate and weather are two very different things. Climate is what you expect; weather is what you get. Weather refers to the state of the atmosphere on any given day, along with the short-term changes in its status in minutes to weeks. Climate, on the other hand, is the long-term weather of a specific region averaged over a period of time, often thirty years.

Studying climate allows us to look for cycles and trends in temperature, precipitation, wind patterns and ocean temperatures, across years, decades, centuries and millennia. Think of weather as the melody, the colorful ups and downs of a song that receive all the frontline attention. Climate, then, would be the baseline, the steady background signal left when you remove the melody. Because weather, and therefore climate, are not uniform across the globe, each region's "song" is a little different.

ROOT CAUSES OF GREENHOUSE GAS (GHG) EMISSIONS AND CLIMATE CHANGE

The primary **root cause of human-made greenhouse gas (GHG) emissions and climate change - both globally and in the USA - is fossil fuel dependency (gasoline, natural gas, diesel, coal, synthetic fertilizers & pesticides, industry including production and "disposal" processes).** This applies to all major sectors of GHG emissions (Transportation, Electricity, Industry, Agriculture, Commercial & Residential).

GLOBAL GHG EMISSIONS: ROOT CAUSES

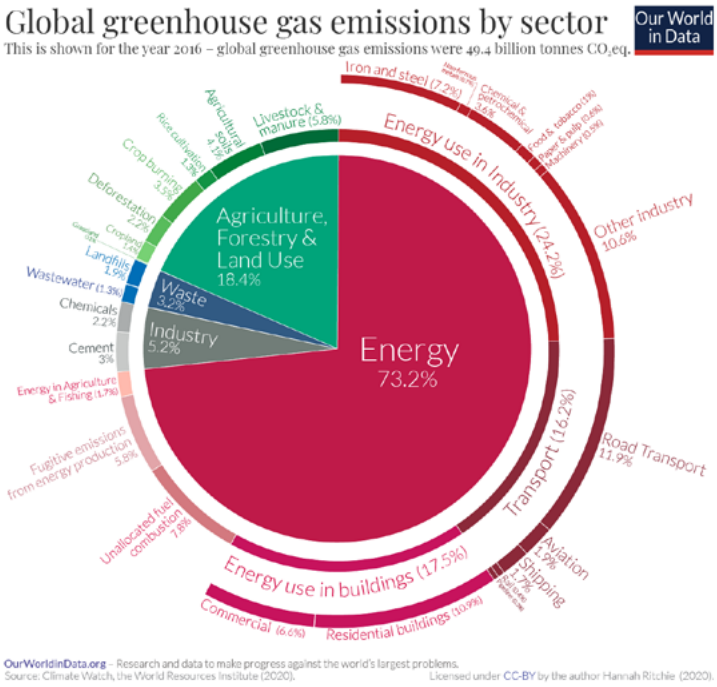
Data from 2018 shows that **globally "Most CO2 emissions (89%) are from the use of fossil fuels, especially for the generation of electricity and heat, transportation, and manufacturing and consumption.** Land use, **land-use change [deforestation, urban sprawl] is another major contributor** (7%) to human-made CO2 emissions, mostly due to deforestation" (Ge and Friedrich, 2020).

While we tend to focus on carbon dioxide as *the* climate change culprit (since it is the most common human source of GHGs), methane and nitrous oxide are much more potent GHGs because they absorb more heat energy than carbon dioxide. For instance, a molecule of methane is about 28 to 36 times more potent than a molecule of carbon dioxide – evaluated over the first one hundred years in the atmosphere. Major sources of methane release include natural gas extraction and flaring, industrial agriculture (especially concentrated animal feeding operations or "CAFOs"), and landfills (from organic material breaking down in a low-oxygen environment). Nitrous oxide is 298 times more potent than carbon dioxide over one hundred years and is produced as microbes in the soil break down fossil-fuel based synthetic fertilizers spread over the soil or when manure that hasn't been aged or composted is spread over soil (Helmenstine, 2020; Borunda, 2019; University of California, n.d.).

"**Methane** and **nitrous oxide** make up 17% and 6.2% of total **global** greenhouse gas emissions, respectively, mostly from **industrial agriculture, handling of waste [landfills, trash incineration, wastewater] and natural gas flaring**. Fluorinated gases (comprised of HFCs, PFCs, SF6 and NF3) from industrial processes make up 2% of global emissions. **These gases are much more potent than CO2 in terms their global warming** potential, and often provide overlooked opportunities for [GHG and climate change] mitigation" (Ge and Friedrich, 2020).

In 2016, "livestock and manure accounted for 5.8% of global GHG emissions, mostly methane and nitrous oxide [two of the most potent GHGs]. Nitrous oxide and methane are produced from the decomposition of animal manures under low oxygen conditions. This often occurs when large numbers of animals are kept in a confined area [such as cows, pigs, and chickens kept on Concentrated Animal Feeding Operations – CAFOs], where manure is typically stored in large piles or placed in lagoons" (Ritchie, 2020). 2016 data also show that "synthetic nitrogen fertilizers accounted for 4.1% of global GHG emissions, mostly nitrous oxide. Nitrous oxide – one of the strongest greenhouse gases – is produced when fossil-fuel based synthetic nitrogen fertilizers are applied to soils. This includes emissions from agricultural soils for all agricultural products – including food for direct human consumption, animal feed, biofuels and other non-food crops like tobacco and cotton" (Ritchie, 2020).

Let's dive further into the breakdown of global GHG emissions by sector, by examining a pie chart produced from 2016 data on emissions from all three types of major human-made greenhouse gases (carbon, methane, and nitrous oxide), produced in a 2020 article by Hannah Ritchie at OurWorldinData.org:



Credit: OurWorldinData.org and Hannah Ritchie

24.2% Energy Use in Industry. Broken down to largest portions: 7.2% iron & steel manufacturing; 3.6% chemical and petrochemical, including **oil & gas extraction**, manufacturing of **fertilizers**, pharmaceuticals, refrigerants, etc.; 10.6% other industry, including mining and quarrying, construction, textiles, wood products, and transport equipment (such as car manufacturing)

18.4 - 25% Agriculture, Forestry, and Land Use. Agriculture, Forestry and Land Use directly accounts for 18.4% of greenhouse gas emissions. The food system as a whole – including refrigeration, food processing, packaging, and transport – accounts for around 25% of global greenhouse gas emissions. Broken down to largest portions: 5.8% mismanagement of livestock and manure; 4.1% fossil-fuel based synthetic nitrogen fertilizers; 3.5% burning of crop residue; 2.2% total net deforestation; 1.7% farm machinery and fishing vessels; 1.4% degrading of cropland (depending on management practices used on croplands, carbon can be lost or sequestered into soils and biomass)

17.5% Energy Use in Buildings. Broken down to largest portions: 10.9% residential buildings (**fossil fuel based heating and electricity** for lighting, appliances, cooking); 6.6% commercial buildings such as offices, shops, restaurants; 7.8% unallocated fuel combustion (combined heat and power (CHP); nuclear industry; and pumped hydroelectric storage)

16.2% Transport. Broken down to largest portions: 11.9% road transport from the **burning of gasoline and diesel from all forms of road transport** which includes cars, trucks, semi-trucks, motorcycles, and buses. Sixty percent of road transport emissions come from passenger travel (cars, motorcycles, and buses); and the remaining forty percent from road freight. This means that, if we could electrify the whole road transport sector, and transition to a fully GHG-free renewable energy electricity mix, we could feasibly reduce global emissions by 11.9%

5.8% Fugitive Emissions from Energy Production. Broken down to largest portions: 3.9% fugitive emissions from oil and gas – this includes **leakage of methane to the atmosphere during oil and gas extraction and transportation**, and also includes **flaring – the intentional burning of gas at oil facilities**; 1.9% fugitive emissions from **coal**

5.2% Direct Industrial Processes. Broken down to largest portions: 3% cement; 2.2% chemicals and petrochemicals, including production of ammonia, **fertilizers, pesticides, and plastics**

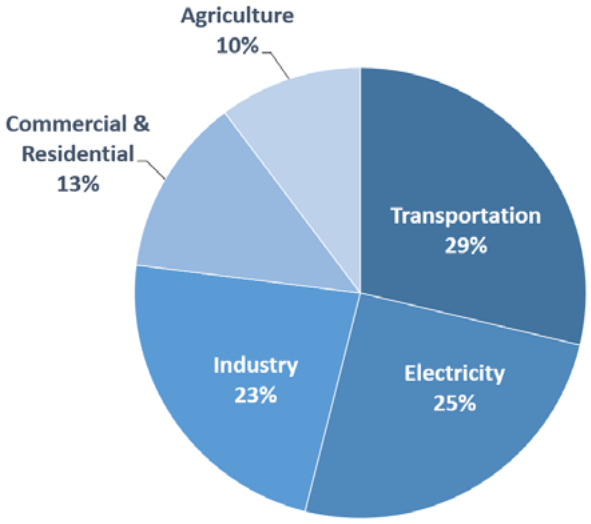
3.2% Waste. Broken down to largest portions: 1.9% **landfills** when organic matter in a low-oxygen environment is converted to methane; 1.3% wastewater

U.S. GREENHOUSE GAS EMISSIONS: ROOT CAUSES

Transportation (29% of 2019 GHG emissions in US) Greenhouse gas emissions from transportation primarily come from **burning fossil fuels** for our cars, trucks, ships, trains, and planes. **Over 90% of the fuel used for transportation is petroleum based, which includes primarily gasoline and diesel**

Electricity (25% of 2019 GHG emissions in US) Approximately 62% of our electricity comes from burning fossil fuels, mostly coal and natural gas

Industry (23% of 2019 GHG emissions in US) Greenhouse gas emissions from industry primarily come from **burning fossil fuels for heat**, and from certain **chemical reactions used to produce goods from raw materials**



Credit: U.S. EPA (2021) Inventory of U.S. GHG Emissions: 2019

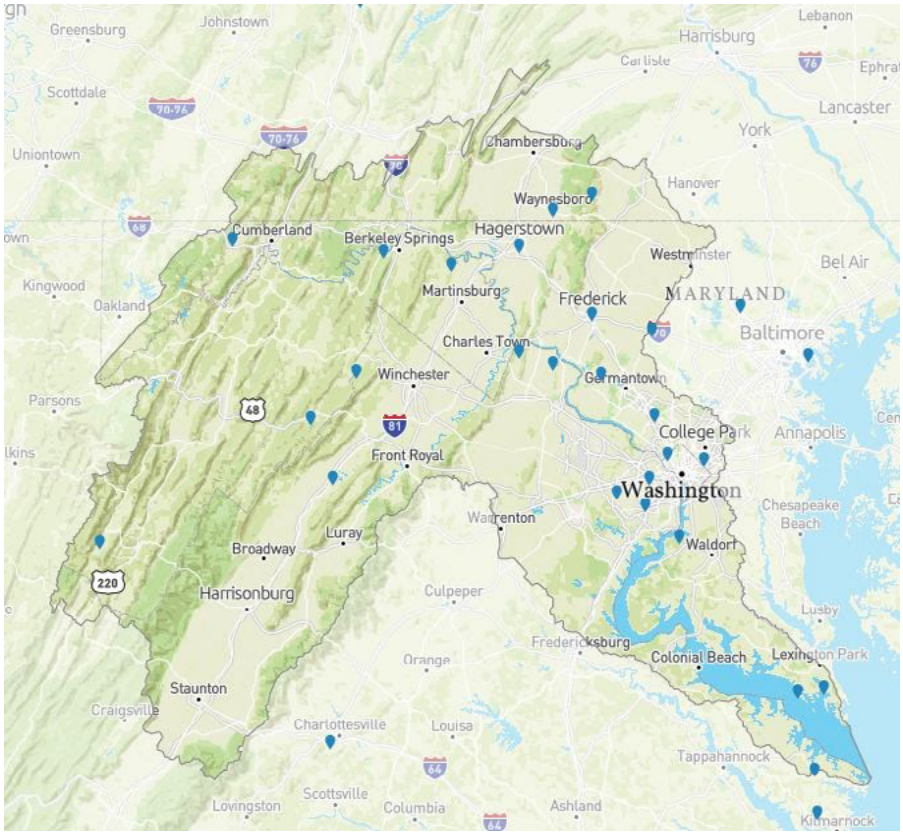
Commercial and Residential (13% of 2019 GHG emissions in US) Greenhouse gas emissions from businesses and homes arise primarily from burning fossil fuels for heat, the use of certain products that contain greenhouse gases, and the handling of waste [landfills, trash incineration facilities, wastewater]

Agriculture (10% of 2019 GHG emissions in US. Note: this percentage does not include processing, refrigeration, packaging, and transport of food; percentage of GHG emissions increases when looking at the food system as a whole.) Greenhouse gas emissions from agriculture come from fossil-fuel based synthetic fertilizers and pesticides applied to agricultural fields, livestock [especially concentrated animal feeding operations, or CAFOs], tilling of soil, and rice production with flooded paddies.

REGIONAL CLIMATE: POTOMAC RIVER WATERSHED

The Potomac River Watershed is the second largest watershed within the larger Chesapeake Bay Watershed, and stretches 14,670 square miles across portions of Maryland (3,818 square miles), Virginia (5,723 square miles), West Virginia (3,490 square miles), Pennsylvania (1,570 square miles), and Washington, D.C. (69 square miles). Its tributaries flow through forests, agricultural lands, rural communities, and urban areas, then join together to form the Potomac River. Based on mapping information available from Native Land Digital, the Potomac Watershed is the traditional territory of the Piscataway, Anacostan, Manahoac, Massawomeck, Tauxenent, Patawomeck, Cuttatawomen, Onawmanient, Nanticoke, Sekakawon, Monacan, Calicuas, Wicocomico, and Namoraughquend tribes, who are still here and continue working to protect land, water, foodways, and sacred sites. According to the 2010 census, approximately 6.1 million people live in this watershed, 81% of whom live in urban areas. The Washington, D.C. metropolitan area alone accounts for about 5.1 million of its residents. **Those living in the region depend upon the watershed for its vital ecosystem functions and, most notably, its abundant water resources (EPA Region 3 Office, n.d.). The Potomac River is the source of the water we drink for 5 million people currently living in the watershed.** Because climate is the most fundamental part of watershed functioning, it is important to understand our regional climate's history, and where we are headed in the future.

The Interstate Commission on the Potomac River Basin notes that the "major cities that are most populated in the Potomac Watershed include: Bethesda, Silver Spring, Germantown, Gaithersburg, Rockville, Frederick, College Park, Cumberland, Hagerstown, Waldorf, and St. Mary's City in Maryland; Alexandria, Arlington, McLean, Reston, Sterling, Centreville, Harrisonburg, Leesburg, Front Royal, and Winchester in Virginia; Harper's Ferry, Charles Town, and Martinsburg in West Virginia; Chambersburg and Gettysburg in Pennsylvania, and the largest city in the watershed, Washington, D.C." (Interstate Commission on the Potomac River Basin, 2020a).

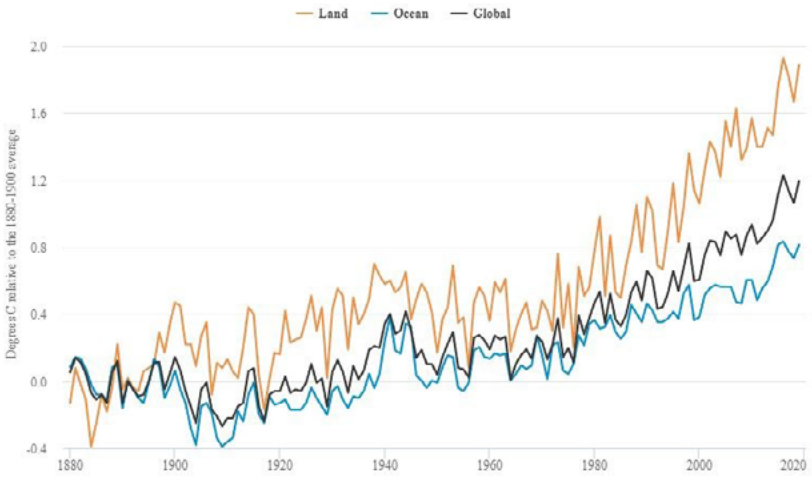


Map of the Potomac River Watershed. Credit: Interstate Commission on the Potomac River Basin

PAST SHIFTS AND SWINGS

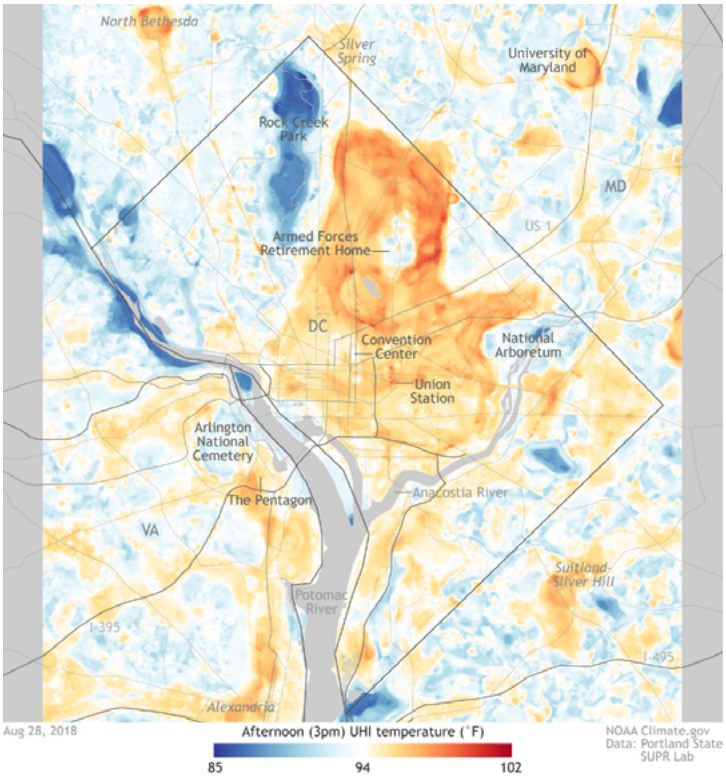
TEMPERATURE

Although, as a whole, the **Earth's temperature has warmed 1.2°C (2.2°F) since the 1880s**, land surfaces and ocean waters warmed at differing rates. Because water has a greater heat capacity, it takes more energy to heat water to the same degree as land. Data from NASA indicates that land surface temperatures have increased about 1.8°C (3.2°F) while oceans have warmed by 0.8°C (1.4°F) (Hausfather, 2020).



Land, ocean and global warming based on 1880-1900 pre-industrial era baseline using data from NASA. Credit: Carbon Brief / NASA GISS.

Further, every sub-region is different. The Potomac River Watershed states of Maryland, Pennsylvania, Virginia, and West Virginia, climate trends were reviewed by the North Carolina Institute for Climate Studies (NCICS) for the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) using data from 1901 through 2014. Results show that, **since the twentieth century, Maryland and Virginia have warmed by about 0.8°C (1.5°F), Pennsylvania by about 1.2°C (2.2°F), and West Virginia by less than 0.6°C (1.1°F) (Ahmed et al., 2020). For Washington, D.C., 2011 to 2019 was the warmest decade on record** (Center for American Progress, 2020).



Credit: National Oceanic and Atmospheric Administration (NOAA)

Since 1947, Ronald Reagan Washington National Airport in Arlington, Virginia, has kept records of daily temperature. From 1947 to 2014, the airport observed a 1.2°C (2.2°F) increase in temperature, warming a bit faster in the summer than in winter. Additionally, the average number of extreme heat summer days over 35°C (95°F) has increased by nine since 1950. The urban heat island effect (where blacktop surfaces absorb and hold heat) likely causes higher temperatures in the city than for the watershed as a whole, although the warming trend is the same throughout. (Hayhoe & Stoner, 2015).

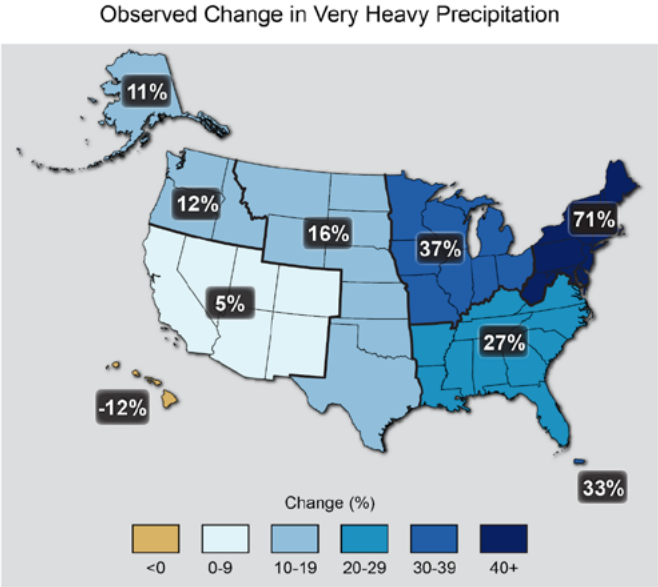
NOAA's Office of Oceanic and Atmospheric Research Climate.gov team produced maps of a set of Washington, D.C.'s citizen science data from August 28, 2018. That day, recorded temperatures reached as high as 38.9°C (102°F) in several neighborhoods while other parts of the city were 9°C (16°F) cooler. The temperature data are colored in shades of blue (coolest half of the day's temperature range) to red (warmest half).

Surface water temperatures have also been rising in the Chesapeake Bay area, to include the Potomac River itself. In fact, a researcher from the University of Maryland Center for Environmental Science stated, "If you take any group of five years, they are generally warmer than the previous five years. A consistent warming trend *is* happening over a really large portion of the Bay." **Following a heat wave in July of 2019, the Potomac River reached a record high temperature, with water thermometers at Little Falls, near Georgetown, reading 34.4°C (94°F) (University of Maryland Center for Environmental Science, 2015).**

PRECIPITATION

Precipitation changes are a bit less austere in the Potomac Watershed, as the year's wettest day drops, on average, only about one fifth of an inch more water than it did in 1950. However, while the total annual precipitation has not wavered much **since 1947, autumn and winter precipitation has been rising, summer precipitation has been declining, and spring precipitation has remained relatively the same. Additionally, when it does rain, it tends to rain harder than it has in the past** (Hayhoe & Stoner, 2015). In Virginia and West Virginia, the average precipitation from 1995-2014 was slightly greater than the century-long average. In Maryland, precipitation was higher than average during these two decades as well. Maryland also saw the greatest number of extreme precipitation events from 2005-2014. In Pennsylvania, 2010-2014, was the wettest in the past century, and it had the second highest tally of extreme precipitation events (Ahmed et al., 2020).

The regional trends in the Potomac Watershed are consistent with patterns across the Northeastern United States where the last two decades (1991-2012) were about 15% wetter than the first half of the twentieth century. **In fact, the frequency of heavy precipitation events in the region, as a whole, has increased by 71% from 1958 to 2012** (Hayhoe & Stoner, 2015). **The IPCC SR15 states that eastern North America is one area expected to see the largest increases in heavy precipitation events as the Earth's climate warms** (Intergovernmental Panel on Climate Change, 2018). This phenomenon is the result of a warming atmosphere, which can hold more moisture. For every 1° Celsius (1.8° F) of temperature rise, the atmosphere holds about 7% more moisture; so when it rains... it pours (Ramming, 2019).



(Figure source: updated from Karl et al. 2009).

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, Hawaii, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012.

FUTURE TRENDS

FRACKING: METHANE RELEASE & WATER POLLUTION

Fracking, which is a shortened word form for hydraulic fracturing, is the relatively recent practice of extracting oil or natural gas from shale deposits by the hydraulic fracturing of bedrock formations within the Earth's crust. Shale deposits can either contain oil and natural gas together, or just natural gas alone, which is stored as bubbles scattered throughout shale deposits deep in the earth deeper than where pockets of conventional natural gas are typically found. Fracking of natural gas deposits is often mistaken as an intermediate solution to climate change (between coal and clean energy solutions), because the carbon dioxide emissions from burning natural gas for energy is lower than carbon dioxide emissions from burning coal for energy ("Understanding Natural Gas," 2020).

However, natural gas, which is predominantly methane, escapes into the air during (and beyond) fracking's extraction and delivery. The drilling, fracking, compressing, and transporting of natural gas via pipelines releases so much methane into the atmosphere, that when combined with emissions from the consumption (burning) of natural gas means fracking is worse than coal with regard to the total amount of greenhouse gas driven climatic warming it causes. In addition, many natural gas extraction companies practice flaring – the intentional burning of gas at oil facilities, under circumstances when it saves the company money to burn the gas at the extraction site rather than to transport it for sale. Natural gas extraction and flaring is one of the major sources of methane release both globally and in the USA.

Methane has a much stronger warming effect than carbon dioxide. Since 2008, levels of methane have been growing steeply in the atmosphere, coinciding with the increase in fracking in the U.S. (J. Ambrose, 2019). In 2019, Cornell University researcher Robert Howarth told The Guardian, **"This recent increase in methane is massive. It's globally significant. It's contributed to some of the increase in global warming we've seen, and shale gas is a major player."**

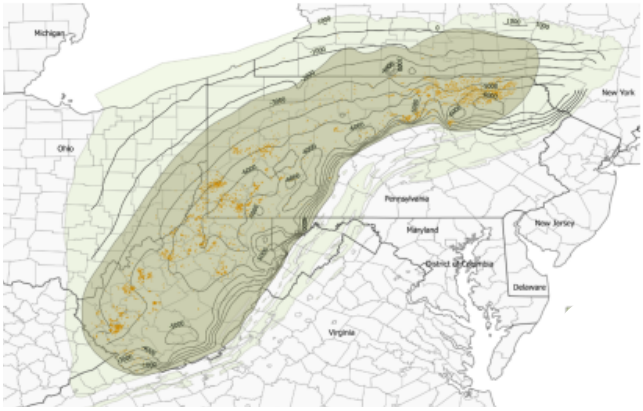
Mounting evidence shows that fracking poses a serious threat to our health, environment, and climate future. The process of fracking natural gas consumes a massive amount of fresh water, taken from groundwater and surface water resources. After that water has been mixed with frack chemicals and used for fracking of natural gas, it is too contaminated to be returned to its source, and is typically disposed of deep underground. **Fracking not only uses up significant amounts of freshwater resources, but also creates a large amount of polluted wastewater, and can contaminate drinking water in private wells near fracking sites.** The fracking activities that pose the biggest threats to the water we drink include spills and leakage of fracking fluids, the injection of fluids into inadequately built wells, and poor wastewater management practices. While drinking water is generally shallower than the gas, there are no geologic barriers separating the drinking water sources from natural gas formations. Some private wells that provide drinking water have been contaminated with methane and other chemicals that may have escaped from the surface pits used to store wastewater or from improperly constructed production wells (Denchak, 2019).

Currently, oil and gas operations benefit from a range of exemptions or limitations from federal environmental laws that are supposed to protect us from contaminated water, hazardous waste, and air pollution, including the Clean Water Act and Safe Drinking Water Act. For example, the "Halliburton Loophole" makes it so that unless diesel is used in fracking fluid, hydraulic fracturing is exempted from regulation under the Underground Injection Control Program of the Safe Drinking Water Act, the bedrock federal law that protects the water we drink from pollutants. Stricter federal oversight of the oil and gas industry would go a long way toward protecting our communities and environment, but state and local agencies can also play a significant role in governing the natural gas industry, either through enacting state-level regulations more strict than federal law, or passing statewide bans on fracking (Denchak, 2019). For example, in May of 2015 Maryland passed into law a two-and-a-half-year moratorium on fracking. Following

this, Maryland lawmakers went a step further, and **in 2017 Maryland passed a permanent ban on fracking** with a bi-partisan, veto-proof majority.

The best policy solution to this problem is to ban fracking of natural gas wherever possible. In the absence of laws banning fracking state by state, **intentional flaring of methane gas should be outlawed**. Mitigating the problems caused by fracking requires rules, such as the practice of Leak Detection And Repair (LDAR) for new oil and gas operators. Both the U.S. Environmental Protection Agency (EPA) and the U.S. Bureau of Land Management play a part in these types of rules; however, portions have since been repealed and reintroduced into subsequent legislation at the national level. In addition, some states have enacted their own, stricter rules ("Fracking, Methane and Climate," 2019; J. Ambrose, 2019).

The Marcellus Shale. This formation of black, organic, carbon-rich shale is composed mainly of grains of clay and similar sized particles of minerals such as quartz and feldspar. The dots on the map indicate wells drilled from 2003 to 2014, which lie in the areas of thickest deposits (Popova et al., 2015).



Credit: U.S. Energy Information Association.

While fracking is not currently practiced in areas of the Potomac Watershed, western Maryland and West Virginia contain a slice of the Marcellus Shale, the geologic basin that has been the target of the hydraulic fracturing, or "fracking" industry for years in Pennsylvania and West Virginia. Within the Potomac Watershed, the Marcellus Shale is also found in the north central and southern areas of the eastern panhandle of West Virginia ("Marcellus Shale," n.d.). **Fracking in the Marcellus Shale formation is a possible future threat to guard against in the Potomac River watershed (particularly in West Virginia near the second and third largest tributaries to the Potomac River - the South Branch Potomac and North Branch Potomac), in order to protect against the negative impacts fracking would have on water, climate change, and public health in our local area.**

CLIMATE MODELING

Today's global climate models (GCMs) stem from mid-twentieth century computerized models for forecasting general circulation of global currents. They are complex simulations generated from physical and chemical equations that represent processes in, and interactions between, the atmosphere, oceans, land and icescapes. They take years to build, and generally require the use of large supercomputers that are operated by teams of skilled specialists. Because a GCM consists of enough computer code to create an 18,000 page book, it needs a machine the size of a basketball court to run (Hausfather, 2020). Modeling climate change is inherently difficult due to both "internal variability" within the physical climate system and "external variability" inflicted upon the climate system by both extreme natural patterns and anthropogenic (human-caused) pressures:

Internal variability refers to the redistribution of energy within the climate system and includes, for example, natural fluctuations in heat exchange between the ocean and atmosphere, or variations in cloud formation or winds. It is yet impossible to create algorithms for every physical interaction in nature, especially because feedbacks within the Earth's climate system can magnify or lessen certain interactions. For instance, the ice-albedo feedback is an intensifying phenomenon that occurs when warming temperatures melt land and sea ice, replacing the reflectivity of the once-white surface with dark land and/or ocean water that absorbs more heat, further increasing the rate of global warming (NOAA Physical Sciences Laboratory, n.d.).

External variability refers to forced variations by factors external to the climate system, including natural (super long-term) changes in Earth's rotation and orbit, and even large volcanic eruptions that spew sunlight-blocking particles into the stratosphere and can lower global temperatures for a few years. However, anthropogenic (human-induced) factors have proven most important in the warming of our current era. We cannot predict what humans will do in the coming decades. Human choices regarding things like population, land cover, technology, and policy all affect future concentrations of greenhouse gas emissions, and it's impossible to predict how the world, as a whole, will move forward in combatting (or not combatting) climate change (NOAA Physical Sciences Laboratory, n.d.).

With the wide variety of sources of internal and external variability in mind, one can see how modeling climate change quickly becomes an intricate process. Many global climate change projections are based upon a standard set of four representative concentration pathway (RCP) scenarios associated with the IPCC's Fifth Assessment Report (The Intergovernmental Panel on Climate Change, 2014). These scenarios, which incorporate the external variability in the concentration of future greenhouse gas emissions, are each named for the value of climate forcing they expect to achieve by the year 2100. In addition, each scenario calls for a different rate of reduction in greenhouse gas emissions over time, and includes differing assumptions for changes in the economy, population growth, and fossil fuel use. They range from a worst-case scenario, RCP 8.5 (indicating 8.5 W/m2), in which greenhouse gasses continue to be emitted at the current rate of increase through 2080, to the low-emissions scenarios, RCP 1.9 (a fifth, no longer likely, scenario) and RCP 2.6, under which the immediate contributions of climate-smart global policies and actions, as set forth in the Paris Agreement, would greatly reduce greenhouse gas emissions in the very short term, thereby limiting global warming to between 1.5° and 2°C (2.7°F and 3.6°F), respectively, by 2100. Most climate models now exclude RCP 1.9 from their projections because years of global inaction has since made it virtually impossible to reverse our emissions impact enough to keep warming to 1.5°C (2.7°F) (Hausfather, 2018b; Van Vuuren et al., 2011).

In addition, climate models generate differing results within the same emissions scenario depending how each model represents the internal variability of complex atmospheric processes such as convection, cloud physics, and surface-atmosphere interactions, each of which requires unique equations be factored into the overall calibration. Therefore, global climate models (GCMs) produce a range of potential results (futures) that become more variable as projections run farther and farther into the future (Maryland Department of Natural Resources, 2015, Chapter 6).

In 2015, ATMOS Research and Consulting for Kleinfelder published a report on climate change projections for Washington, D.C. This study is important because it is both recent as well as specific to the Potomac region. In her work, Anne Stoner, the report's coauthor, expertly downscales whole-earth GCMs to create *local* climate reports for cities that request them. Because GCMs are large-scale, their spatial resolutions are coarse (broad) and therefore lack the ability to generate specific projections for local temperature or precipitation. So, Stoner and her colleagues "fix" this by using historical observations from local weather stations to fine-tune, or calibrate, the coarse, large-scale projections of GCMs. In this case, historic data from Dalecaria Reservoir, National Arboretum, and Ronald Reagan Washington National Airport were used to generate fine-tuned, local climate projections for the Washington, D.C. area (Hayhoe & Stoner, 2015).

As is the case for all climate modeling, the ATMOS researchers incorporated different greenhouse gas emissions scenarios into their models to account for a range of potential futures. In this particular study, the climate scientists used the RCP 4.5 (indicating 4.5 W/m2) greenhouse gas concentration scenario as their lower limit. According to Anne Stoner, the ATMOS study excludes RCP 1.9, and even RCP 2.6, (described above) as a viable lower limit because "it will require very quick action, globally, to go that low." The RCP4.5 scenario represents an outcome whereby emissions peak by mid-century then drop 50% by 2100, driving an average global temperature increase of 2.4°C (4.3°F) above the pre-industrial baseline. **(For reference, this outcome is more severe and much more likely than the terms of the United Nations (UN) Paris Agreement, which call for a 1.5°C (2.7°F) temperature increase or less, and also which climate scientists would now generally agree is a pipe dream)** (Wayne, 2013).

The study's upper limit was produced using the RCP 8.5 (W/m2) emissions scenario, which represents a worst-case outcome wherein emissions are not reduced, but rather continue to rise throughout the century, driving an average global temperature increase of 4.9°C (8.8°F) by 2100. The study input these two scenarios (RCPs 4.5 and 8.5) into nine different GCMs to project the average range of responses of the Washington, D.C. area's local climate system to global climate change. Thus, as is the case with climate modeling at any spatial scale, results are similar, not identical, to the results of other studies (Hayhoe & Stoner, 2015).

Although it was not incorporated into the ATMOS study, RCP 6.0, where emissions peak by 2080 then drop 20%, drives an average global temperature increase of 3°C (5.4°F) by 2100 and is very similar to RCP 4.5. The large gap in RCP scenario projections between RCP 4.5 and RCP 8.5 is noted in the 2.5°C (4.5°F) jump from RCP 4.5 to RCP 8.5 in average global temperature outcomes, from 2.4-4.9°C (4.3-8.8°F), respectively. This gap is driven by the large differences in assumptions for both global population growth and global emissions growth between the two scenarios by the end of the century (Hausfather, 2019). Anne Stoner notes **"[RCP] 8.5 is likely if we continue with business-as-usual, without regulating emissions to a greater extent and switching many of our energy sources to renewable energy. This scenario is generally considered the worst-case scenario, although some scientists think it could go even higher if we do not make any changes, because people [around the world] are becoming more and more dependent on the western lifestyle that has been relying on the use of fossil fuels.** Although we are beginning to see a switch to renewable energy, the process is not as fast as it needs to be to slow the speed at which we are changing the climate. **[Individuals] Switching to electric vehicles and installing solar panels, for example, is absolutely great, but we need large corporations to switch to renewable energy and reconsider their impact on the climate as well as on the environment as a whole."** She continued, "Considering both a lower and higher scenario, such as RCP 4.5 and RCP 8.5, is important to show the range between how low we could go if we make great strides toward cleaner energy, and how high we are likely to go without many changes to the ways [things are currently]. Right now, we cannot say that one scenario is more likely than the other. It depends on our energy choices."

TEMPERATURE

Overall, the ATMOS study projects temperatures to increase for both greenhouse gas concentration scenarios that resulted in the low and high values of the temperature ranges appearing in the outcomes below. According to Anne Stoner, these projected temperatures also take into account Washington, D.C.'s heat island effect, "because the weather stations are located inside the city area….It is not anything that we have had to include on top of the projected values, because it is already included in the [locally incorporated] observations and calculations." **This means that while the watershed as a whole will warm by this same amount, Washington, D.C. will still be slightly warmer (as it is now) than other areas of the watershed that have more greenspace and less concrete} (Hayhoe & Stoner, 2015).**

Average Summer Temperatures. According to the ATMOS study, climate change is expected to increase the average summer temperature in the Washington, D.C. area. At the beginning of this century, the daily maximum temperature averaged 30.6°C (87°F) while the nightly minimum temperature averaged 18.9°C (66°F). By the 2020s, these values are projected to rise by 1.4-1.7°C (2.5-3°F). By midcentury, they are projected to rise by (2.3-3.9°C) (5-7°F). By the 2080s, they are projected to rise by 2.8-3.9°C (6-10°F). Can you imagine a summer when the daily temperature consistently hovers around 36°C (97°F) at its hottest point? Still, even an increase of 3.3°C (6°F) (which mirrors current temperatures in Greenwood, Mississippi) by the 2080s will be destructive to our northern ecosystems and human health (Hayhoe & Stoner, 2015).

Summer Temperature Extremes. At Ronald Reagan Washington National Airport, there have historically been an average of 11 days per year when the maximum daytime temperature has topped 35°C (95°F), also known as extreme heat days. That statistic is projected to rise by 7-9 days through the 2020s. As we look farther into the future, projections under the higher emissions scenarios are much more drastic than those under lower emissions scenarios. **By 2050, the lower emission scenario projects the maximum daytime temperature**

will exceed 35°C (95°F) 30 days per year, while the higher emission scenario projects 45 days per year. By 2080, the lower emission scenario projects 40 days per year, while the higher emission scenario projects 70 days per year that the daytime temperature exceeds 35°C (95°F) (Hayhoe & Stoner, 2015).

Summer Heat Index. The heat index describes how hot the air feels to the human body by incorporating both temperature and humidity into the equation. It provides one more way to analyze how the summer climate is changing locally. **While we've historically seen an average of 11 extreme heat days per year when the maximum daily temperature exceeded 35°C (95°F), there has been, in fact, an average of 30 days per year when the heat index indicated that it felt over 95°F. Looking to the future, this study projects that we could see 50 days per year where the heat index exceeds 95°F in the 2020s, 70 to 80 days by 2050, and 75 to 105 days by 2080. This drastically increases the potential for heat stroke and other public health crises** (Hayhoe & Stoner, 2015).

Summer Heatwaves. In the Potomac region, a heat wave is described as a three (or more) day period in which the heat index (temperature plus humidity) exceeds 35°C (95°F). From 1991 to 2010, we averaged 4 heat waves per year. This study projects that heat waves will increase to 6 per year in the 2020s, 7 per year by the 2050s, and 8 per year by the 2080s. However, not only will the number of heat waves increase, but the length of these events will increase as well – from an average of 5 days (1991-2010) to around 10 days by 2080 (Hayhoe & Stoner, 2015).

PRECIPITATION

In this study, every metric used to model and analyze the future of the Washington, D.C. area's precipitation showed increasing levels of extreme precipitation events throughout this century – consistent with the IPCCs projections. Moreover, the **climate scientists found that today's 1-in-100-year storms – meaning a rainfall event that is so heavy and unordinary that it only statistically happens once every 100 years – will become a 1-in-25-year event by the middle of this century**, and a 1-in-15-year event by the 2080s (Hayhoe & Stoner, 2015). **Precipitation events across the entire Northeast are expected to become less frequent, but last longer, increasing risk for both flood and drought.** Additionally, winters are consistently projected to become wetter, with more rain than snow (Intergovernmental Panel on Climate Change, 2018).

SOLUTIONS: CARBON SEQUESTRATION TECHNIQUES

While the most obvious and effective solution to prevent these climate changes from occurring would be to stop emitting carbon yesterday, there are some nature-based solutions and engineering solutions that could help us reach our targets. In fact, the lower RCP scenarios require carbon to be sucked out of the atmosphere through either natural or artificial processes, and sequestered (hidden away) in the crust of the Earth where it came from. RCP 2.6, for instance (which, again, projects warming of 2°C by 2100), requires that worldwide emissions begin declining by 2020 – which did not happen – then decline at the rate of two gigatons (one billion metric tons) of carbon dioxide being absorbed per year (Hausfather, 2019).

FOREST PROTECTION, TREE PLANTING, AND FOOD FORESTS

A solution as simple and affordable as protecting our existing forests, and planting trees and forest will help immensely, as trees naturally draw carbon out of the air and store it within their biomass through the process of photosynthesis. **Forests are the most effective and affordable nature-based solution to combat climate change.** We must protect existing forests wherever possible, as well as planting and caring for new patches of diverse forest ecosystem. Planting trees to remove carbon dioxide from the air generally costs no more than $50 per metric ton of carbon capture, and trees provide the additional benefits of clean water, clean air, greenspace people can turn to, and wildlife habitat. Tree planting can also provide more food locally through the planting of food forests, which mimic the patterns of a natural forest using edible and medicinal plants, and provide all the ecological benefits of a forest while also producing food.

The World Resources Institute estimates that "the carbon-removal potential from forests and trees outside forests in the United States alone is more than half a gigaton per year, equivalent to all annual emissions from the U.S. agricultural sector" (Mulligan et al., 2020).

One major opportunity to plant trees and forest across the USA is available through a **federal bill currently being discussed, the Climate Stewardship Act, which, if passed, would result in planting 100 million new trees in urban areas, and planting several billion trees in large forest landscapes on public lands throughout the USA by 2030.**

"The billions of trees to be planted and grown under the Climate Stewardship Act **would help naturally sequester and store almost 620 million tons of carbon dioxide for each billion trees planted. That is equal to the emissions from almost 135 million cars driven for one year**. To make sure these trees do more than just capture carbon, **the legislation prioritizes planting in areas that provide drinking water and critical wildlife habitat corridors.** It also **devotes 100 million of the trees to be planted in urban areas**, dramatically exceeding prior federal investment, **with a focus on Tree Equity for the socioeconomically disadvantaged neighborhoods that are systematically lacking in trees all across America. That is a life-or-death matter today, because climate change is dramatically increasing heat-related illness and loss of life in these communities**. The bill's investment in Tree Equity over the next decade is projected to save more than 200 lives and avoid 50,000 incidences of heat and respiratory illness, while generating more than $2.5 billion in health care and energy savings", said Jad Daley, in an April 12, 2021 statement from American Forests on the Climate Stewardship Act. He continues, "**The Climate Stewardship Act would also provide a job creation engine**; each million dollars invested in planting trees and other natural resource restoration through the Climate Stewardship Act could support as many as 39.7 jobs. **The bill is projected to create and support hundreds of thousands of jobs in tree planting and nurseries alone, benefitting both rural and urban areas**."

SEQUESTER CARBON THROUGH AGRICULTURAL PRACTICES THAT REGENERATE NATURAL SYSTEMS

Agricultural practices that regenerate natural systems also capture carbon in the soil. **Capturing carbon in soil can both contribute to removing carbon from the atmosphere, and benefit farmers and ranchers, as it increases soil health and crop yields.** Planting trees on farms can provide significant carbon capture and water quality benefits, while also providing shade for livestock, or being planted as windbreaks to protect crops. Creating and {using compost to amend soil increases yields, stores the compost's carbon content in the soil, and also improves rainwater absorption of the soil, both retaining water on-farm to help crops and preventing stormwater runoff into streams and rivers that are the source of the water we drink (Mulligan et al., 2020). One of the best examples of regenerative agriculture that captures carbon and regenerates natural systems while producing food is the food forest. Food forests - being patterned after forest systems and planted with a variety of food-producing trees, bushes, herbs, and mushrooms - capture carbon, produce food, and create a biodiverse ecosystem instead of a monoculture, thereby decreasing the threat of pests, making fossil-fuel based synthetic fertilizers and pesticides unnecessary, lowering the amount of maintenance required, and providing ecosystem services like clean air and clean water.

DIRECT AIR STORAGE

Direct air capture removes carbon directly from the ambient air. However, the technology remains quite costly, at about $94 - $232 per metric ton of carbon capture according to a 2018 study in Joule. Plus, taking one gigaton of carbon dioxide from the air could require about 10% of global energy consumption, so the technology would have to be powered by zero-carbon energy sources to actually reduce the total amount of carbon dioxide in the atmosphere (Mulligan et al., 2021).

CARBON MINERALIZATION

Like direct air storage, carbon mineralization is another concept being developed by scientists whereby minerals react naturally with atmospheric carbon, turning it from a gas to a solid. However, this process transpires slowly, over hundreds or thousands of years, so scientists have been studying how to speed it up. One way to do this is to crush up mined substrate – either mechanically or through the use of enzymes – to increase the surface area available for interaction with the air. Carbon mineralization can also act as storage by injecting carbon into the right kind of rock, with which it will react to form a solid precipitate. Some start-ups have even tossed around the idea of then using these rocks for building materials, but work is still being done to make it cost-effective (Mulligan et al., 2021).

From these examples, we can see that nature-based solutions are some of the most reliable, viable, equitable, and cost-effective methods of carbon sequestration. Solutions like protecting forests, tree planting programs, and regenerative agriculture help combat climate change and contribute to healthy lands, waters, and communities.

EXTREME WEATHER

It is impossible to say for certain whether one particular storm was or was not caused by climate change. However, scientists can use high resolution climate models to tell whether an extreme event was made more likely by climate change – whether it served as a key ingredient in the storm's formation. This is called "extreme event attribution." Sometimes, these studies can reveal how much more severe a storm was made by climate change; for instance, they can decipher how much lower the storm surge of a hurricane would have been without the contribution of sea level rise due to global warming (Lindsey, 2016).

Sean Sublette, a meteorologist with Climate Central, told State Impact Pennsylvania that extreme event attribution is "kind of like loading the dice: At any one time, your odds of rolling a five or seven or eleven are a certain way, but you can tweak the dice a little bit, and suddenly you're rolling more sevens," he said. "So what we're doing [with climate change] is fixing the dice, weighting the dice a certain way so that a very high impact weather event becomes more likely" (S. Phillips, 2020).

Residents of the Potomac Watershed have already begun to see the effects that a warming climate has on local weather, especially with regard to the strength of its storms. A warming atmosphere can build up more moisture before it precipitates, eventually falling (less often) as more intense rain or snowstorms. **Flash flooding is becoming more common across the region – as is drought.** Additionally, **although winters are becoming warmer and shorter, blizzards are now more likely when snow occurs. Hurricanes and nor'easters are also becoming more frequent and intense.** And as local weather intensifies, it is more likely to impact local infrastructure.

DROUGHT

Let's start with drought – the "creeping disaster." While natural disasters usually make themselves known, sweeping through and inducing destruction on impact, drought flies below the radar, quietly building over time. Yet this extreme weather event can be just as deadly as any other. Actually, in the past forty years, drought has troubled more individuals worldwide than any other kind of natural disaster (Denchak, 2018).

In the Potomac Watershed, droughts are becoming more common, especially during the summer-autumn timeframe. Maryland specifically - and thus the region generally - is currently experiencing an annual dry spell average of 15 days, but that number is expected to rise to 17 after mid-century. Moreover, the number of days between rain events, what climatologists call "consecutive dry days," is expected to increase by an additional 1-5 days in this region. **Currently, month-long droughts are expected to occur every 40 years, but by the end of the century, higher emissions scenarios project this could occur every eight years.** Although simultaneous increases in annual precipitation are expected, **heavy rains are not as likely to soak into the drier soils**. Rather, downpouring water will run off the land, washing away the

most productive top layers of soil and its corresponding nutrients into waterways (Maryland Department of Natural Resources, 2015, Chapter 6).

HURRICANES

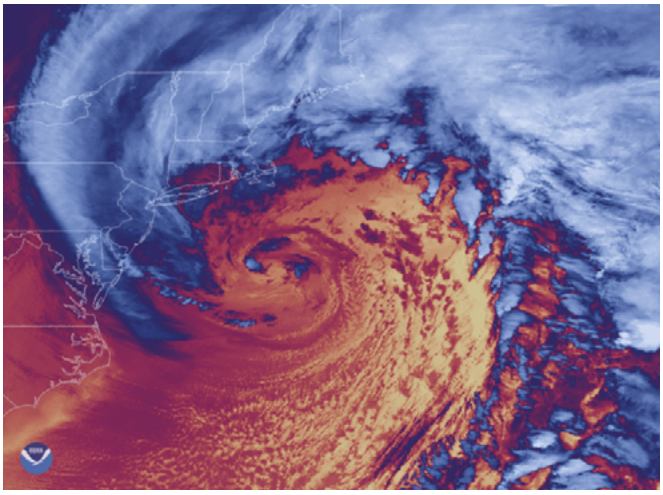
Hurricanes are also becoming more frequent and intense. The year 2020 set a record, with 30 storms having formed in the Atlantic by the end of November (S. Phillips, 2020). Forecasters - out of names to call hurricanes - started referring to them by letters of the Greek alphabet. Yet that's not the entire story. Six of these storms – Arthur, Bertha, Fay, Omar, Isaias and Sally – developed in the mid-latitudes, right off the coast between Florida and the Carolinas. This means that storm tracks are shifting northward along the coast as hurricanes make more frequent landfall in the northern coastal states. Thus, hurricanes are becoming more of a worry for the Potomac Watershed (Korten, 2020).

Usually, hurricanes develop off the west coast of Africa and are blown east toward the Atlantic coastline on the prevailing winds, turning into low pressure systems as they reach the Gulf of Mexico and the Caribbean. The fact that the water was warm enough in the mid-latitudes to allow for the development of so many hurricanes in 2020 is unnerving, as this is historically very rare. As a result of climate change, ocean temperatures have risen a whopping 0.41°C (0.7°F) over the past fifty years. Studies predict that the probability of future storm generation will continue to rise off the coast of North America as waters continue to warm (Korten, 2020).

"What society should be concerned about is the frequency of high-category hurricanes, categories threes, fours and fives," advised Kerry Emanuel, a climate scientist at the Massachusetts Institute of Technology who has been modeling the impact of climate change on tropical storms for thirty years. "After all, it only takes one major storm to devastate a community forever," he said (Korten, 2020). **The destructive potential of Atlantic hurricanes has risen since 1970 as warming sea surface temperatures promote increased rainfall and wind speeds. This trend is likely to continue as ocean waters keep warming** (Boesch et al., 2008).

NOR'EASTERS

Like hurricanes, **nor'easters are cyclones that form in low pressure zones over the Atlantic Ocean**. However, nor'easters differ in that they originate farther north, within one hundred miles off the eastern coast of the United States, anywhere between Georgia and New Jersey. They also gather strength from the cold atmospheric air of the polar jet stream, rather than from warm air like hurricanes. Nor'easters are named after the direction from which the strongest winds usually blow. These storms produce heavy snow and blizzards, rain and flooding, large storm surges, and wind gusts that are even stronger than those of hurricanes. While they can occur any time of year, they are most common between September and April **and are most severe during the winter months, as this is the season when the difference between cold air and warm ocean water is greatest** ("What is a nor'easter?," n.d.).



This image of a January 2018 nor'easter was created by NOAA-20's VIIRS instrument, which is sensitive to changes in atmospheric temperature. In this thermal infrared image, blue and white indicate cold cloud tops, while the red and yellow shades indicate lower clouds and clear sky over the ocean. Credit: NOAA

Both the strength and frequency of nor'easters are predicted to intensify with climate change. Warming air temperatures result in clouds that can hold more moisture, so when these warmer, wetter clouds meet cold Canadian winds over the northeast, intense winter storms explode from

these overstuffed skies. And, as was the case for hurricanes, there has also been a northward shift in the storm tracks of nor'easters. It is not now possible, however, to quantify this increased risk, but according to a 2015 National Geographic article, "such heavy storms have increased by more than 70% in the past six decades in the Northeast, according to the 2014 National Climate Assessment report" (Boesch et al., 2008; Vergano, 2015).

RAINSTORMS

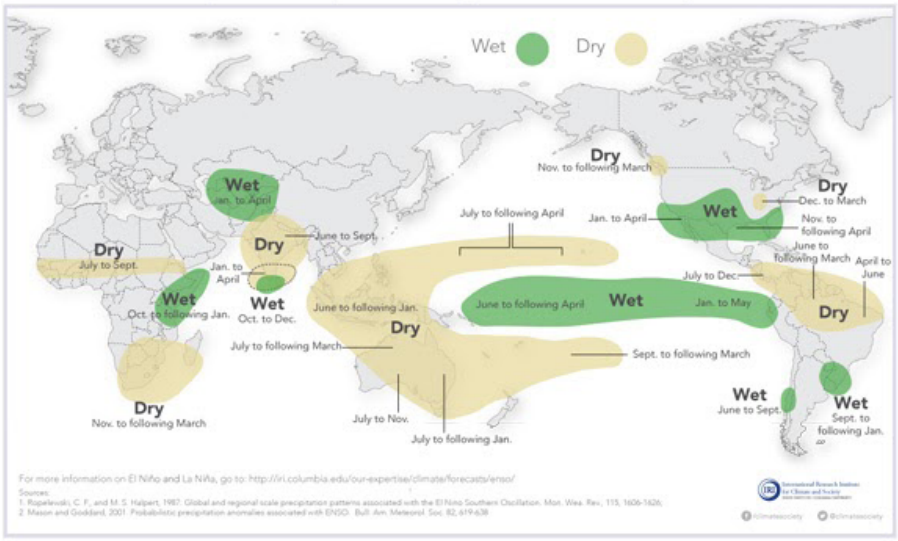
Let's take a look at the year 2020, specifically. **November 30th marked the seventh time in 2020 that Washington, D.C. accumulated at least two inches of rain in one day – a record for a calendar year. It also marked the second day in November that received over two inches of rain, making November, 2020, the wettest of any in the Washington, D.C. region's recorded history.** Indeed, rainfall of this capacity is quite rare during colder months. Prior to this year, multiple occurrences of two-inch rainfall events happened only twice: in 2002-2003 and in 1997-1998. Yet, these two cases happened during El Niño events, when an abundance of subtropical moisture from the Pacific Ocean moved across North America, dumping more rain than usual in the region. Curiously, November 2020 was in the midst of a dryer La Niña event (the opposite of an El Niño), so rainfall should, in theory, have been less than usual... not more. 2020's weather was wildly atypical (Livingston, 2020).

During 2020, the Washington, D.C. region recorded 57.34 inches of rain, coming in at around the seventh wettest year on record – just two years after 2018 was crowned the wettest year, with 66.28 inches of rainfall (NOAA's National Weather Service, 2021). Two-inch rainfall days have become much more likely since 1950, following trends expected as a result of climate change. And, although these two-inch rainfall days are not yet prevalent enough in the Washington, D.C. region to distinguish a clear, long-term climate trend, this past decade (2010-2019) has ranked among the top five for such events, with twenty two-inch rainfall days (Livingston, 2020).

EL NIÑO SOUTHERN OSCILLATION (ENSO)

El Niño

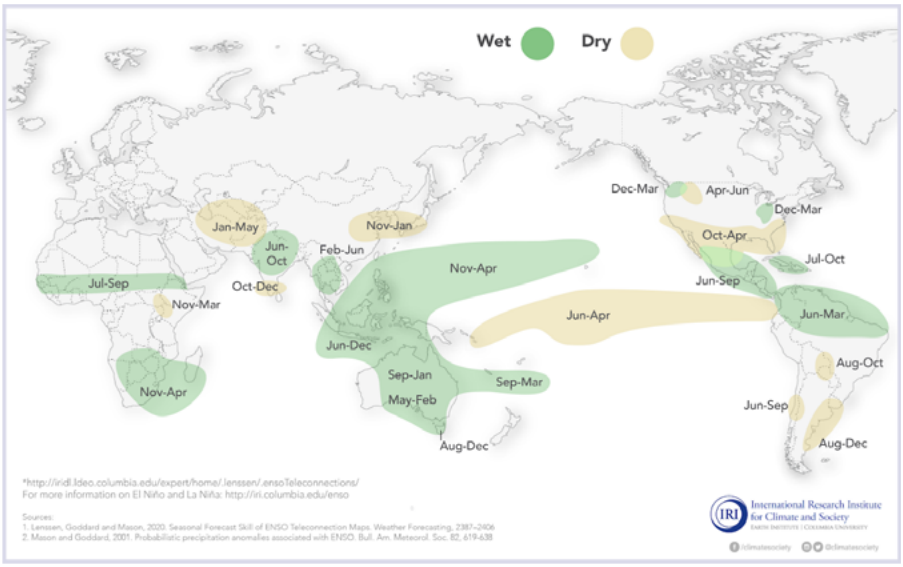
El Niño events occur on a global scale every two to seven years, when a weakening of the atmospheric trade winds allows warm ocean water to stretch across the Pacific Ocean from Australia and pile up on the western coast of South America. Rain clouds then form over this warm ocean water and move inland, dumping more rain than usual across North America. This phenomenon simultaneously leads to dry conditions in Australia because the warm ocean water, normally pushed up against Indonesia and the eastern Australian coast by the trade winds, has drifted away from the eastern coast of Australia, across the Pacific, and has been replaced by cold water that upwells from the depths of the ocean. Cold water does not lead to convection and the formation of rain clouds, so in this part of the world, drought ensues.



Typical rainfall patterns during El Niño events. Such teleconnections are likely during El Niño events, but not certain. Credit: IRI Data Library / Climate.Gov

La Niña

During a La Niña event, the opposite happens. Trade winds strengthen in the equatorial region, pushing piles of warm ocean water toward Indonesia and the eastern Australian coast. In this part of the world, rainfall and tropical storms increase. On the other side of the Pacific, cold ocean water upwells along the western coast of South America to replace the surface water pushed eastward by the trade winds. The cold waters lead to dryer, drought-like conditions in the southern United States and South America.



Typical rainfall patterns during La Niña events. Such teleconnections are likely during La Niña events, but not certain. Credit: IRI Data Library / Climate.Gov

El Niño 101 / National Geographic; El Niño and La Niña / Met Office Weather

FLASH FLOODING

On July 8, 2019, a month's worth of rain (3.3 inches) fell in just one hour in the Washington, D.C. area. Near Alexandria, streams experienced an 11-foot rise in water level, flooding neighborhoods, waterfalling into metro stations, creating sinkholes, and stranding drivers during their morning commute. As roads turned to waterslides on that historic morning, over 100 rescues were made by local fire departments – approximately fifty by the Montgomery County Fire Department alone (Brownlee, 2019). This event marked the **region's first ever flash-flood emergency declared by the National Weather Service. Climatologically speaking, it wasn't even a 1-in-100-year storm; it was worse than that. It had less than a 1% chance of happening.** These types of storms have lately been occurring with greater frequency (Poon, 2019).

Residents of D.C. Area Capture Extent of Flash Flooding on Camera / NBC News

On September 10, 2020, a half foot of rain fell in Washington, D.C. and caused creeks and streams to rise up to eight feet in just one hour. This overloaded drainage systems, stranding motorists as widespread flooding engulfed the roads. Two to six inches of heavy rain fell throughout a narrow zone, passing through Alexandria and southern Montgomery County, and continued east through Washington, D.C. and the northern portion of Prince George's County, Maryland, where College Park and Adelphi were hit hardest. Hyattsville, Maryland, experienced the heaviest total rainfall, at 6.35 inches. **The National Weather Service was informed of 40 flood reports that day. For this specific case, two weather forecasting models failed to predict rainfall** (Halverson & Samenow, 2020).

Rainfall intensifies as the climate warms, leading to more and more flash flooding within the Potomac Watershed. As explained above, precipitation events are inherently variable and difficult to predict on both the long-term climate and short-term weather scales. Though weather forecasting models can detect when a large region is experiencing the right atmospheric conditions for a potential downpour, we still do not have the technological capacity to pinpoint exactly when and where the heaviest rainfall will occur. Convective (rising) cells are extremely localized, and can drop rain at 1-3 inches per hour. Even with the best high-resolution forecasting models, the location and timing of these cells is nearly impossible to predict (Halverson & Samenow, 2020).

Click here to see a time lapse of extreme events (including extreme cold, extreme heat, extreme flooding, extreme rain, and extreme wind events) recorded throughout every county of the Potomac Watershed from 1956 to 2018. The data comes from NOAA's Storm Events Database (EPA Region 3 Office, n.d.).

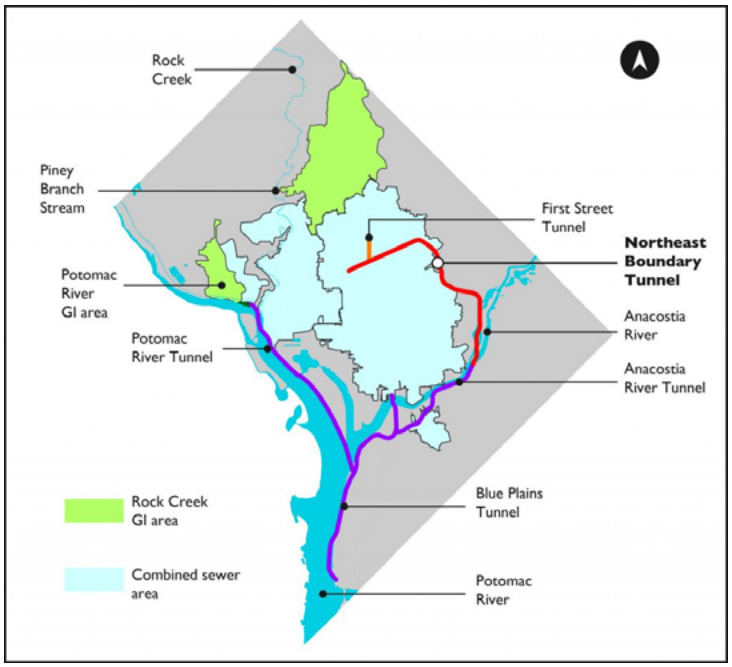
Torrential rain triggers widespread flooding in D.C. area / Washington Post

SOLUTIONS: STORMWATER MITIGATION THROUGH GREEN INFRASTRUCTURE & GREY INFRASTRUCTURE

Heavier rainfall events will continue to spell disaster for local infrastructure. Let's look at 2020's summer storms in particular:

One such storm on July 6, 2020 dropped four inches of rain near Clinton and Camp Springs in Prince George's County, Maryland, and damaged parts of Temple Hill Road. Prince George's County Department of Public Works and Transportation is working to construct a new bridge that will be higher, larger, and wider to account for future storms.

In early August 2020, Tropical Storm Isaias wiped out Route 5 at St. Clements Creek in St. Mary's County, Maryland, resulting in detoured traffic through October. Following Isaias, water tables remained high, and the compounding effects of torrential morning rainfalls over the subsequent week led to the overspill of many streams in Prince William County, Virginia. For example, Quantico Creek recorded the highest peak streamflow in 69 years at the Joplin Road bridge, making this particular situation a 1-in-100-200-year event. The Virginia Department of Transportation has initiated a long-term closure of the road to allow for bridge repairs (Dildine, 2020). These examples represent only a portion of the **millions of dollars in damage to infrastructure from climate change-induced extreme weather in the Potomac Region**.



Credit: DC Water.

Since 1901, rainfall levels have increased 4% across the United States, overwhelming drainage systems across cities nationwide. In 2016, Washington, D.C. finally built a water storage tunnel in the Bloomingdale neighborhood, which floods often. It is 2,700 feet long and can hold eight million gallons of water. This tunnel was eventually connected to a series of underground tunnels installed throughout the Washington, D.C. region (Poon, 2019).

Washington, D.C.'s Anacostia River and Potomac River tunnel systems include more than 18 miles of tunnels that are larger than the Metro tunnels, and are constructed more than 100 feet below the ground. They are designed to capture sewage wastewater for treatment before it flows into nearby rivers.

DC Water's Clean Rivers Project is investing huge amounts of money – 2.6 billion dollars to be exact – to build a series of these holding tunnels near the Potomac and Anacostia Rivers. They are designed to capture sewage wastewater for treatment before it enters the local rivers and, thus, the local water we drink. These new spaces will store stormwater and sewage until the region's water treatment plants can act upon it. **Prior to this update in infrastructure being finished, stormwater and raw sewage will spill into neighborhoods from century-old pipes during heavy rainstorms** (Fenston, 2019a).

"Nearly 800 cities across the United States have a similar problem: old, combined sewers, where stormwater and rain share the same pipes, and discharge into waterways during wet weather. Most of those cities are remedying the situation using what's known as grey infrastructure: concrete tunnels and pipes," reported Jacob Fenston of WAMU 88.5. "The idea is basically to increase the capacity of the old sewer pipes by building big new ones underneath them," (Fenston, 2019a).

The Northeast Boundary Tunnel project, the final phase of DC Water's Clean Rivers' 2.6 billion dollar project, is currently ripping apart Rhode Island Avenue and First Street NW in Washington, D.C. This project began in September 2017 and is expected to be completed in 2023. **Once the Northeast Boundary Tunnel is linked to the others, the 13-mile capacity upgrade will reduce sewer overflows to the Anacostia River by 98%** (Morris, 2017). In the summer of 2020, the Arlington County, Virginia, board voted to devote $189 million to water infrastructure projects similar to those in Washington, D.C. **But, even with all these new tunnels, downtown neighborhoods could still flood during intense storms, which are becoming more frequent** (Poon, 2019).

DC Water is also planning to spend about $60 million on "green infrastructure," wherein the landscape is redesigned with trees, vegetation, rain gardens, and permeable pavers in place of concrete, allowing for the capture of stormwater from over two hundred city blocks. So, rather than having stormwater rush in and overwhelm the storm strains, this new green infrastructure would absorb it into the environment. After all, the sewers cannot overflow if they're not overloaded with stormwater in the first place.

Currently, much of this stormwater discharges into Rock Creek, the stream that runs through Rock Creek Park in the northwest quadrant of Washington, D.C. **"If you've ever been for a hike in Rock Creek Park after a rainstorm, you probably know the smell," notes Fenston. "'It smells like somebody has just flushed directly into the creek,' [said] Jeanne Braha, executive director of the nonprofit Rock Creek Conservancy.** In a sense somebody – or many somebodies – have flushed directly into the creek. Each year, some 50 million gallons of raw sewage, mixed with stormwater, discharge into Rock Creek. It makes the creek inhospitable to aquatic life, and dangerous for humans to wade in. DC Water's unique implementation of both green and gray infrastructure is a huge step in reducing sewage overflow during these more frequent heavy storm events. Not to mention, the "green infrastructure" half of this hybrid plan provides co-benefits, such as increases in property value and reductions in air pollution – benefits that a DC Water consultant found to be worth nearly $25 million. This hybrid project, which requires EPA approval, will be completed by 2030 (Fenston, 2019a; Fenston, 2020).

To meet a July 1, 2025, deadline promulgated in law by Virginia's General Assembly, **Alexandria, Virginia is investing in a tunnel system initiative (similar to DC Water) called RiverRenew, which is a large-scale solution to resolve its aging combined sewage system's incapacity for handling both sewage and rainwater runoff.** On a regular basis, rain events cause raw sewage overflows into the Hooffs Run, Hunting Creek and the Potomac River at four "outfall" locations (AlexRenew, n.d.). In RiverRenew's solution, below-ground "diversion facilities" will be built to divert millions of gallons of combined sewage into a new tunnel system (Alexandria Renew Enterprises, 2021).

In an interview with The Potomac Conservancy, **Jack Browand, acting deputy director of the Alexandria, Virginia Department of Recreation, Parks, and Cultural Activities, noted "...they're going to be digging a new channel, similar to what D.C. did. It's approximately 100 to 200 feet below the river bottom, but it's going to run the entire length of the city** from Oronoco Street to the north, all the way down pretty much to Jones Point, which is the federal property in Alexandria to the south. And then it's going to head west and pick up stormwater that way and take it to RiverRenew." There, **the water will be cleaned and returned to the Potomac River. The projects are scaled to successfully operate in weather conditions in the year 2100, with the city having planned for climate change's effects on sea level and the intensity and frequency of rainfall.** In addition, "Proposed RiverRenew facilities will be built at an elevation higher than the future 100-year flood event (Alexandria Renew Enterprises, 2019)," which the project calculated at 11 feet above sea level in 2019 and at 14 feet above (a higher) sea level in 2100 (Alexandria Renew Enterprises, 2019).

SEA LEVEL RISE

GLOBAL SEA LEVEL RISE

Since 1880, the global average sea level, also known as mean sea level, has risen by 8-9 inches – and a third of that (about 2.8 inches) has occurred only within the past twenty-five years. From 2006-2015 the rate of sea level rise was 0.14 inches per year. That's more than double the rate that global sea level was rising throughout the entire twentieth century (0.6 inches per year, on average). As a result, global sea level rose approximately 5.5 inches during the twentieth century. A 2016 joint research article published by the National Academy of Sciences concludes that without human influences on climate change, global sea level rise would have been about 51-78% lower, resulting in an increase of only 1.2 to 2.7 inches during the same period (Kopp et al., 2016). The increasing rate of global sea level rise is due to climate change, which drives both the melting of glaciers and ice sheets, and the thermal expansion of seawater as it warms. Thermal expansion is the phenomenon whereby the upper layer of the ocean absorbs heat from the warming atmosphere and expands. Before 1970, these two factors contributed, roughly, equally to sea level rise. But since then, climate change has accelerated the irreversible melting of glaciers and ice sheets. Now, since 2004, melting contributes to nearly twice the amount of sea level rise as thermal expansion (Lindsey, 2021; National Aeronautics and Space Administration, n.d.).

Animation: How a Glacier Melts / NASA

According to the U.S. Geological Survey (USGS), glaciers and ice sheets store enough water to raise sea level by about 68 to 70 meters (223 to 230 feet) (Cronin, n.d.). New research from the European Geosciences Union, published January 2021, confirms that the Earth is now losing 1.2 trillion tons of ice each year to climate warming – an increase of almost 60% from 760 billion tons per year in the 1990s. In total, the Earth has lost 28 trillion tons of ice since 1994 (Mooney & Freedman, 2021). Here are two incredibly devastating facts from NOAA (Lindsey, 2021).

"Ice loss from the Greenland Ice Sheet increased seven-fold, from 34 billion tons per year between 1992-2001 to 247 billion tons per year between 2012 and 2016."

"Antarctic ice loss nearly quadrupled from 51 billion tons per year between 1992 and 2001 to 199 billion tons per year from 2012-2016."

It takes about 360 billion tons of ice to produce one millimeter of global sea-level rise (Mooney & Dennis, 2019.) **At this rate, global sea level rise around the year 2100 will be greater than the 1-2 foot increase predicted by the 2007 Intergovernmental Panel on Climate Change's (IPCCs)** Fourth Assessment Report

(Cronin, n.d.). **But for the Potomac Watershed region, climate change – by way of global glacial melt and thermal expansion – is only half of the story around sea level rise.**

REGIONAL SEA LEVEL RISE: POTOMAC WATERSHED

UNIQUE MID-ATLANTIC SLR FACTORS

In the Potomac Watershed, flooding not only results from intense hurricane and rainstorm events, but also from increases in sea level. One way to think about it is that hurricanes and rainstorms are more acute, resulting in flash floods and dramatic storm surges, while sea level rise constitutes a slower, less dramatic and less obvious disaster.

Curiously, sea level rise is actually occurring *more rapidly* in our corner of the globe – about twice as fast as the global average. Again, ***global*** **sea levels have risen about 8 inches on average since 1900.** However, **the entire Northeast coast of the United States has experienced a higher rise, about a 1-foot increase.** And **here in the Mid-Atlantic, the change in sea level rise is higher yet, rising about 1.5 feet during the same time period** (Maryland Department of Natural Resources, 2015, Chapter 6). This is primarily because "natural forces in the Mid-Atlantic region are magnifying the worldwide effect" (Brainard, 2013).

ATLANTIC GULF STREAM

As a result of climate change, a huge amount of freshwater from Arctic sea ice and the Greenland Ice Sheet is flowing into the ocean and slowing the Atlantic Gulf Stream. As such, the slower Gulf Stream no longer pulls ocean water away from the eastern coast of the U.S. as strongly as it once did. The Gulf Stream is a powerful ocean current that originates in the Gulf of Mexico, bringing warm water up the entire length of the eastern U.S. seaboard, then sending it across the Atlantic to the waters surrounding the British Isles. At up to 90 miles in width, it is sloped, with the side closest to our coastline as much as five feet lower than its eastern, Europe-facing edge. When the Gulf Stream flows faster, its slope is steeper, aided by the Earth's rotation. However, when it flows slower, the angle of the slope decreases and the water level on the coastline side rises, resulting in higher sea level flooding during high tides (Morrison, 2018).

Therefore, the effects are compounding: we have thermal expansion and melting glaciers that are affecting sea level rise in the northeastern U.S., which is higher than the global scale average; we have a slowing gulf stream that is affecting sea level rise on the regional, eastern U.S. scale; and we have yet another phenomenon, known as post-glacial or isostatic rebound (the mid-Atlantic is sinking), that is affecting sea level rise on the regional and local scale (Reuell, 2019).

POST-GLACIAL REBOUND.

At the end of the last ice age, 11,000 years ago, massive glaciers and ice sheets began retreating from the surface of the Great Lakes region. These ice masses, which were miles thick, had literally pushed the Earth's crust down into the upper mantle. This lowered the elevation of Canada and parts of the northeastern United States, and raised the elevation of the U.S. Mid-Atlantic Coast – like a seesaw. **After this glacial ice disappeared, the Earth's surface in the Great Lakes region began rising upward, while the U.S. Mid-Atlantic coast began settling back down – and it is still settling.** Because of the thick consistency of the Earth's upper mantle, it will take many thousands of years for the land to return to its original equilibrium level; just as an exercise mat, pushed down, takes some time to return to its original shape, or as a spoon leaves an imprint on jam in a jar. Therefore, **the Potomac Watershed, as well as the greater Chesapeake Bay Watershed, are expected to sink over six more inches in the next 100 years, exacerbating the effects of sea level rise from climate change** (Ramming, 2019; National Oceanic and Atmospheric Administration, 2021).

In 2015, a projection of sea level rise for the Washington, D.C. area, reported by *Climate Central,* incorporated this type of local data into three climate change scenarios from the National Oceanic and Atmospheric Administration's (NOAA) broader report on the National Climate Assessment (Strauss et al., 2014). The local data, which were historic data observations taken by NOAA's water level station at Washington, D.C., produced low, medium and high estimates for the Potomac River, and represent slow, medium, and fast rates of sea level rise. Projections from the NOAA's high-end scenario incorporate a setting for "rapid ice sheet breakdown." Further, the historic local data would account for local trends from the mid-Atlantic post glacial rebound. **The study's scenarios project that by mid-century, local sea level rise can range from a low of 0.6 ft. to a high of 1.8 ft. by midcentury, and corresponding projections of 1.9-6.4 ft. by the end of the century** (Strauss et al., 2014).

Forecasting Sea Level Rise for Maryland / MD Sea Grant.

SHORELINE FLOODING

SUNNY DAY FLOODING

Rising seas not only threaten coastal cities around the globe, but also present critical risks to communities located near tidal rivers; and the Potomac River Watershed has just that. **Near Washington, D.C., the Potomac and Anacostia tidal rivers have risen 11 inches in just 90 years, increasing nuisance flooding along the riverfronts by over 300%. Because of warming temperatures, this trend is sure to continue. The U.S. Army Corps of Engineers estimates that water levels will rise an additional 3.4 feet by 2080**, and 4 feet by the end of the century. A 2013 study group determined that slowing of the Gulf Stream alone could raise sea level at Washington, D.C., 7 inches by 2100 (Brainard, 2013).

"Sunny day" flooding, also called "nuisance" flooding, occurs when high tide triggers the flood, rather than a rainfall event. This flooding can happen under perfectly clear skies and cause road closures and overflowing storm drains. According to NOAA, a dozen locations across the nation broke or tied their sunny day flooding records between May 2018 and April 2019. Washington, D.C. was one of them, with 22 days. Lewisetta, Virginia also set a record with 15 days of flooding. **Along the Northeast Atlantic coast, sunny day floods increased by 100% - 150% in 2019 as compared to 2000** (Spiegel, 2019).

In an interview with the Potomac Conservancy, Jack Browand, acting deputy director of the Alexandria, Virginia Department of Recreation, Parks, and Cultural Activities, recalls the biggest sunny day flood: "It was at the end of a literally ...about a twenty-three day dry spell here in Northern Virginia, [a] bright, sunny day on a Saturday. We had a special event going on. There was a storm in the [Chesapeake] Bay that increased the level of the Potomac [River]. And the Potomac hit four and a half feet, it flooded out the park, all the roads. We had to cancel the event....As you know, the watershed area here is so vast, anything that affects the level of the River potentially will contribute to one of our...nuisance flooding events."

The owner of the restaurant Chadwicks, located along the Alexandria waterfront, *told DCist* in an interview that, "Everyone down here is very casual when it comes to flooding. There'll be a foot and a half of water, cars will be parked in it, halfway up their door. People walk by like it's no big deal because they've gotten used to regular flooding," he said. But it is a big deal. **By the end of the century, much of the Washington, D.C. area could be permanently underwater** (Fenston, 2019c).

STORM SURGE

According to local research from *Climate Central,* lower emissions scenarios pretty much guarantee flooding of over six feet above the Washington, D.C. high tide line by 2030 – a level exceeded only once within the past seven decades. Over 1,300 acres of land in Washington, D.C. lie less than six feet above the high tide line, including the Southwest, Greenway, and Foggy Bottom ZIP Codes. This area represents $4.6 billion in property value as it contains over 1,400 people in 400 homes, 21 miles of road along the water's edge, two military facilities, one hospital, and one museum. The area also contains 12 federally listed hazard sites, such as waste dumps and sewage plants, that face the risk of seeping into rising waterways (Strauss et al., 2014).

Higher emissions scenarios predict flooding of more than ten feet by the end of the century, which would submerge approximately 2,500 acres of Washington, D.C. The area under the ten-foot high tide line incorporates nearly 5,000 people in 1,900 homes, 46 miles of road, four military facilities, one hospital, three museums, and one power plant – collectively valued at $9 billion. The number of hazard sites listed by the EPA increases to 26, worsening the burden on water quality, including sources of the water we drink (Strauss et al., 2014).

Yet, sea level is still only the "launch pad" from which coastal flooding takes off amidst storm events. For instance, **as the climate continues to warm, stronger hurricanes will bring more powerful storm surges and higher floodwaters to the Potomac Region's low-lying coastal plains.** These stronger storms will also become more frequent. In 2003, Hurricane Isabel made landfall at the same coastal area and with a force equal to a 1933 storm known as the Chesapeake- Potomac Hurricane. However, Isabel had a higher storm surge, at 6-8 feet above the normal water levels of the Chesapeake Bay. As sea levels continue to rise, a storm like this will bring even higher floods (West & Hunt, 2019).

SOLUTIONS: GREEN AND GRAY INFRASTRUCTURE

INFRASTRUCTURAL FORTIFICATION

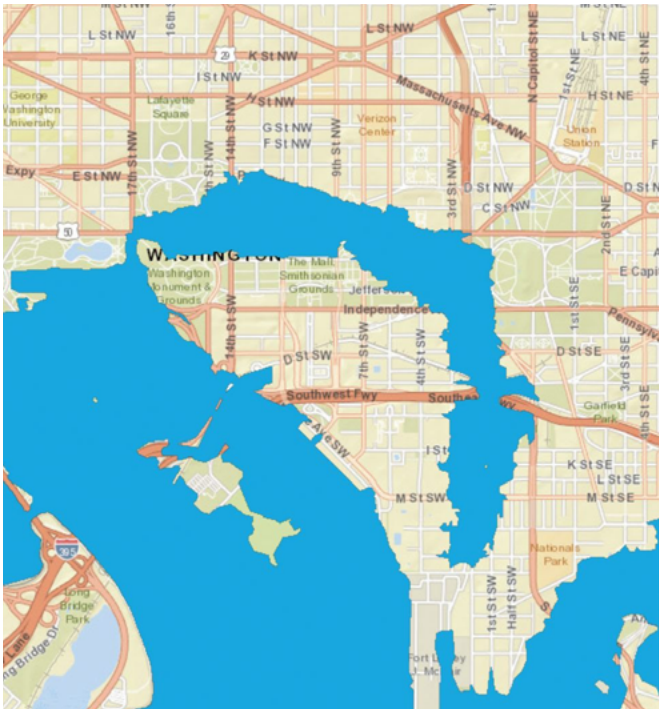
Some areas, like the Georgetown waterfront, have fortification infrastructure, a type of gray infrastructure, in place to help counter tidal surges, such as floodgates that rise to protect downtown restaurants and retail shops. The National Mall is protected by a levee system designed to keep Potomac River flooding from endangering "more than 40,000 people and $14 billion in property including significant infrastructure that is critical to our nation" (U.S. Army Corps of Engineers, 2018). **"The [levee] wall across 17th Street is a 380-foot berm, nine feet high, that crosses the street at a critical low point,"** notes a HillRag article. Though most consider it an eyesore, **"it is capable of withstanding a flood tide of about nine feet of water but has yet to confront a perfect storm of tidal surges and torrential rains"** (Wennersten, 2017). Moreover, **DC Water's Blue Plains Wastewater Facility, located along the Potomac in Southwest Washington, D.C., is in the process of constructing a $13 million concrete sea wall, just over 17 feet high, to protect the sewage plant against high tides and flooding from the Potomac River.** Sewage treatment plants are often found in flood zones because they require gravity to carry sewage and stormwater downhill to collection tanks – but moving them uphill out of the flood plain is arguably more trouble than erecting flood infrastructure (Yap, 2019).

However, developers and planners ultimately understand that water cannot be kept out forever. Aside from adding stilts, **buildings are now being constructed with underground cisterns that trap floodwaters. The water can then be pumped to the top of buildings to power turbines, generating clean energy which helps reduce emissions.** In fact, the city's largest waterfront development project, The Wharf, was completed in 2017 with sea level rise in mind. Located on the Southwest D.C. waterfront, **The Wharf has a gigantic underground cistern that traps floodwaters, and has raised water pumps and generators for electricity** (Wennersten, 2017).

In 2016, Mayor Muriel Bowser established a Commission on Climate Change and Resiliency to assess the impacts that a changing climate will impose upon D.C. The D.C. government now has a Chief Resilience Officer, and in April of 2019, her administration released *Resilient D.C.*, **a report that outlines strategies for climate change preparation. Resilient D.C. advises the fortifying of buildings for climate-related hazards, and relocating those that can't be retrofitted, by 2050.** Additionally, "Resilient Rivers" is introduced as one of two key focus areas. Resilient Rivers concerns efforts to address the "increased risk of flooding caused by climate change, erosion, and land subsidence" (Government of the District of Columbia, n.d.) along Washington, D.C.'s 47 miles of riverine coastline. It calls for investment in a resilient combinations of parks, roads and permeable sidewalks instead of traditional gray infrastructure, such as levees. This would make Washington, D.C. the first city in the nation to embark upon such a plan (Banister, 2020).

REIMAGINED LANDSCAPES

In the historic areas of Washington, D.C., both locals and tourists are feeling the effects of our sinking land, rising seas, and failing infrastructure repeatedly assailed by high tides and escalating rainstorms. **The National Mall sits within the 100-year flood plain, and the entire Tidal Basin is sinking slowly due to the silt and water of the Potomac Flats, which is a tidal wetland to the west of the Washington Monument.** Sidewalks surrounding the man-made reservoir – adjacent to the Franklin Delano Roosevelt and Martin Luther King Jr. memorials – regularly flood twice a day at high tide. Pedestrians often must walk across the roots of the cherry trees lining the paths to avoid stepping through water, sometimes as much as three feet deep (Poon, 2020; Trust for the National Mall, 2020).



Source: HillRag / FEMA

Aerial view of the Tidal Basin, 2014.
Credit: Mario Roberto Durán Ortiz / National Park Service

Architects from five landscape architecture firms, (Reed Hilderbrand, GGN, DLANDstudio, James Corner Field Operations, and Hood Design Studio), have partnered with the National Trust for Historic Preservation, the Trust for the National Mall, and the National Park Service, to **reimagine the National Mall and Tidal Basin within the new climate reality**. James Corner Field Operations espouses the climate trend by allowing the space to flood, rather than trying to preserve it with an elevated regimen of maintenance. This dystopian-like scheme would generate "a landscape in which entropy (the increasing disorder of the universe) is on display." This design firm also proposes creating a series of islands to showcase the memorials, effectively "balancing preservation with the acceptance of future instability" (The National Trust for Historic Preservation, 2020; Poon, 2020).

A plan by DLANDstudio calls for a land bridge to be constructed between the Jefferson Memorial and the White House, whilst underneath, green

infrastructure consisting of wetlands and green walls act like a sponge to soak up the rising tides thereby protecting the upland memorials and museums. Reed Hilderbrand's ideas involve relocating the cherry trees along a new upland pathway while also incorporating protective wetlands and green spaces, an elevated pedestrian bridge, and new walkways into the design. GGN envisions incremental changes, gradually adapting to change through the protection and relocation of memorials, and the incorporation of regional ecology. Hood Design Studio proposed enhancing the visitor experience through an emphasis on African American history. One such proposition, called "Let the Waters Be Free," intends to "restore narratives of how the wetlands were valued by indigenous and enslaved peoples" (The National Trust for Historic Preservation, 2020).

CHECK OUT RISKFINDER

A flood mapping tool for Washington, D.C.

The Alexandria, Virginia Waterfront on the Potomac River. Credit: William F. Yurasko / Flickr

In March 2021, Alexandria, Virginia's Interim Waterfront Park on the Potomac River kicked off its third annual public art installation titled Groundswell, by artist Mark Reigelman, in a series that coincided with the Park's opening in 2019. The art series, named "Site See: New Views in Old Town," commissions artists to create designs specific to the town's riverfront history. Alexandria's officials request the artists visit the site to meet and talk with historians and local waterfront workers before designing their work (Scott, 2020). Groundswell, which was inspired by the near 275-year history of the city's migrating waterfront, "features a ground mural depicting the floor of the Potomac River and more than 100 wood pilings throughout the site" ("New Public Art," 2021). The height of each piling ranges between 12 to 42 inches to match the topography of the river floor, and is topped with a "cobalt-blue, mirrored surface etched with tree growth rings that suggest the passing of time," and that "glisten in the light like the nearby water..." ("New Public Art," 2021).

Like the artwork, the Park itself is temporary, as noted in its name, and will be revitalized and extended in later phases of Alexandria's 20-30 year Waterfront Plan which was created by the city in January 2012. In June 2014, the city approved the Plan's Phase I landscape and flood mitigation design. The Phase I design incorporates flood mitigation measures based on a 2010 Potomac River Flood Mitigation Study of the Alexandria waterfront "to evaluate flooding conditions and to identify feasible flood mitigation alternatives along the Potomac River ("Potomac Waterfront," 2012)." Although the Study considers low (4ft), intermediate (8ft), and extreme (10ft) nuisance level flood elevations, the current Waterfront Plan solution splits the difference between the low and intermediate scenarios (at 6ft), based on cost effectiveness and amount of visual intrusion (the view). "The level was set at 6 feet so it would not destroy the character of the viewshed or the city's historic character, but this flood mitigation will be overtopped eventually," Tony Gammon, acting deputy director of Alexandria's Department of Project Implementation told Smart Growth Voice. "It won't be a surprise to us," he said (Camuti, 2015; City of Alexandria, 2012).

In an interview with The Potomac Conservancy, Jack Browand, the city's acting deputy director of the Department of Recreation, Parks, and Cultural Activities, noted the Waterfront Plan is more of a living

document. He said that "... since there's been a lot of time, there's been roughly five to six years since [the Plan] was adopted... we know that best practices change, regulations change. So we're now embarking on it, sort of evaluating that. And there are alternative measures that would be better employed with regard to flood mitigation. We're also looking at resiliency. You know a lot of areas allow flooding....like a whole Mississippi Valley area has berms sometimes that are several hundred yards off the rivers. They design things that can take occasional water. So, we're going to be looking at all of those factors." The city's current Waterfront Plan contains the following gray infrastructure solutions:

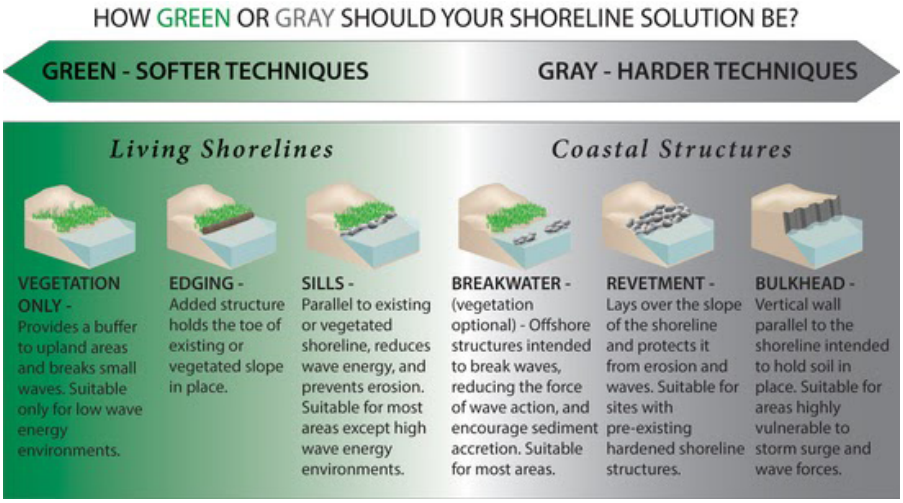
"structural measures, such as a combination floodwall/pedestrian walkway at an elevation 6.0 feet...

- elevating the street level... and adding drainage improvements and a pumping system... to prevent flood waters from coming up through the storm drains
- dry flood proofing individual buildings
- incorporating berms into landscaping (City of Alexandria, 2012)"
- The current plan also includes the following green infrastructure solutions:
- "improve the condition of Alexandria's shoreline: to naturalize it where possible
- improve the condition and function of seawalls
- reduce the need for dredging and debris removal

Other green space features, such as bioswales, rain gardens, bioretention areas, and geographically appropriate plantings, will beautify the environment and create a better organized arrangement of green infrastructure (City of Alexandria, 2012)."

LIVING SHORELINES

As sea levels rise and storm surges become stronger, communities are at increased risk of infrastructure damage and loss of habitat from flooding and erosion. **Since tropical storm Sandy raged through the Potomac region in October of 2012, climate change and resiliency have been on the forefront of legislative agendas from the federal to the local level.** In President Obama's 2013 Climate Action Plan, resiliency became a focus for both infrastructure and investment (Reshetiloff, 2021; Executive Office of the President, 2013).



Coastal Shoreline Continuum and Typical Living Shorelines Treatments. Credit: NOAA

Living shorelines are green infrastructure resilience projects that incorporate natural, native vegetation, either alone or in combination with harder materials for structure and stabilization. They are solutions for "restoring ecosystems that naturally withstand and recover from the inland and coastal flooding that has become more common because of rising seas, stronger storms and heavier precipitation" (Reshetiloff, 2021). **Living shorelines have proven more resilient than hardened shorelines**, such as fixed concrete,

wooden bulkheads or retaining walls, by absorbing the wave energy that normally causes infrastructure damage during storm events. **Living shorelines are a better solution for sea level rise when there is room for marshes to migrate inland. Their living elements, such as oyster reefs and saltwater marsh root structures, can naturally grow in elevation with the rising seas; and, as they accrete sediment on the lands behind them, the marsh plants are not only able to migrate inland, but they can even retain their original position, leading to the overall expansion of marshland** (NOAA Living Shorelines Workgroup, 2015).

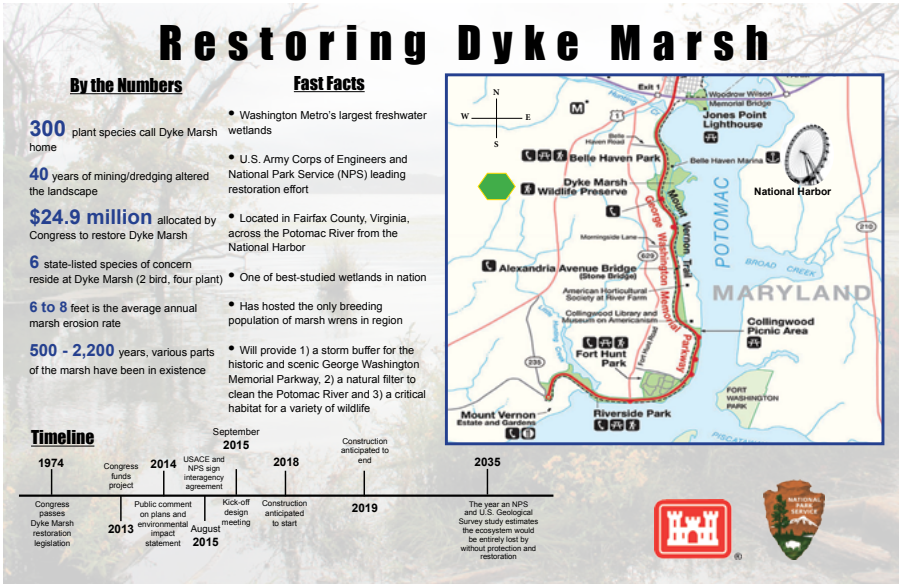
In addition, living shorelines build habitats that sequester, or store, carbon. According to NOAA, "one square mile of saltwater marsh stores the carbon equivalent of 76,000 gallons of gas annually" (NOAA Living Shorelines Workgroup, 2015). They protect adjacent marshes and habitats by preventing substrate erosion and loss of submerged aquatic vegetation (SAV) and protect and promote biodiversity. **Their natural ability to remove excess nutrients and sediments through erosion control both improves water quality and enhances food production, thereby providing beneficial ecosystem services to people and wildlife** (NOAA Living Shorelines Workgroup, 2015).

Bringing Your Shoreline to Life / AnneArundelCoVideo

Shoreline erosion control has long been a problem in Maryland. In 1968, the state created the Shore Erosion Control Revolving Loan Fund to provide both financial and technical support to property owners. Today, more than 1,000 miles of Maryland shoreline is protected by gray infrastructure: fixed concrete or wooden retaining walls or rock piles (revetments) which stop water from dissolving the shoreline. Because they reflect, rather than absorb, wave energy, these hard solutions destroy shallow-water habitat and marshes where crabs and fish thrive. **In 2008, Maryland implemented the Living Shoreline Protection Act, which *requires* erosion control solutions be that of natural, green infrastructure – unless the property owner can prove that gray infrastructure is the only viable solution.** However, there is no requirement to backfit a living shoreline into an existing hard barrier (Fuchs, 2019). **In 2020, similar legislation was enacted in Virginia in support of the Virginia Marine Resources Commission's (VMRCs) mandate to protect shorelines. Plus, the zoning ordinances for protecting wetlands were updated at Virginia's local level, requiring project planners to first consider living shorelines**, thereby making it more difficult to implement hardened barriers (Romero, 2020).

DYKE MARSH RESTORATION

In 2013, the U.S. Department of the Interior awarded $24.9 million in grant funding to restore Virginia's Dyke Marsh, which is operated by the National Park Service. This marsh, one of the most studied wetlands in the nation, is part of the 485-acre Dyke Marsh Wildlife Preserve located on the west bank of the Potomac River, south of Alexandria, Virginia (and across the River from Washington, D.C.'s National Harbor). The marsh was first converted to a dike in the late 1800s by the construction of earthen walls. It has been



Restoring Virginia's Dyke Marsh on the Potomac River.
Credit: USAvCE

subject to intense dredging and erosion for almost 40 years. Beginning in 1940, a construction company dredged at least 270 acres, to include marshland, sand and gravel, and forested wetlands south of the marsh, before giving up their mining rights in 1975. **In 2013, the USGS projected that storm waves moving northward up the Potomac River, which erode about 1.5-2 acres of marshland per year, would completely eradicate the marsh before 2035 if no restoration action was taken** (Friends of Dyke Marsh, 2021a; "Dyke Marsh Wildlife," n.d.).

Breakwater. Source: Andrey Korchagin / Flickr

As a result, in 2014, the NPS created a formal environmental impact statement (EIS) with alternative plans for restoration and resiliency, which "bring beneficial impacts to the marsh's hydrology, sediment transport, vegetation and wetlands and stabilize erosion" (Friends of Dyke Marsh, 2021b). This preferred alternative would restore the marsh, in full, through a phased implementation plan. In February 2020, as part of Phase One, NPS restored the former promontory on the southern end of Dyke Marsh that existed as far back as 1864. In its place is a **new 1800-foot breakwater that shields the River's geologic wave action from eroding the planned and existing marsh**, and will, per USGS, "encourage accretion and deposition of sediment and restore ecosystem services that benefit the Potomac River...." (Friends of Dyke Marsh, 2021b). These **ecosystem services include providing a storm buffer for NPS's scenic George Washington Parkway, and cleaner water in the Potomac River** ("Dyke Marsh Wildlife," n.d.). Indeed, the **EPA notes that "When rivers overflow, wetlands help to absorb and slow floodwaters. This ability to control floods can alleviate property damage and loss and can even save lives. Wetlands also absorb excess nutrients, sediment, and other pollutants before they reach rivers, lakes, and other waterbodies"** (U.S. Environmental Protection Agency, 2004).

REGIONAL WATER SECURITY

WATER MANAGEMENT

Over the years, the Interstate Commission on the Potomac River Basin (ICPRB) has published a number of potential impact reports, assessing the damage climate change could have on the area's water supplies. Their goal is to assist the region's water suppliers in planning and creating new operational measures to address future water shortages that may ensue as a result of climate change (Interstate Commission on the Potomac River Basin, 2020b).

Over thirty-five years ago, a cooperative system of water supply management was established by the three main water suppliers in the Washington metropolitan area: Fairfax Water, Washington Aqueduct, and Washington Suburban Sanitary Commission. Fairfax Water serves Fairfax County, Virginia, the City of Fairfax, the City of Falls Church, as well as a number of wholesale customers in Virginia, including Dulles International Airport. Washington Aqueduct, a division of the U.S. Army Corps of Engineers, serves Washington, D.C. and Arlington County. Washington Suburban Sanitary Commission (WSSC) serves Montgomery and Prince George's Counties in Maryland, and provides both limited water to Howard and Charles counties in Maryland and emergency water supplies to the City of Rockville, Maryland. **Together, these suppliers manage water resources – sharing in times of drought – to provide potable drinking**

water to over 5 million people living in the area. Three quarters of that drinking water comes from the Potomac River. In 2018, Northern Virginia's Loudoun Water joined the other three suppliers, **establishing a withdrawal location on the Potomac River to meet its own demand, stemming from customers in Loudoun County, which is the "second fastest growing county in the U.S."** (Loudoun Water, n.d.). Previously, Loudoun had primarily serviced its customers with water purchased from Fairfax Water (Ahmed et al., 2020).

Though most water comes from the Potomac River, daily water supplies also draw from the Occoquan, Virginia, and Patuxent, Maryland, reservoirs. **During times of drought, the Washington metropolitan area reinforces Potomac River flow by drawing from two upstream reservoirs located in the northwestern portion of the watershed, at the border of West Virginia and Maryland: The Savage Reservoir and the Jennings Randolph Reservoir. Little Seneca Reservoir in Montgomery County is also used as a backup drinking water supply** (Interstate Commission on the Potomac River Basin, 2015).

WATER DEMAND AND STREAMFLOW

The temperature and precipitation effects of climate change can affect both the *demand* for water, and the *streamflow*, which is an indication of the supply of river water in both volume and velocity. **Sharply rising temperatures propelled by climate change will increase the demand for water, especially in the summer months** (Interstate Commission on the Potomac River Basin, 2015). Rising temperatures not only increase the human demand for water during hotter summers, but also the rate of evapotranspiration, which occurs when hot air draws moisture from the soil, plants, and other surfaces (Interstate Commission on the Potomac River Basin, 2017). In the Potomac Watershed, precipitation projections are variable, potentially rising in some seasons and falling in others, but call for a wetter climate overall.

The ICPRB's Cooperative Water Supply Operations on the Potomac (CO-OP), made up of federal and state commissioners from Washington, D.C., Maryland, Virginia and West Virginia, monitors water demand for the Washington, D.C. metropolitan area. **Currently, demand is defined as water withdrawal needs from both the Potomac River and local reservoirs, *plus* a measured streamflow of 100 million gallons per day at Little Falls dam on the Potomac River near Washington, D.C. Adding this streamflow into the demand equation helps to preserve the River's ecology** (Interstate Commission on the Potomac River Basin, n.d.a; Interstate Commission on the Potomac River Basin, n.d.c).

Generally, climate models indicate that the mid-Atlantic states are becoming wetter on average. Indeed, the ICPRB studies of the Potomac region suggest that precipitation will increase 8% by 2040 and 10% by 2050. Obviously, the amount of precipitation influences streamflow because it, quite directly, determines how much water is flowing through our waterways. For the most part, increases in precipitation decrease the demand for water, but according to the ICPRB's studies, **the population of the Washington metropolitan area is expected to grow 24% through 2050, from 5 to 6.1 million people. This is expected to increase water demand from 2018's annual average of 455 million gallons per day (MGD) to 501 MGD in 2040 and 528 MGD by 2050**, factoring in the effects of population and climate change (using GCMs downscaled to the Potomac basin) (Ahmed et al., 2020).

Although they project the mid-Atlantic to become wetter, climate models also indicate that **droughts will become more extreme and severe in the region's future**. The ICPRB monitors daily streamflow conditions in the Potomac Watershed during periods of drought anytime the River's flow at Point of Rocks in Frederick County, Maryland, falls below 2000 cubic feet per second, as measured by the USGS. When needed, water withdrawals are coordinated between the Potomac River and off-river reservoirs when forecasted streamflow does not meet demand (Interstate Commission on the Potomac River Basin, n.d.a; U.S. Geological Survey, 2021).

Curiously, temperature also influences streamflow. We know temperatures are expected to rise throughout the Potomac Watershed as a result of climate change: based on the ATMOS study, the Washington, D.C. area is expected to see a rise of about 2.8-3.9°C (5-7°F) by 2050. Higher temperatures drive higher rates of evapotranspiration, which is predicted to limit the amount of water available to recharge underground aquifers, streams, and the Potomac River – thus drying out regional reservoirs. **This also makes water supply planning extremely tricky** (Interstate Commission on the Potomac River Basin, 2017).

WATER SUPPLY PLANNING

This range of possible climate projections leads to a vast spectrum of potential alterations in the Potomac basin's water availability. The results of ICPRB's climate models (downscaled by the USGS to focus solely on the Potomac Watershed) vary under differing scenarios. In one scenario, stream flows are expected to increase with precipitation, but **because of the increasing regional demand of water during hotter summers, the study predicts that the water suppliers would still not be able to meet the needs of its residents during a severe drought**. Under another, moderately severe scenario, the summer streamflow drops 7% by 2040. This reduces water flow both in the Potomac River and in the streams that recharge our water supply reservoirs. For instance, **Little Seneca Reservoir, an important backup drinking water reservoir in Montgomery County, is likely to be emptied during drought by 2040, potentially leading to water shortages and emergency water use restrictions** (Ahmed et al., 2013; Interstate Commission on the Potomac River Basin, 2017).

Thus, the region will require the development of new long-term planning strategies for water storage and stream management. As of 2017, ICPRB identified three effective strategies: (1) the implementation of a new quarry for water storage, (2) improved one-day forecasts for streamflow, (3) and further restricting the amount of water released from reservoirs during periods of drought (Interstate Commission on the Potomac River Basin, 2017).

To address the first strategy listed above, water suppliers have been on the search for quarries that could serve as additional water storage facilities in the future. As of 2020, ICPRB has identified the addition of Loudon Water's Milestone Reservoir to be online by 2024. Two additional proposed reservoirs, Travilah Quarry in Montgomery County, Maryland, and Luck Stone Quarry B, in Loudoun County Virginia, are still in the planning stages (Ahmed et al., 2020). Fairfax water has also committed to their Vulcan Quarry project, which will hold an added 17 billion gallons of water by 2085.

FAIRFAX WATER VULCAN QUARRY

To ensure the region's population is water secure in the future, Fairfax Water has partnered with Vulcan Materials Company to transform a rock quarry into a water storage reservoir in the southern portion of Fairfax County. Susan Miller, the public affairs manager at Fairfax Water, enlightened the Potomac Conservancy on the topic over email:

"As a region, Fairfax Water and other water utilities work collaboratively with ICPRB (Interstate Commission of the Potomac River Basin) to study climate change's potential impacts on the water supply. (See ICPRB's '2020 Washington Metropolitan Area Water Supply Study Demand and Resource Availability Forecast for the Year 2050,' located here, specifically section 6-1.) The study notes that the region is likely to be "wetter", with more extreme floods and droughts. The region will need to provide for more raw water storage to meet demands during low flow periods.

We are not seeing any impact on water supplies at this time. It is always important to be prepared, and Fairfax Water, along with ICPRB and other regional water utilities, is always evaluating future water supply needs for the region. One project to help meet those needs is our Vulcan Quarry project:

In the early 2000s, Fairfax Water pursued a unique opportunity to increase future water supply significantly. The scene was set for water utilities in the area to begin considering water supply alternatives to address possible impacts of climate change and as a back-up plan for possible instances of contamination of the Potomac River, the Washington, D.C. region's most heavily utilized water source. In 2003, state legislation required that all jurisdictions in Virginia prepare and submit water plans to the Virginia Department of Environmental Quality (DEQ). Fairfax Water and the Vulcan Materials Company began discussions on using the Vulcan Quarry as a future water supply. The quarry would be an ideal alternative water supply for Fairfax Water due to its serendipitous location right next to Fairfax Water's Griffith Water Treatment Plant and the Occoquan Reservoir.

Through this project, **Fairfax Water will turn what is now a rock quarry into a 17-billion-gallon water supply reservoir, assuring the region's water supply into the next century. This means the northern Virginia area will meet water needs for generations to come.**

In 2011, the Northern Virginia Regional Water Supply Plan was completed and officially identified the Vulcan Quarry as an alternative for meeting future water supply/storage needs. The Fairfax County Board of Supervisors unanimously approved a Comprehensive Plan Amendment to provide for the conversion of a reconfigured Vulcan Quarry to a water supply storage facility to meet the long-term needs of Fairfax County and the region. Thirty-five public meetings, presentations, or hearings were conducted on the project, resulting in approvals from the Planning Commission, Board of Supervisors, and Board of Zoning Appeals. In October of 2016, Vulcan Materials Company and Fairfax Water signed an agreement that set the conditions for transforming the rock quarry into a water storage reservoir in southern Fairfax County.

This new reservoir will be used to supplement water supply to accommodate population growth in Northern Virginia and ensure the success of Fairfax Water's mission to provide reliable, high-quality drinking water well into the future. The conversion of the quarry to a reservoir will be a two-phased plan. **Phase One will provide initial storage of approximately 1.8 billion gallons by 2035. Phase Two will provide an additional storage capacity of up to 15 billion gallons by 2085, resulting in a total of 17 billion gallons.**

According to Miller, this project is beneficial to the region as it "provides an innovative solution to meet the region's critical future water supply needs that is cost-effective for the citizens of northern Virginia. In fact, it is millions of dollars less expensive than other options for future water supply," she wrote in her email. Plus, the agreement "provides certainty on the beneficial final use of quarry property," and **because of its proximity to existing water treatment infrastructure, the impact on communities and the environment is lower compared to other water supply options.**

#ValueWater / The Metropolitan Washington Council of Governments (COG)
A Strategic Partnership / Vulcan Materials Company

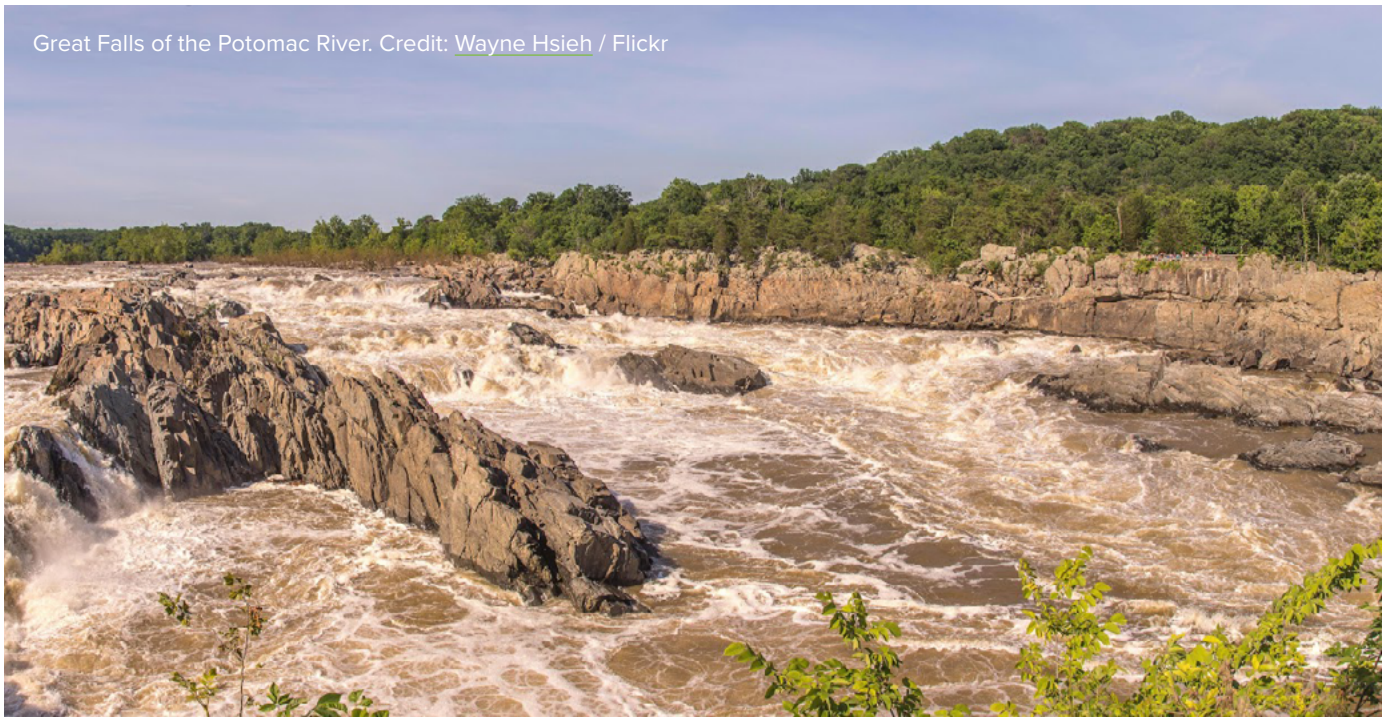
POTOMAC RIVER ECOLOGY

WATERSHED LANDSCAPE

Credit: Kmusser / Wikimedia Commons

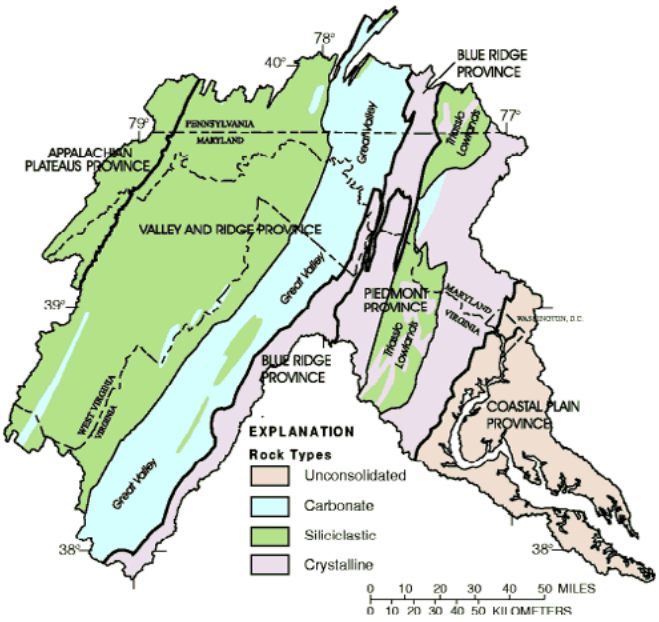
The Potomac River originates high in the Appalachian Mountains of West Virginia, more than 3,000 feet above sea level. It meanders 405 miles, down through the Allegheny and Blue Ridge mountains, drawing water from the Cacapon River, the Savage River, Conococheague Creek and Antietam Creek as it travels southeast toward Harpers Ferry, West Virginia. Here, it widens to welcome the merge of the Shenandoah River. It then picks up water from the Catoctin Creek and continues past Point of Rocks, Maryland, joined shortly thereafter by the Monocacy River. After flowing through farm fields of Virginia and Maryland, it welcomes Seneca Creek and plummets over the rocks of Great Falls, dropping 77 feet in just one mile. Continuing through Georgetown, the Potomac River is next joined by the Anacostia River. During its last 100 miles, the river widens and receives the Occoquan and Wicomico Rivers before dumping into the Chesapeake Bay. (Dalphonse, 2020; Interstate Commission on the Potomac River Basin, 2020a).

"The Potomac is a natural river to this day, which is unusual," Garrett Peck, author of The Potomac River: A History & Guide, told The Washingtonian. "You look at other cities, and their rivers are full of dams and levees. But you look at the Potomac, and it has just two major dams, way up in the West Virginia highlands, and one levee, at Georgetown Harbor. This is a wild river right at our doorstep, which is incredible."



Great Falls of the Potomac River. Credit: Wayne Hsieh / Flickr

The Potomac River's watershed is more than just its waterways. It also encapsulates all the land that channels rainfall and snowmelt into the creeks and streams that eventually flow into the Potomac River. It covers 14,700 square miles. The National Land Cover Database estimates that 55% of the watershed's land area is covered by forests, 26% is devoted to agriculture, 14% has been developed, and 6% is covered by wetlands and open water. The watershed's land crosses five physiographic provinces, or sectors, which define the area's topography, bedrock and climate. They include the mountains of the Appalachian Plateau, the Valley and Ridge and Blue Ridge provinces, the rolling hills of the Piedmont Plateau, and the Coastal Plain. These five sectors influence soil development, hydrology, and land use, and therefore ultimately define the types of plant and animal life found within them. As such, the Potomac Watershed is home to a vast array of species inhabiting a variety of ecosystems (Potomac Conservancy, 2020; Elmore et al., 2013).



Physiographic Provinces. Source: USGS

VULNERABLE ECOSYSTEMS

There are five key ecosystems that are most vulnerable to a changing climate: urban ecosystems, upland forests, tidal marshes, tidal forests, and coldwater streams. Together, these habitats provide homes for national wildlife treasures like the great blue heron and the bald eagle as well as bobcats, minks, cottontails, porcupines, and flying squirrels. In the Potomac River itself, native fish like the muskellunge, pike, walleye, bass, American shad, brook trout and white perch abound. In addition, river otters, eels, and even dolphins can be spotted. Moreover, because more attention has been paid to the health of the Potomac River in recent years, animals whose numbers have long been in decline – including beavers, seahorses, blue crabs, ravens, and horseshoe crabs – have been making a comeback (Kliefoth, 2019). Fascinating native plants of the watershed include fruit trees like the pawpaw and persimmon, and medicinals like orange jewelweed which can soothe the skin from poison ivy (Dalphonse, 2020).

Serotinous cones of the Pitch Pine, which require fire to melt its resins and release its seeds. Credit: Sandra Richard / Flickr

As the climate changes, so too do ecosystems. However, "there's always winners and losers when you're talking about climate change," said Dana Limpert, an eastern region ecologist with Maryland's Department of Natural Resources (DNR). She continued, Change happens, but all is not lost because nature abhors a vacuum and something else will take its place. And that is an important message to get across." So, **while some ecosystems may find themselves in peril, others are remaining stable or even expanding – especially those that thrive in warmer, dryer climates.**

For instance, ecosystems like the Shale Barrens or Serpentine Barrens that consist of sparse woodland and occupy dry, fire-prone landscapes in the Appalachian

Plateau, Ridge and Valley, and Blue Ridge provinces, are likely to benefit from an increase in drought and fire. Only species well acclimated to drought stress – like the chestnut oak, Virginia pine, eastern red cedar, and pignut hickory – prosper here. Another example is the pitch pine, located in the Coastal Plain province, which has many fire adaptations that allow it to regenerate in recently burned areas. Thus, conservation managers might not have to hold as many prescribed burns to protect these rarer ecosystem types in the future (Maryland Department of Natural Resources, 2015, Chapter 6).

Still, **the climate is changing faster than some species in the Potomac Watershed can adapt**. The Maryland DNR has long focused on protecting species and their habitats through its Natural Heritage Program (MD NHP). **DNR's Dana Limpert notes** the connection between the traditional, near-term actions of the MD NHP and longer-term climate change: "So many of the things that we're trying to conserve are being threatened by more immediate stressors that can be more quickly devastating. Fortunately, though, **when you know what species and habitats are vulnerable to climate change, you can use what we call a 'no regrets strategy', that addresses the more immediate stressors but also addresses climate change."**

NatureServe's Climate Change Vulnerability Index determined that flatworms, freshwater mussels, tiger beetles, butterflies, freshwater fish, amphibians, and turtles are the most vulnerable to climate change; and sea-level rise is expected to affect some birds and mammals living in coastal habitats as well. High elevation trees like the red spruce and coastal trees like the swamp tupelo are not predicted to adapt well to the changing climate, and half of Maryland's globally rare plants were also found to be extremely vulnerable to climate change (Maryland Department of Natural Resources, 2015, Chapter 6).

Changes in climatic patterns will have critical implications for many ecosystems in the watershed, though it is likely to exhibit greater impacts on those already compromised by human stressors. These stressors may include the introduction of non-native invasive species, forest fragmentation, habitat fragmentation, or pollution from industry and industrial agriculture. An intact, well-functioning habitat would be much more resilient to the added stress of a changing climate than an already deteriorating one. (Salisbury University Environmental Studies Department, 2018a).

In all ecosystems, the threat of nonnative species outcompeting native species for resources intensifies with climate change. **The changing climate is likely to favor invasives because they tend to have resilient traits** – like high reproductive rates, greater environmental tolerances, and the ability to migrate long distances – that allow them to easily invade and colonize established communities. The northern snakehead and blue catfish are two invasive species that have reduced native fish populations in the Potomac River. Another example is the hemlock woolly adelgid, an invasive insect from East Asia that feeds on sap from hemlock and spruce trees, impacting the forests in the Potomac Watershed's Appalachian Plateau that Dana Limpert notes "are also under a temperature stress as well, because…we are getting warmer" (Maryland Department of Natural Resources, 2015, Chapter 6).

URBAN ECOSYSTEMS

CHERRY BLOSSOMS

The effects of climate change are not only felt out in the woods; urban ecosystems are changing, too. In Washington, D.C., a thirty-year study found that 89 out of 100 plants (across 44 different genetic families) bloomed four and a half days earlier to keep pace with increasing local temperatures (Maryland Department of Natural Resources, 2015, Chapter 6). The district's beloved cherry tree blossoms, in particular, are now blooming about five days earlier than they did last century, reaching peak bloom around the tidal basin sometime between late March and early April. According to the National Park Service, the Cherry Blossom Festival attracts more than 1.5 million people each year, generating approximately $150 million in revenue (Hijazi, 2020).

The blooming period begins when the cherry blossoms are 20% open, and peak bloom is the day that 70% are open. A good chill and calm weather will extend the length of peak bloom, which lasts a few days. However, a late frost can prevent the trees from blooming at all and if the air temperature drops below freezing, all the early bloomers could be damaged. The final freeze of winter has moved up two weeks since 1900, from the second week in April to the end of March, bringing with it an even earlier spring. **The first real sign of spring, the 70° day, has adjusted as well, from mid-March to mid-February.** This early warmth can prove troublesome should a cold snap occur during the blooming season, as happened in 2017 (News, A. B. C., 2021, Livingston, 2021; Official Tourism Site, n.d.).

Each decade, the National Oceanic and Atmospheric Administration (NOAA) updates their 30-year "Climate Normals" for weather and climate data. The updated information for Washington, D.C., available online in April 2021, indicates that **every month of the year, except for November, has warmed. This is significant, because we can see, currently, in real time, that the new norm is shifting – we are experiencing warming across the decades.** February and March, which can now feel more like spring, have actually warmed less than most months, at about 0.5° and 0.33°, respectively. As climate change continues to affect these springtime observations, near term temperatures become more variable, making the Washington, D.C. Cherry Blossom Festival harder to plan – especially since the peak blooming period only lasts about a week (Livingston, 2021; National Oceanic and Atmospheric Administration, n.d.).

Aside from flustering eager tourists, climate change can also create vulnerability for the pollinators that depend on these blossoms. In 2021, Washington, D.C. saw 70° days the second week in March, driving early-season tree pollen counts to levels not seen in twenty-three years (since 1998). The onset of warm weather brings earlier blossoms. Therefore, **a mismatch could arise between the timing of the blooms and when bees and butterflies are mature enough to pollinate, throwing an entire urban ecosystem out of sync** (Hijazi, 2020; Livingston, 2021).

Cherry Tree in peak bloom, Washington, D.C. Credit: Carol Highsmith / National Park Service

Climate Change and Cherry Blossoms in Washington, D.C. / National Park Service

ROCK CREEK PARK

In the most heavily urbanized area of the Potomac Watershed, Rock Creek Park acts as an oasis of greenspace for people to turn to that is filled with an abundance of plants and animals, protected amongst the hustle and bustle of metropolitan life. Geographically, Rock Creek Park lies within a zone of ecological transition, where the Northern Piedmont and Coastal Plain provinces meet, creating a unique landscape with diverse soil and vegetation that supports an array of natural communities in the midst of Washington, D.C.'s urban commotion. However, as temperatures rise and weather becomes more extreme, these communities become progressively more vulnerable to climate-driven stress, and therefore will have to learn to adapt amidst this environmental change. **By maintaining the park's naturally wild features, we can ultimately help mitigate the effects of climate change and provide our fellow wildlife urbanites with the greatest chance of survival** (Smyth et al., 2019).

According to a climate change vulnerability assessment by NatureServe, **"analyses of annual and seasonal climate data reveal that Rock Creek Park is already experiencing climate change and indicate that park managers can anticipate significantly more change in the near future"** (Smyth et al., 2019). According to their research, which is based on weather station measurements, Rock Creek Park has already observed an average increase of 0.7°C (1.3°F) in overall annual temperature from 1981-2014 compared to the 1948-1980 baseline, as well as a modest increase of 13.5 mm (0.5 in) in overall annual precipitation for the same time period. NatureServe then used an ensemble of global climate models from the IPCC's 5th Assessment Report to project near-future climate conditions of Rock Creek Park. They found that by 2040, temperature will increase by 1.7°C (3.1°F) from the 1948-1980 baseline, while precipitation increases by 30.3 mm (1.2 in). However, this annual increase in precipitation translates to a 20% decrease of summer rain, with a 50% rise in winter precipitation (Smyth et al., 2019).

Plants and animals respond to changing climate by adapting, shifting their range, or fleeing completely. Species that reproduce quickly are able to adapt or migrate more readily than slower growing, long-lived species – like Maryland's bald cypress that regularly lives up to 600 years. **If the fragmented landscape prevents their movement, or if new habitat is not available for species to migrate, the Potomac Watershed could experience a decrease in species diversity as the climate warms.** Moreover, because different species shift their ranges at different rates, **relationships crumble between species dependent on one another's existences, increasing the probability of extinction** (Salisbury University Environmental Studies Department, 2018a). As such, **connectivity between fragmented areas is important for the adaptation and survival of many species in response to climate change.**

FRAGMENTATION AND MIGRATION CORRIDORS

Fragmentation occurs when humans divide large expanses of habitat into smaller, isolated plots through the construction of roadways, housing developments, agricultural fields, etc. Fragmentation decreases the genetic diversity of species by impeding the migration of their populations between fragments. **Fragmenting landscapes also encourages the disappearance of larger, longer-lived species that need expansive areas of uninterrupted habitat to roam. Instead, invasive species prevail, as they are adapted to disturbance** (Salisbury University Environmental Studies Department, 2018a).

For example, **whitetail deer are well-adapted to human activities and have greatly increased in number over the past few decades as their natural predators (bobcats, wolves, and coyotes) have been forced out of the area. Their overbearing presence and grazing activities have destroyed habitat both in the Potomac Watershed's northern forests and elsewhere** as they roam throughout the watershed. In Rock Creek Park, a 2012 plan instituted by the National Park Service prescribes the annual reduction of whitetail deer density through both lethal and non-lethal means, to "support long-term protection and restoration of native plants and to promote a healthy and diverse forest" When needed, expert hunters from the U.S. Department of Agriculture work with police to scale down their population size. Keeping 300 feet away from Park boundaries, they use night vision gear and special short-range ammunition to take their shots, aiming only towards the center of the Park (National Park Service, 2020).

In the 2019-2020 fall-winter season, NPS donated 1,320 pounds of venison collected from Rock Creek Park to help Washington, D.C. families in need. Looking toward 2021 and beyond, NPS plans to add additional areas under the management of Rock Creek Park, which could include Melvin Hazen Park, Pinehurst Parkway, Glover Archbold Park and Fort Totten Park, among others. NPS plans to continue donating venison obtained from deer management activities in these areas (Nortrup, 2020).

Here, we introduce a new term: **adaptive capacity**. In this context, adaptive capacity refers to the ability of a habitat to continue to support its species and ecosystem functioning as the climate changes. NatureServe defines adaptive capacity by two criteria: (1) the *diversity of landscape topography* that provide wildlife a variety of microhabitats and resources, and (2) the *connectivity of the land* to other green spaces via

"migration corridors" which allow wildlife the opportunity to wander farther in search of food, water, mates, pollen, nesting or dwelling sites, etc (Smyth et al., 2019). Think of the bees! They utilize these green spaces as stepping stones to reach the pollen of trees and flowering plants across the urban region – and we need them to keep regenerating our flora so that plants can continue to sequester carbon, produce oxygen, filter the air and the water, as well as provide animals with habitat, and humankind with clean water, clean air, beauty, and mental well-being.

Diversity of landscape topography at Rock Creek Park. Credit: Geoff Livingston / Flickr

SEE A MAP OF ROCK CREEK PARK

From the Library of Congress Geography and Map Division

Because of Rock Creek Park's abiding geographic features, and because it is fairly connected to other natural areas via outward facing spokes of urban green space that serve as **migration corridors like a patchwork of stepping stones, many of the park's ecosystems actually have a pretty good chance of remaining relatively stable as climate stress worsens**. Areas of highest adaptive capacity include where the Rock Creek passes through, and where there are a variety of soil types, elevations, and landforms such as ridges, coves, floodplains, and slopes (Smyth et al., 2019).

Conversely, the areas of the park that will be most vulnerable to intensifying climate change stressors are those that have high exposure to changes in temperature and precipitation, and which also have a low adaptive capacity – such as the areas along major roadways or the narrow, isolated portions of the park that are surrounded by development. Examples include the Fort Circle Parks, a series of forts encircling the District that were once built to protect the nation's capital during the Civil War, and which are now administered by Rock Creek Park as historic areas (Smyth et al., 2019; NatureServe and The National Park Service, n.d.).

Wood Thrush

Wood Thrush Song / NPS Climate Change Response

The wood thrush is the official bird of Washington, D.C., and is a species of greatest conservation need associated with the watershed's hardwood forest ecosystems (Maryland Department of Natural Resources, 2015, Chapter 4). A good place to observe them is Rock Creek Park, as it provides this critical nesting habitat; in fact, hardwood forest is the most abundant ecosystem in the park. Unfortunately, **the past five decades have witnessed a drop of over 60% in the overall wood thrush population as a result of habitat loss by forest fragmentation from human development. "They are the poster child of declining forest songbirds,"** Calandra Stanley, a

Wood Thrush. Credit: Tom Benson / Flickr

postdoctoral fellow at the Smithsonian Migratory Bird Center, told The Washington Post. "There's a mixture of factors. But the big one is habitat loss" (Blitz, 2020).

Forest fragmentation reduces the area available for nesting and breeding; but, while the wood thrush needs expansive stretches of forest to survive, other local species, like the brown-headed cowbird, do not need as much space. Cowbirds sneak their eggs into other birds' nests (including those of the wood thrush), and their aggressive chicks outcompete the others for their foster mother's provisions. Furthermore, forest fragmentation favors the survival of other predators like the raccoon, possum and blue jay that steal eggs and chicks from the wood thrush nests. White-tailed deer thrive in Rock Creek Park too, and because they eat saplings, they eliminate nesting grounds for the wood thrush (National Park Service, n.d.).

Climate change is likely to exacerbate an already stressed population as it disrupts the food supply of insects and fruit in late summer when they are bulking up for migration. An Audubon scientist from Pennsylvania notes that "if climate change decreases the availability of ripe fruit when these birds are fattening up, wood thrush could be undernourished and suffer greater mortality during migration." The Audubon also predicts an 82% reduction in the wood thrush's summer range by 2080 as a result of temperature increases and heavier rainfall disrupting foraging patterns (Campbell, 2018). This reduction in forest cover and food availability, along with rising temperatures, may prompt the wood thrush to migrate further north during the spring and summer months to breed.

Scientists believe there to be a 75% chance that the wood thrush population completely disappears from Washington, D.C. by the end of the century (National Park Service, n.d.). "This statistic isn't shocking to scientists and experts," writes The Washington Post. Again, the article quoted Stanley, revealing that, "there's been 3 billion birds total lost since the 1970s. It's happening right in front of us… In D.C., where there's so much development, it's completely a reality that in D.C. proper, we may no longer have wood thrush" (Blitz, 2020).

SOLUTIONS: MANAGING CLIMATE CHANGE AND PREVENTING ECOSYSTEM FRAGMENTATION

According to their climate change vulnerability assessment, NatureServe suggests a focus on **maintaining biodiversity and ecosystem function in areas of *low* adaptive capacity** as the climate continues to evolve. This can be achieved through direct, species-specific actions such as translocating certain species (to artificially restructure communities) and aggressively controlling invasives (Smyth et al., 2019). In 2020, Jeanne Braha, executive director of Rock Creek Conservancy, wrote in a website post that, "Increased levels of carbon dioxide and warmer, damper conditions combine to make Rock Creek Park more vulnerable to invasive plants, which are already threatening the park's forests." Braha continued: "Rock Creek Conservancy volunteers have removed hundreds of bags of English ivy, Japanese knotweed, and Japanese honeysuckle (among others) from the mini-oases that demonstrate the potential for restoration to Rock Creek" (Braha, 2020).

On the other hand, wildlife in less vulnerable areas of *high* adaptive capacity should be indirectly managed through the reduction of non-climatic stressors. This includes **controlling invasive species, preventing habitat loss, and promoting connectivity by reducing the subdivision, or fragmentation, of forests and other green spaces** (Smyth et al., 2019).

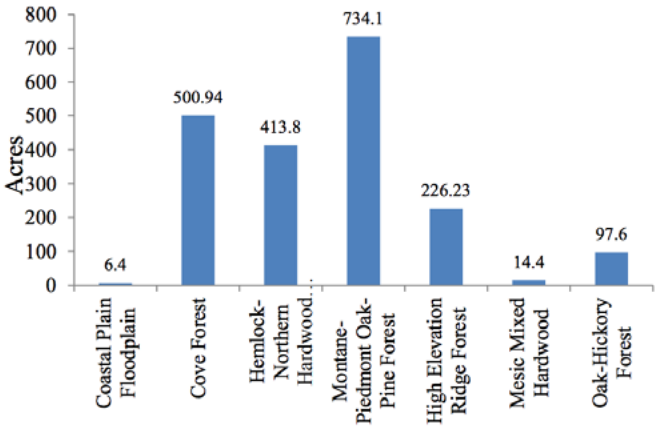
Rock Creek Park provides a critical connection corridor to natural areas more north of the Washington D.C. and is one of the few options for wildlife movement in and out of the District. It is imperative that connections to these other natural areas be maintained, and ideally improved upon, in order to support the future of the park's wildlife by offering chances to migrate and adapt. Alternatively, **should these areas of forest become further fragmented, wildlife will find it difficult to cope with amassing climate stress** (Smyth et al., 2019).

UPLAND FORESTS

TREE MORTALITY

In recent decades, **large stands of mature upland forests have perished across much of North America, both as a result of increased deforestation, and also because of extreme water deficits brought about by drought and extreme heat, which are increasing in intensity due to climate change**. Ironically, this mortality of large stands of trees then further fuels climate change. **Mature forests store most of the world's terrestrial carbon, and increased tree mortality causes the stored carbon to be released into the atmosphere** – either slowly through decomposition, or quickly in fire events. Moreover, the smaller trees, shrubs and grasses that take the place of fallen forests store much less carbon than mature forest. One study in Nature Climate Change found that shorter trees will fare better than tall trees in the future as they have higher turnover rates and are better adapted to disturbance. However, because they can't take in as much carbon (or live for as long), this ultimately results in a loss of terrestrial carbon and a gain of atmospheric carbon, thus propagating the greenhouse gas warming effect (McDowell & Allen, 2015; U.S. Department of Agriculture, n.d.).

Globally, **conifers and tall trees with broad leaves, especially those of old-growth forests, are the most vulnerable** to a future where drought and heat stress – as well as associated wildfires and pest outbreaks – are more common. **Due to their sheer size, old growth forests are at the greatest risk of loss, and this has foreboding implications for terrestrial carbon storage**. Carbon is found in every part of a tree's anatomy – including the roots, trunk, branches and leaves. It makes up nearly 50% of a tree's dry weight as the tree sequesters it from the air for use in photosynthesis (U.S. Department of Agriculture, n.d.). Because old growth trees have been around since pre-settler colonial times, they've been drawing atmospheric carbon into their biomass for hundreds of years. Moreover, they represent some of the most diverse and productive ecosystems on the planet. Unfortunately, only a few stands remain across the northeastern United States, and represent only a small number of forest types (McDowell & Allen, 2015; Maryland Department of Natural Resources, 2015, Chapter 4).



Acreage of old growth forest documented on Maryland public land by habitat type. Credit: Maryland State Wildlife Action Plan / Maryland Department of Natural Resources

The Maryland Department of Natural Resources defines old growth forest as:

"...a minimum of...five acres in size with a preponderance of old trees, of which the oldest trees exceed at least half of the projected maximum attainable age for that species, and that exhibits most of the following characteristics:

1. Shade tolerant species are present in all age/size classes.
2. There are randomly distributed canopy gaps.
3. There is a high degree of structural diversity characterized by multiple growth layers (canopy, understory trees, shrub, herbaceous, ground layers) that reflect a broad spectrum of ages.
4. There is an accumulation of dead wood of varying sizes and stages of decomposition, standing and down, accompanied by decadence in live dominant trees" (Maryland Department of Natural Resources, 2015, Chapter 4).

The chart above shows **that there are currently about 2,000 acres (about 3 square miles) of old growth forest scattered across Maryland's public lands. They are predominantly located in the Valley and Ridge province in the northwestern portion of the Potomac Watershed**, and together comprise about 0.4% of Maryland's total public lands and protected open space. These old growth areas most likely represent the scattered remains of historic logging sites, either within inaccessible terrains or that were part of property ownership disputes, which left them standing (Maryland Department of Natural Resources, 2015, Chapter 4; "About Our Lands," n.d.).

NORTHERN HARDWOOD FORESTS

FIND AN OLD GROWTH PUBLIC FOREST

Visit the Old-Growth Forest Network

The northern hardwood forests are key wildlife ecosystems found in cool, elevated areas with a well-balanced supply of moisture. **Northern hardwood forests are a critically vulnerable ecosystem type, because the range of suitable habitat for these deciduous broadleaved trees is expected to decrease with rising temperatures and increased drought, brought upon them by climate change. Currently, there are about 414 acres of *old growth* northern hardwood forest remaining in Maryland, also in a critically vulnerable state.** In the Potomac Watershed, northern hardwood forests congregate upon the higher elevations of the Appalachian Plateau, as well as on north-facing mountain slopes of the Ridge and Valley and Blue Ridge provinces. **Sightings of this forest type can be made in Allegany, Carrol, Frederick, Garret, Montgomery and Washington counties of Maryland; in Warren, Page, Rockingham, Augusta and Highland counties of western Virginia; in Adams, Franklin, Fulton, Bedford and Somerset counties of southern Pennsylvania; and across the eastern panhandle of West Virginia** (Maryland Department of Natural Resources, 2015, Chapter 4; Virginia Department of Conservation and Recreation, 2021a; Fike, 1999).

The composition of northern hardwood forests varies depending on the site, especially since logging and destructive fires eliminated much of this ecosystem type in the early 1900s. However, today's forests often include sugar maple, American beech, black cherry, and yellow birch. Other companion trees can include northern red oak, white oak, white pine, sweet birch, red spruce, white ash, basswood, and red maple. The understory is commonly composed of species such as striped maple, witch-hazel, maple-leaf viburnum, and dense collections of great laurel and mountain-laurel. Because the soil is shaded and moist, northern hardwood forests support an array of ferns and herbs at its base, including Indian cucumber-root, whorled aster, Canada mayflower, bellworts, violets, hay-scented ferns, New York ferns, and wood-ferns.

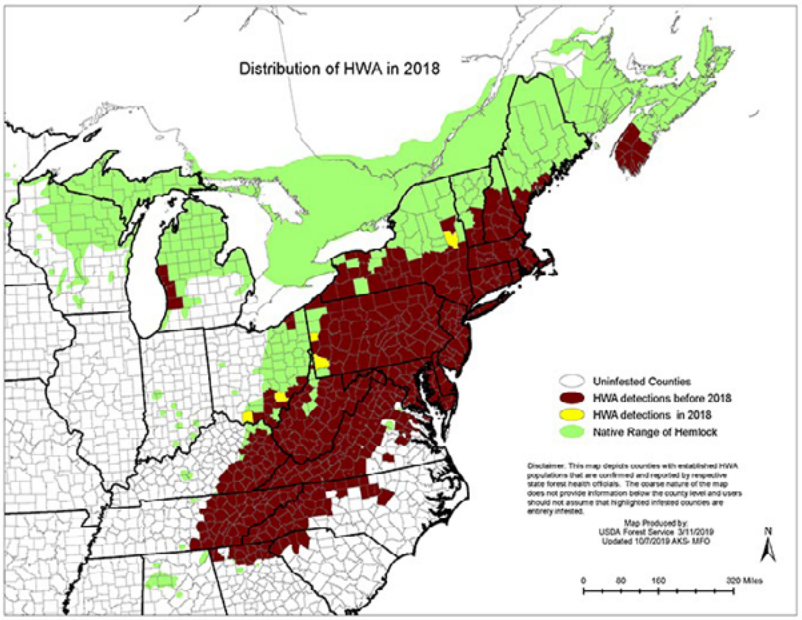
Many northern songbirds, including the brown creeper, mourning warbler, and yellow-bellied sapsucker, breed only in northern hardwood forests. Plus, a variety of bats, snakes, salamanders, woodrats, and cottontails also make their homes in these imperiled ecosystems (Virginia Department of Conservation and Recreation, 2021a; Maryland Department of Natural Resources, 2015, Chapter 4).

Often, the northern hardwood forests contain mixtures of eastern hemlock, a tall conifer with soft, coarse-grained wood – the state tree of Pennsylvania. **Conifers are particularly hindered during extreme drought because they are unable to quickly drop their leaf area in response to environmental stress** (Maryland Department of Natural Resources, 2015, Chapter 4; Virginia Department of Conservation and Recreation, 2021a; Fike, 1999).

Eastern hemlocks are currently threatened by the hemlock woolly adelgid, an invasive insect that attaches to the soft, woody plant tissue and sucks valuable nutrients from the sap of these trees. The insect was introduced to the United States from Japan in 1924, and was first detected in the eastern United States in Richmond, Virginia in the 1950s. Since then, the adelgid has spread throughout the Appalachian Mountains, though more rapidly in the southern part of its range (around 16 km/yr) than in the north (around 8 km/yr), the reduction owing to colder temperatures.

Dense stands of hemlocks and northern hardwoods. Credit: Nicholas A. Tonelli / Flickr

Once the insect establishes a population on a hemlock, it can kill the tree within four years. After the pest arrived in Shenandoah National Park's ecosystem in 1951, it has turned the once thick tree canopy into patches of sunlight. There are thousands of dead trees still standing in its wake. Reaching maturity at age 250 and living up to another 500 years, the 100-foot-tall eastern hemlock typically grew in lush pockets throughout Shenandoah National Park. At one time there were an estimated 800,000 hemlocks in the Park, but only 30,000 to 40,000 remain. Over the past fifty years, states have made ample attempts to stop its spread, including chemical and biological control. Most recently, the Park introduced a Japanese beetle whose only meal is believed to be the woolly adelgid. Before the beetles were an option, the Park team injected an insect neurotoxin into the soil to be absorbed by the roots of the hemlocks, as well as coated the trees with insecticidal soaps. However, the adelgid's range continues to expand, and **as the climate warms, the sap-sucking hemlock woolly adelgid will have an easier time spreading faster (and potentially farther) throughout the north** (Foley et al., 2018, McDowell & Allen, 2015; Repanshek, 2017).



Geographic range of the Eastern Hemlock and the Hemlock Woolly Adelgid. Credit: Maine Forest Service / USDA Forest Service

The impacts of the adelgid upon the forest ecosystem, as a whole, are less obvious at first glance. **A healthy hemlock forest cools the ecosystem and acts as a humidifier to keep soils sheltered and moist. "If you look around, look at the understory. It's much drier. You don't see ferns very much," said Gubler, the Parks' forest pest manager, told The National Parks Traveler.** "You see a few. You don't see as many mosses. In terms of stream water temperatures, you're seeing increases in stream temperatures wherever we lose hemlocks along waterways," he said. And these warmer stream temperatures pose threats to aquatic life – particularity the native brook trout which require cool, shaded water with high levels of dissolved oxygen (see Coldwater Streams for more information on the Potomac Watershed's native brook trout) (Repanshek, 2017).

"Even bird species that normally flit through Shenandoah's forests are affected by the adelgid," notes the *The National Parks Traveler.* "Blackburnian warblers, winter wrens, and blue-headed vireos that prefer spruce/fir/hemlock forests are not showing up as often in bird surveys along the Limberlost Trail and around Rapidan Camp on the Rapidan River," it states. Gubler added, "The park's just not offering that spruce/fir/hemlock dynamic that we used to be able to, so those species have to go elsewhere to find that mixture." As climate change facilitates the spread of the woolly adelgid, it is quite possible that this story is, and will be, retold across much of the Potomac Watershed and throughout the Northeast United States (Repanshek, 2017).

SOLUTIONS: INCREASING RESILIENCY AND MITIGATION

INCREASING UPLAND FOREST RESILIENCY TOWARD CLIMATE CHANGE

Obviously, **the most impactful solution to preserve key ecosystems, like the northern hardwood forests, from climate change impacts is to curtail global greenhouse gas emissions**. Reducing the density of trees within a given forest is an alternative adaptation option for mitigating anticipated drought stress from climate change. This technique improves the water balance, making moisture available for the rest of the trees. Stand density reduction has also been shown to increase the trees' generation of defensive compounds, which shield them from pest invasions. Certainly, it would not be advisable to thin every forest, as this raises concerns over ethics, conservation, and other unforeseen ecosystem imbalances. Still, forest thinning and underbrush clearing through controlled, prescribed burns has been a crucial part of maintaining lower density forests in many semi-arid locations (McDowell & Allen, 2015), as well as a key part of healthy forest management and forest fire prevention among many indigenous tribes since pre-colonial times.

Another alternative solution to cutting greenhouse gasses is to **intentionally plant more southerly and low-elevation species into these northern, high-elevation ecosystems. This technique increases the resiliency of future forests by planting, now, what will come to thrive there in a warmer climate**. In any case, growing temperatures and the resulting water stress from projected climate change is likely to drive major shifts in plant dominance, stimulating the emergence of new vegetation patterns not only in the Potomac Watershed, but also worldwide (McDowell & Allen, 2015).

PROTECT AND PLANT FOREST TO MITIGATE CLIMATE CHANGE

While climate change can clearly negatively impact certain forest types and create imbalances within the ecosystems, it is also imperative we remember that **forests, themselves, are key to combating the climate crisis through their ability to extract and sequester large amounts of carbon** from the atmosphere.

In Maryland, the Montgomery County Technical Group on Sequestration recommends improving carbon sequestration within the county, specifically for the purpose of climate mitigation, starting with revising government policy. Updated land use policy goals would bolster the county's substantial authority over land use and set the stage for maximizing carbon sequestration, thereby increasing resilience toward climate change. This is recommended together with communicating across all county departments and integrating, when possible, with the state and with entities in the greater Washington, D.C. metro area. (Bogdonoff et al., 2020).

Secondly, an additional set of goals recommended by the Group would focus on the **potential contribution of the county's forest and wetland ecosystems to foster climate resiliency through carbon sequestration practices, which also improve ecosystem services such as reductions of extreme streamflow, abatements in related erosion, sediment flow and polluted runoff, and decreases in the likelihood and severity of floods** (Bogdonoff et al., 2020).

The first of the ecosystem goals aims to **protect existing forest and trees on both public and private**

county lands, and is the most cost effective measure. This is paired with the need for **expansion of forest and tree canopy** by 2030 using planning, zoning and permitting processes, the creation of tax benefits, stricter prohibitions and penalties on the cutting of mature trees, aggressive tree planting initiatives that include urban and micro-forests in residential areas, and maintenance of mature trees (Mackie & Boucher, 2019; Bogdonoff et al., 2020).

A second ecosystem goal would be to **protect the county's naturally flooding wetlands and streamside forests, under a "no further loss" policy, and also would restore and expand these ecosystems, if possible**. The process of expansion would include assessing whether reintroduction of beavers is feasible "to naturally expand wetlands and manage stormwater" (Bogdonoff et al., 2020).

A third ecosystem goal would call for **preserving, restoring, and expanding Montgomery County's forest area from 34% in the period 2001-2016 to 37% in 2027 and 45% in 2035. To this end, the County would utilize all its parks and lands "not required for other uses (e.g. sports fields, visitor centers)" for planting trees** (Bogdonoff et al., 2020). To further promote carbon sequestration objectives, the Montgomery County Technical Group on Sequestration recommended for the County to amend its existing Forest Conservation Law to require developers to replant more acreage than they destroy, resulting in a net gain of trees (and therefore carbon sequestration). In addition, the County would score existing forest and wetlands on their overall "ecological condition" to indicate the level of investment required for regeneration, restoration, or management activities. This would include a focus on reducing damage caused by invasive species, such as high populations of whitetail deer, and increase the active management of natural areas to reduce threats from drought, unplanned fire, and encroachment by developers. Finally, the County would work with public land management entities outside its jurisdiction to manage ecosystem restoration plans on a broader scale. Montgomery County would also hold public outreach events to share and promote the recommended practices of carbon sequestration and climate resiliency at home (Bogdonoff et al., 2020).

Abel Olivo is a newer member of the Montgomery County Forest Coalition, and also the Director of Defensores de la Cuenca (a Spanish title that translates to "Defenders of the Watershed"), a non-profit group "dedicated to sharing experiences and educating the Latino community on nature and the environment" ("Defensores de la Cuenca," 2020). In an interview with Potomac Conservancy, he noted that while it is important to support carbon sequestration efforts, such as "no net loss" of forests, as a start for mitigating climate change, many of Defensores de la Cuencas' participants do not have the time to actively think about how climate change affects them and how they may have ownership over it: "You know, if we're going around creating these BMPs [best management practices] everywhere, and just kind of sticking them into these communities without taking the time to explain the importance and value of them, well, people aren't going to necessarily respect them," Olivo said.

In this role, Olivo is interested in urban forestry to bring in more trees with community buy-in. He notes that **"...we recognize that the communities that are most impacted by climate change are communities of color who generally live in highly dense areas... or in areas that are more prone to flooding, or low land areas. And we need these people to be in the conversation when we're talking about programs and policies and ways to make improvements, and planning for the future." Olivo continued, "We can't accomplish those things with just our White middle-income, upper middle-income cohorts, so we need everyone to participate, especially the communities most impacted by those climate-driven severe weather events." Olivo added, "I think that having more people from the communities with a greater first-hand understanding will help the overall goal of combating climate change."**

"Conceptually, people know what that is. People know about climate change and some of the impacts. But, when you talk about climate change to the [Latinx] communities that we engage in, it's hard to make it relate. You know, how does that relate to putting food on the table... ?" To bridge that gap, Olivo begins conversations that "allow Latinx people to share their experiences, and feel comfortable doing that."

Many community members of the Latinx community in the DMV grew up in places where they could personally harvest fruits and nuts from trees in their native country. It was "a big part of their life, their daily life, going out of their house every morning and picking fresh mangoes off the tree," Olivo said. "There [was] that stronger-than-here connection. So, they are lamenting the loss of that connection… knowing that there aren't as many green spaces around here to go out and take a walk." So it is important that we promote, "going into these [green] spaces and saying, 'You belong here. We belong here. We can come anytime.'" Olivo continued, mentioning that conversations around photosynthesis, the water cycle, how trees help water absorb into the ground and replenish the aquifers, and how it's all connected through a system that is so perfectly symbiotic, enhances a type of spiritual connection. It is "that understanding that we all have an obligation to care for creation," that motivates many members of Defensores de la Cuenca toward environmental stewardship.

Olivo states that the goal of Defensores de la Cuenca is to create "a network of Latinx leaders to grow in the green space, because as it stands now, there are very few people, Spanish speakers, Latino-led organizations, that work to engage the community in a similar way and at the levels… that we see in the mainstream." He works with a group in a densely urban area of Silver Spring, Maryland in Montgomery County, which is a suburb just north of Washington, D.C. "But you know, we also recognize that throughout the Potomac Watershed, there are large and growing pockets of Latinos that are completely unengaged that are the future of, not only the watershed, but of their communities," he said. "It's something that is on our mind and something that we want to build into our future engagements."

Increasing access to green space in urban areas, "especially in places with high rates of impervious surfaces, will automatically help to clean the water, clean the stormwater runoff, and capture it." Plus, he states that these spaces lend themselves to opportunities for affected communities to plant more trees that capture carbon dioxide, clean the air and produce more oxygen. **"And I think that if we can all live in a place that looks like…Wakanda, it would be ideal. You know, you'd have these big buildings with trees and terraces of greenery and pockets of green space."**

An example of community leadership comes from the high-density Silver Spring community in which Olivo is currently engaging. In 2013, the Silver Spring Citizens Advisory Board wrote a letter of concern to the Montgomery County Executive and the County Council President to request the County's new Tree Canopy Law require an immediate replanting of trees near the original place it was removed, instead of randomly replanting a tree somewhere else in the region. It also called for promoting tree plantings in areas with patchy canopies in order to fill them in and maximize shade (Silver Spring Citizens, 2013). While the resulting law allowed developers to pay a fee for every tree removed in lieu of replanting, the Law requires "the mitigation funds must be used to plant and establish shade trees, and that priority should be given to sub-watersheds where the disturbance is occurring and to areas that have relatively low tree canopy coverage" ("Montgomery County Tree," 2017). A 2017 annual report noted that the *Tree Montgomery* program used most of those fees to plant trees in Montgomery County's highly urbanized areas. However, Tree Montgomery funds are not used to plant street trees, as many cities and towns in Montgomery County have separate programs for that ("Montgomery County Tree," 2017).

In the summer of 2020, the largest county in Maryland, Frederick County, passed the strongest local forest protection laws in all of Maryland, by both reinstating its 2008 "no net loss of forest" law, and amending its zoning ordinance to protect existing woodlands, wetlands, and historic and cultural sites (Wheeler, 2020). In 2017, the U.S. Forest Service reported that 43% of Frederick County is covered with tree canopy, and noted that agriculture is the primary land use (O'Neil-Dunne, 2017). **Frederick County's previous "no net loss of forest" code had been rolled back in 2011, resulting in a Countywide loss of about 500 acres of forest from 2012 to 2019. In the 2020 law reinstating "no net loss of forest", it is stated "if an acre of forest is taken down as part of land development, it must be replaced by another permanently preserved 'newly planted' forest acreage that is under protective easement"** (George, 2020). Frederick County is bordered by the Monocacy River which has its origins in Adams County,

Pennsylvania, and flows 58 miles south into the Potomac River. Due to deforestation and scant tree buffers, the Monocacy River and streams throughout Frederick County "are some of the worst polluted waterways in all of Maryland" (Diemand, 2020). **Frederick County's 2020 laws are the "strongest forest protection measures in all of Maryland"** (Diemand, 2020).

Passing these types of strong forest protection measures in other jurisdictions throughout the Potomac River watershed (at the county and/or state level) would be a significant solution to combat climate change, protect the water we drink, clean our air, and preserve green spaces that plant, animal, and human communities all rely on for well-being.

COLDWATER STREAMS

COLDWATER STREAM HABITAT

Coldwater streams make up approximately 2,750 miles of Maryland's freshwater streams and are mostly located within the northwestern Appalachian Plateau and Valley and Ridge provinces of the Potomac River Watershed, though they can also be found in the Piedmont Plateau province. In Maryland, they span across Allegany, Garrett, Frederick, Carroll, Washington, Montgomery, and Prince George's counties. (Maryland Department of Natural Resources, 2015, Chapter 4). In West Virginia, the watershed's coldwater streams are found chiefly in the eastern panhandle. In Virginia, coldwater streams meander through the mountains and valleys of the Interstate 81 corridor, stretching across Augusta, Rockingham, Shenandoah, Warren, and Frederick counties up through Berkeley County in West Virginia (Virginia Council of Trout Unlimited, n.d.).

Streams have been warming throughout the continental United States, and the Potomac Watershed is no exception. A 2014 study from the *Journal of Climatic Change* shows that **most streams in the Chesapeake Bay Watershed, to include those within the Potomac River sub-watershed, have experienced significant warming from 1960-2010** – though warming was more prominent toward the end of this period. Between 1986 and 2010, average stream water temperatures increased by 0.39°C (0.7°F) (Rice & Jastram, 2015).

Location of coldwater streams in Maryland. Credit: Maryland State Wildlife Action Plan / Maryland Department of Natural Resources

In DNR's chapter on climate change for the Maryland State Wildlife Action Plan that she helped to produce, **Dana Limpert writes, "of all the rivers and streams systems that occur in the region, the coldwater stream habitat is thought to be the most vulnerable to climate change"** (Maryland Department of Natural Resources, 2015, Chapter 6).

By definition, coldwater streams have an average daily water temperature maximum of less than 20°C (68°F) and are often found at the headwaters of a watershed. Logs and leaf litter compose the base of the food web and support the stoneflies and mayflies that dominate the macroinvertebrate community in the bottom waters. Coldwater streams support Maryland's greatest diversity of salamanders, including the spring, seal, and Allegheny mountain dusky salamanders. Disturbance by beavers creates mosaics of habitat forms for a myriad of wildlife species, including those of greatest conservation need like the brook

trout. **However, many coldwater stream habitats have been degraded as a result of industrial agriculture and urban development** (Maryland Department of Natural Resources, 2015, Chapter 4).

CLIMATE CHANGE AFFECTS COLDWATER STREAMS

Warming air temperature is the main cause of warming water temperatures; in this case, it explains about 85% of the warming trend. Yet there are other watershed characteristics that can also influence stream temperatures. For instance, the forest canopy shades streams, preventing water temperatures from rising as fast as air temperatures. Thus, when forests are cleared for developmental or agricultural use, streams become partial to the sun's rays and warm faster. This highlights the need for protecting and planting riparian forest buffers – buffers of trees planted along the banks of waterways. Dams also allow waterways to warm faster because when parcels of water are held back in one location, rather than flowing through a moving stream, they have more time to heat up. In urban areas, stormwater runoff from warm, paved surfaces and the discharge of heated wastewater passing through electric power plants can also raise water temperatures faster than air temperatures (Rice & Jastram, 2015; University of Maryland Center for Environmental Science, 2015).

The warming of the Potomac Watershed's freshwater streams has critical ramifications for ecosystem functioning. Colder water can hold more oxygen, so **when streams warm, the amount of dissolved oxygen in the water decreases, stressing fish and other wildlife species that require oxygen to breathe** (Rice & Jastram, 2015).

Warming stream water shifts both the life cycles and the distributions of plant and animal species. The spawning times of native fish may come earlier in the spring season, throwing cycles of feeding and migration out of sync with other plant or animal species they might depend upon. Cool-water fish that need extended time in low temperatures may be pushed out while warm-water species, including invasive species and pathogens, move in to take their place (Maryland Department of Natural Resources, 2015, Chapter 6).

Drought frequency and duration is also expected to increase in the Potomac Watershed as a result of climate change. This could fragment aquatic habitat for extended periods of time, limiting resources and resulting in the death of local populations of fish and other aquatic life. Moreover, when water levels become lower, plants and animals can become physically stressed which, **when combined with habitat fragmentation, can drastically reduce survival, and prevent species migration to more permanent streams** (Maryland Department of Natural Resources, 2015, Chapter 6).

EUTROPHICATION

A warming climate worsens [eutrophication], defined as the enrichment of nutrients within an ecosystem. The Potomac River itself has a long history of eutrophication, due to nutrient inputs from external sources like industrial waste and fertilizer runoff from agricultural fields, sports fields and lawns. These excess nutrients encourage the growth of algae at the water's surface – especially as the water becomes warmer due to climate change. The algal blooms block sunlight, preventing bottom-dwelling plants from photosynthesizing and releasing oxygen to the water. Then, as the surface algae die and sink to the bottom of the streambed, bacteria decompose them. This process consumes even more oxygen, leading to a larger reduction of habitat for stream creatures that need oxygen to survive (Rice & Jastram, 2015).

Fortunately, the water quality has been slowly improving over the past two decades as a result of mindful agricultural advancements. In 2020, the Potomac Conservancy's Potomac River Report Card stated that **"improvements in agricultural land management practices over the last two decades have resulted in decreasing concentrations of pollution from rural areas; however, excess nutrients and sediment from polluted urban runoff is increasing over time and threatens to undo decades of progress." The river is still too polluted for safe swimming or fishing** (Potomac Conservancy, 2020).

SOLUTIONS: STREAMSIDE FOREST BUFFER

Within the Potomac Watershed, the Washington, D.C. area will see the greatest changes in water temperature and the largest temperature spikes after rainstorms as runoff heated by paved surfaces enters waterways. We know that **streams draining from forested areas warm more slowly than those draining from urban or agricultural areas; so, one way to mitigate these climate change impacts would be to encourage the protection, planting, and regrowth of forested ecosystems along the watershed's freshwater streams** (Maryland Department of Natural Resources, 2015, Chapter 6).

BROOK TROUT

Brook trout, also known as "speckled trout" or "brookies," is a fish native to the eastern United States. In fact, **brook trout are the only trout species native to Maryland, West Virginia and Virginia** – and, aside from lake trout in Lake Erie, it is the only trout species native to Pennsylvania as well. Brook trout require cold, clear, well-oxygenated waters and are very sensitive to environmental changes such as pollutants, lowered oxygen levels, and changes in stream temperature or pH. Because of this sensitivity, **brook trout are known as indicator species, meaning they help qualify the overall health of a stream**. Large numbers of brook trout indicate that a stream is likely healthy, while diminishing numbers signify poor water quality and deteriorating habitat (U.S. Fish and Wildlife Service, 2020).

Native Brook Trout.
Source: Eric Engbretson / U.S. Fish and Wildlife Service

Warming waters are the most critical stressor on brook trout populations, which require stream temperatures to remain under about 18°C (65°F). Exposure to temperatures 24°C (75°F) and over can kill these fish after only a few hours. For this reason, the Maryland Department of Natural Resources (DNR) designated brook trout as a "species of greatest conservation need" associated with coldwater streams (Vermont Fish and Wildlife Department, n.d.). Rainbow trout (from the western U.S.) and brown trout (from Europe) are two nonnative species that were introduced to the region in the late 1800s. They have slightly higher temperature tolerances and, once temperatures reach 20°C (68°F), they can out-compete native brook trout (Hokanson et al., 1973). Elimination by competition is already occurring in some streams (Vermont Fish and Wildlife Department, n.d.).

Human-induced ecosystem stressors also weaken brook trout populations. This then makes them less resilient to the added impacts of rising stream temperature from climate change. For example, **human activities such as land development and stream channelization disrupt water clarity by promoting siltation, which refers to the increase in sediment concentration both in the water column and on top of stream beds. Siltation makes trout reproduction difficult** because it covers gravel on the stream bed where they lay their eggs. Clean gravel is required as it promotes the movement of oxygenated water over the eggs. As little as a quarter inch of silt can compromise the entire hatch. **The removal of streamside trees and other streamside vegetation can also cause trout numbers to plummet as they require such coverage for habitat**. In some Appalachian Plateau streams, acid rain, caused by air pollution, has lowered the pH of coldwater streams enough to wipe out local populations of brook trout (U.S. Fish and Wildlife Service, 2020; Virginia Department of Wildlife Resources, n.d.).

SOLUTIONS: STREAMSIDE FOREST, PREVENTING ACID RAIN, SOLAR OVER PARKING LOTS, AND TROUT UNLIMITED

To promote the conservation of brook trout, we may first turn our focus to reducing the impacts of non-climate stressors on coldwater stream ecosystems so as to buffer them from the negative effects of climate change. **We can increase forest cover and streamside vegetation to create cool microclimates. We can reduce stream channelization to limit sediment and siltation. We can increase emissions and air quality standards for vehicles and industry, thereby reducing acid rain events. We can install solar canopies over parking lots, which will keep paved surfaces cooler so that stormwater runoff into streams will be less heated, while also producing renewable energy. Additionally, increased forest cover, solar canopies over parking lots, and stronger emissions and air quality standards for industry and vehicles would benefit both brook trout and human health.**

Luckily, some organizations do exist to help tackle these issues. For instance, Trout Unlimited is a national organization comprised of about 140,000 volunteers, lawyers, policy experts, and biologists committed to conserving and restoring coldwater fish habitat from Maine to Virginia to Alaska. They collaborate with local communities, as well as state and federal government, to restore the natural resiliency of watersheds and provide species like trout and salmon a chance to survive as the climate warms throughout the 21st century (Virginia Council of Trout Unlimited, n.d.).

In 2011, **Trout Unlimited created the Chesapeake Bay Coldwater Land Conservancy Fund, "which provides matching grants to land trusts and conservation agencies to permanently protect habitat for eastern brook trout through land and conservation easement acquisition."** These projects are strictly located **within the Chesapeake Bay Watershed – of which the Potomac Watershed is part** – and are supported by the National Fish and Wildlife Foundation, U.S. Forest Service, and U.S. Fish and Wildlife Service (Virginia Council of Trout Unlimited, n.d.).

In 2003, the Virginia Department of Game and Inland Fisheries (VDGIF) reintroduced native brook trout into a coldwater stream in Frederick County, Virginia, called Redbud Run. In the 1970s, Redbud Run was deemed a Class 3 Trout Stream, meaning it had little natural reproduction and marginal trout habitat. In 1975, nonnative rainbow trout were observed naturally reproducing there, most likely due to stocking efforts by private citizens. Rainbow trout will outcompete native brook trout because they can survive in warmer waters. Redbud Run's springwater-fed headwaters, near Interstate 81, were cold enough to reintroduce native brook trout species, which were once popular in the stream. Virginia's Winchester Chapter of Trout Unlimited has been working together with VDGIF to establish a population of native brook trout in Redbud Run ("Red Bud Run," 2021).

Bill Prokopchak, Newsletter Editor of *Lateral Lines* – the monthly journal of Winchester's Chapter of Trout Unlimited – is currently involved with the restoration and restocking of Redbud Run, which originates from two large upstream springs and meanders for 3.7 miles until it empties into Opequon Creek. **In an interview with The Potomac Conservancy, Prokopchak noted that, "we're trying to do erosion control and work with landowners along Redbud Run. The problem is that the headwaters of that stream are now being developed as shopping centers, and the runoff from the parking lots from those shopping centers is providing a couple of hazards."**

He explained, "**Number one…it's a spring creek, and typically, in the middle of the summer the temperature of the water will be in the 50s. Yet you get this blast of [hot] water that runs off from the parking lots.** So, the fish, thus far, have been able to survive those surges of hot water because as a summertime thunderstorm blows through, they get this pulse of hot water but it's not sustained. So, it doesn't seem to kill them. Or at least it doesn't seem to kill the adults." He continued, "And then you have the problem that it's a limestone stream, so the limestone precipitates when the water from the springs comes out into the air. The lime that it's carrying precipitates on everything, which inhibits, to some extent,

the population of bugs that the fish eat. So, we build structures in the stream to aerate the water and to provide cover for the fish, so that they can hide from the… predators like herons and…river otters and things. And after a couple of years, if we make a structure out of logs, even after a year it will be totally coated with limestone, so that the structure looks like it's made of concrete… so **that stream, we're really struggling to keep it livable for those wild trout."**

VDGIF also sponsors the annual introduction of brook trout "fingerling" fish into Redbud Run in conjunction with Trout Unlimited's "Trout in the Classroom" Program. This program is targeted to elementary, middle and high school students learning about conservation and the environment. Classrooms have specially chilled aquariums that keep the water at 10°C (50°F) so they can raise native brook trout using eggs supplied by VDGIF hatcheries. "And you know this year, because of COVID, we don't have so many tanks," Prokopchak told The Potomac Conservancy. "But in a normal year we have 20 cold water aquariums that are raising brook trout…So, you get 20 kids, and let's say each school deposits 30 trout, you're talking about 600 little fingerlings getting dumped into that stream every year." However, the brook trout still have trouble maintaining a self-sustaining population in Redbud Run. The Winchester Star reported that a section of the stream running through a local historic battlefield is still "swampy and slow — not exactly trout habitat." Still, "Every once in a while we manage to find a brook trout that survived," local conservationist Bud Nagelvoort told *The Winchester Star* (Castiglia, 2018; "Education," 2021).

The *national* Trout Unlimited organization funded another project in the Potomac River Watershed, called Sprout Run. "Now, there are at least 20 'Spout Runs' in the area, so I would have to point this out to you on a map," Prokopchak explained to The Potomac Conservancy. "But it also has rainbow trout surviving in it from some stocking that somebody did, who knows how many decades ago. And because of that, the national Trout Unlimited organization worked with the landowner and re-graded that whole stream area."

Trout Unlimited hired a professional crew to fix the problem of silt eroding into the run, which is not good for trout. Prokopchak continued: "There was erosion occurring, so they brought in heavy equipment and cut back those banks and leveled the area so that instead of the streambed looking like a V, or like a small canyon (you know when I say small canyon, I'm talking maybe 6-7 feet deep), they simply removed that steep wall and made a very gradual gradient, and then over-seeded that with native plants and shrubs. And the idea is so that **when the water – the spring rains or summer thunderstorms or whatever comes through – and the water gets high, the water is not only flowing through the stream channel, but it spreads out into a vegetated area. And that slows the flow of the water and enables any particulate matter in the water to fall out….you know, that's the way nature designed these streams to work.** But human inventions messed that up."

In 2007, the broader Virginia Council of Trout Unlimited also started the Interstate-81 Coldwater Area Restoration Effort or "I81 – CARE" campaign aimed at reducing pollution and restoring coldwater stream habitat for brook trout (the state fish of Virginia) along Interstate 81, from Tennessee to the West Virginia border (Virginia Council of Trout Unlimited, n.d.).

In West Virginia, the Department of Natural Resources (DNR) are working with the Reymann Farms aquaculture facility in Hardy County to grow native brook trout in a hatchery. In April of 2020, over one thousand juvenile trout were released into four streams in the eastern panhandle. "We're trying to create brook trout populations that look like the populations some of our streams once had," a DNR biologist told the Gazette-Mail. "We're not out to stock fish that will be caught immediately; we're trying to establish populations of spawning, self-sustaining native brook trout."

SALAMANDERS

Like the brook trout, salamanders are also considered indicators of ecosystem health, and are known to favor cooler temperatures. These amphibians can diffuse water and breathe directly through their skin; thereby rendering them quite sensitive to toxins and changes in their surrounding environment (Maryland Department of Natural Resources, 2015, Chapter 6).

Climate change threatens the survival of salamanders in a number of ways. First, there is the effect of temperature. Salamanders are ectotherms, meaning they regulate their body temperatures through their environment, so they sun themselves on rocks to warm up. They cool off in streams or shaded areas. **Salamanders are known to favor cooler temperatures.** They operate between 0.6°C (33°F) and 15.6°C (60°F), though their metabolism slows and heart rates decrease around 10°C (50°F), signaling environmental stress (Catenazzi, 2016). **The northern spring salamander is especially aquatic and therefore highly susceptible to warming water temperatures.** Larvae remain in the streams for an average of four years before metamorphosing into adult salamanders; and even as adults, they spend most of their time in the water, leaving every now and then to forage in the streamside vegetation (Refugia Research Coalition, n.d.).

Body sizes have also decreased in some populations as salamanders divert more energy to overall maintenance and reproduction at higher temperatures than to growth. “Indeed, body sizes of salamanders and frogs have shrunk over periods as short as 23 years,” says one PeerJ study (Catenazzi, 2016). Even though salamanders may sometimes be able to adjust their behavior to avoid warm temperatures – by retreating underground for example – they will still inevitably be exposed to warmer summer temperatures. However, if winter temperatures warm from sub-freezing (in which salamanders are not normally active) to above freezing, salamanders could become more active during winter periods, offsetting the time lost during the summer season when they must remain underground (Catenazzi, 2016).

The second way that climate change affects salamanders is through drought. Salamanders must remain moist to survive and require pools of standing water for reproduction. Unfortunately, as we have learned, the Potomac Watershed is likely to experience decreases in *regular* rain events, causing seasonal pools and standing water to abate. Drought has been shown to negatively affect the larvae of northern dusky salamanders, which require standing water to survive (Maryland Department of Natural Resources, 2015, Chapter 6).

Thirdly, climate change can also promote the spread of fungal diseases like chytridiomycosis as temperatures in certain regions become optimal for the survival and reproduction of chytrid fungi (Maryland Department of Natural Resources, 2015, Chapter 6).

SOLUTIONS: HABITAT COVER, FOREST PROTECTION, AND CONNECTIVITY

The Maryland DNR considers the eastern hellbender, northern red salamander, seal salamander, and northern spring salamander as “species of greatest conservation concern” in coldwater streams. **Because salamanders live both in the forest and streams, it is important the habitat between the two remain unfragmented.** Moreover, because salamanders are amphibians, their skin requires tree canopy to shade the cool moist soil underneath; so encouraging the protection, planting, and regrowth of forested ecosystems along the watershed’s coldwater streams can also help to make this group more resilient to climate change (Maryland Department of Natural Resources, 2015, Chapter 4).

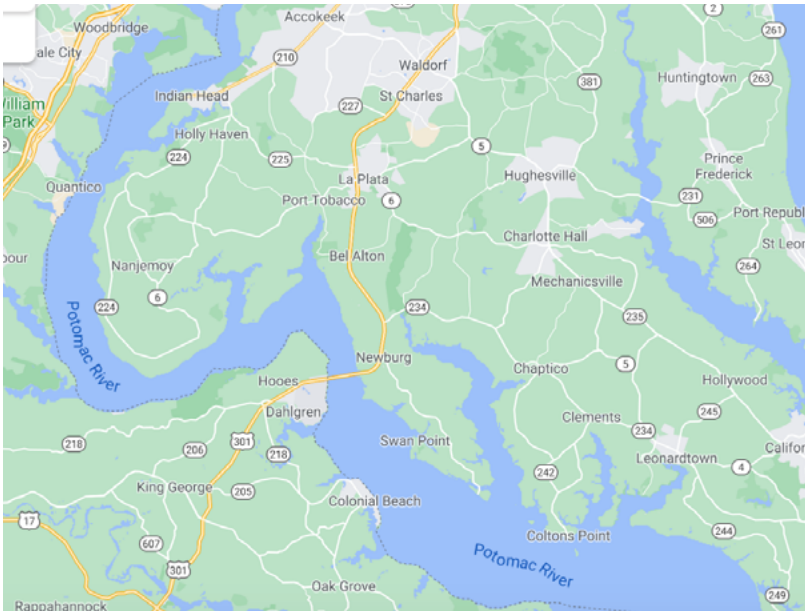
TIDAL MARSHLANDS

Tidal Marsh Wetlands. Credit: Eric Vance / The EPA Blog

Marshes are wetlands that are found along the edges of rivers, lakes and streams. They form the buffer between the open water and the upland ecosystems. *Tidal* marshes are different in that they form along coastlines and tidal rivers (like the Potomac, or the Nanticoke) where the tides influence the water level as they ebb and flow. In the Potomac Watershed, tidal marshes are found along the length of the Potomac River, from its mouth at the Chesapeake bay to where the tides diminish just above Washington, D.C. As we work our way upriver from the Chesapeake Bay, tidal marsh ecosystems transition from slightly salty *oligohaline* marsh, where salinity ranges from 0.5-5 parts per thousand (ppt), to *freshwater* marsh, where salinity is lower, between 0-0.5 ppt. As salinity decreases, oligohaline plants, like black needlerush and the cordgrasses give way to pickerelweed and spatterdock (commonly known as the Water Lily), which flourish better in fresher waters (Maryland Department of Natural Resources, 2015, Chapter 4).

CLIMATE CHANGE AFFECTS TIDAL MARSHES

Currently, the oligohaline-freshwater marsh transition zone – where salinity is 0.5 ppt on average – stretches from the U.S. Highway 301 bridge upriver to Quantico, Virginia. **As the warming climate causes sea level to rise, the saltwater edge will be pushed farther upriver, affecting the distribution of species along the Potomac.** However, according to a 2016 study in PLoS One, this edge might only be pushed up as far as Indian Head by the end of the century due to the region's topography and the potential for water to spill out cross-sectionally (widening the river), rather than being pushed far upstream (Cadol et al., 2016).



Screenshot depicting the oligohaline-freshwater marsh transition zone along the Potomac River between the Highway 301 bridge and Quantico, VA, as well as Indian Head, which may become the upper limit of the salty edge by 2100. Credit: Google Maps

But just how far will water and marsh migrate inland? This answer depends on a multitude of variables. The elevation of the shoreline is one major factor, as low-lying land areas are more easily flooded from rising water levels and will allow for a swifter inland migration of the marsh edge than higher shoreline areas. Another factor involves how suspended sediments settle because marsh plants cannot grow in open water – they require their substrate to rest at a specific depth so that their roots remain oxygenated. Marsh can either move inland, becoming replaced by open water, or – if sediments remain high enough – the preexisting marsh will stay and the entire marsh area will expand. It is hard to know, for sure, what exactly will occur because sediment dynamics, like an increase in shoreline erosion,

are difficult to model on a spatial scale. One method to alleviate marsh habitat loss could be to intentionally allow managed open spaces, like golf courses and parks, to succumb to sea level rise and become flooded by the tides (Cadol et al., 2016).

Both the tidal oligohaline and tidal freshwater marsh support an abundance of wildlife. Birds include the American goldfinch, coastal plain swamp sparrow and marsh wren. The least bittern (*Ixobrychus exilis*), one of the smallest herons in the world, also makes its home amongst the reeds and cattails of fresh and slightly salty marsh. Bats include the big brown bat, silver-haired bat, and eastern-red bat. Reptiles include the eastern kingsnake, rainbow snake, and northern diamond-backed terrapin. Most vegetation, however, differs significantly between oligohaline and fresh marsh (Maryland Department of Natural Resources, 2015, Chapter 4).

TIDAL OLIGOHALINE MARSH

In the Potomac Watershed, tidal oligohaline marsh represents the transition between the higher salinity marshes along the Chesapeake Bay and upland freshwater marsh. Tidal oligohaline marsh can be found in specific areas along the Potomac River in King George's and Northumberland counties in Virginia, as well as in Prince George's, Charles, and St. Mary's counties in Maryland. However, **as sea level rise advances the salinity gradient upriver, the location of these marshes may shift into more northerly counties along the Potomac. Thus, some freshwater tidal marshes may be converted to tidal oligohaline marshes, while some stretches of oligohaline tidal marsh may very well become more salty** (Maryland Department of Natural Resources, 2015, Chapter 4; Virginia Department of Conservation and Recreation, 2021c).

Locally, the most common plant species of a tidal oligohaline marsh are big cordgrass (*Spartina cynosuroides*) and narrow-leaved cattail (*Typha angustifolia*) which often grow in large, tall plots along the edges of tidal channels. The diversity of plant species generally decreases as salinity increases, so oligohaline marsh is often less biodiverse than freshwater marsh, but some freshwater species like the dotted smartweed and arrow-arum can sometimes be found in these marshes alongside the more salt-tolerant species. Other species found in these slightly salty marshes include (Maryland Department of Natural Resources, 2015, Chapter 4; Virginia Department of Conservation and Recreation, 2021c):

- water-hemp pigweed (*Amaranthus cannabinus*)
- swamp rose-mallow (*Hibiscus moscheutos*)
- seashore mallow (*Kosteletzkya pentacarpos*)
- saltmarsh bulrush (*Schoenoplectus robustus*)
- halberd-leaved tearthumb (*Persicaria arifolia*)
- swamp barnyard grass (*Echinochloa walteri*)
- swamp dock (*Rumex verticillatus*)

INVASIVE PLANT: COMMON REED

Vast colonies of the invasive, and highly aggressive, common reed (*Phragmites australis***) have overtaken many tidal marshes throughout the mid-Atlantic region as a result of dredging, development, and the changing climate.** Unlike many native species, the common reed is highly resilient to disturbance and can therefore outcompete the native plants for habitat. It poses a serious threat to the Potomac Watershed's marshes as it alters water flow and reduces habitat space for wildlife by growing in extremely dense stands. Moreover, because it grows to over fifteen feet tall, it accumulates a lot of dead biomass and increases the potential for uncontrolled fire (Virginia Department of Conservation and Recreation, 2021c).

Solutions for the Common Reed include an herbicide that breaks down quickly in the environment and is approved by the U.S. Environmental Protection Agency (EPA) for use in wetlands (Environmental Concern, n.d.). Other methods include cutting and burning that may have short-term adverse effects on the native ecology. These solutions are labor-intensive and expensive. In addition, an initial increase in plant diversity may eventually give way again to this aggressive, nonnative species (Smithsonian Environmental Research Center, n.d.).

SPOTFIN KILLIFISH

Tidal oligohaline marsh also provides habitat for the little **spotfin killifish**, a nonmigratory, permanent resident of the Potomac, as far up as Dumfries, Virginia and Marbury, Maryland (see map above) where the salinity drops to become freshwater marsh. Because it prefers medium to high salinities, and because it is highly tolerant of extreme changes in temperature and dissolved oxygen levels, its **range is actually likely to expand within the Potomac Watershed as climate change promotes the warming of water temperatures and the inundation of saltwater up the Potomac River** ("Spotfin killifish," 2014).

TIDAL FRESHWATER MARSH

Tidal freshwater marshes represent the upper most reaches of the Potomac's tidal zone, where the water remains consistently fresh – aside from the occasional pulse of salinity from large spring tides. Here, the backflow of saltwater from the tides is diluted by the larger inflow of freshwater from upriver, as it travels on its way toward the bay, and eventually the ocean. Freshwater marsh can be found throughout Stafford, Fairfax, and Arlington counties in Virginia, as well as in Charles, Prince George's, and St. Mary's counties in Maryland (Virginia Department of Conservation and Recreation, 2021b). Currently, Potomac salinity gives way to become freshwater marsh at Dumfries, Virginia and Marbury, Maryland.

This ecosystem floods twice per day, guided by the lunar tides. There are two apparent zones in a freshwater marsh: a low elevation zone adjacent to the open water that is dominated by short, broad-leaf plants, and beyond that, a higher elevation zone dominated by taller, grass-like plants. Though species diversity varies with salinity, disturbance and time spent underwater, the most common plants in these ecosystems include (Maryland Department of Natural Resources, 2015, Chapter 4):

Low marsh zone:

- Arrow-arum (*Peltandra virginica*)
- Pickerelweed (*Pontederia cordata var. cordata*)
- Spatterdock, more commonly known as water lily (*Nuphar advena*) - Mud flats that are completely exposed during low tide can support large fields of spatterdock

High marsh zone:

- Dotted smartweed (*Persicaria punctata*)
- Jewelweed (*Impatiens spp.*)
- Wild rice (*Zizania aquatica var. aquatica*)
- Rice cutgrass (*Leersia oryzoides*),
- Halberdleaf tearthumbs (*Persicaria arifolia*)
- Arrowleaf tearthumb (*Persicaria sagittata*),
- Beggar-ticks (especially *Bidens laevis* and *Bidens trichosperma*)

In the high marsh zone, sweetflag (*Acorus calamus*), tidal-marsh amaranth (*Amaranthus cannabinus*), marsh partridge-pea (*Chamaecrista fasciculata var. macrosperma*), and southern wild rice (*Zizaniopsis miliacea*) can become dominant locally, growing by themselves in large stands. Tidal freshwater marsh also provides critical habitat for the sensitive joint-vetch (*Aeschynomene virginica*) plant, which is globally rare. However, **as climate change promotes the inundation of saltwater up the Potomac, the geographic ranges of these plants are likely to decrease within the watershed** (Maryland Department of Natural Resources, 2015, Chapter 4; Virginia Department of Conservation and Recreation, 2021b).

INVASIVE PLANT: MARSH DEWFLOWER

Meanwhile, **invasive species like the marsh dewflower (*Murdannia keisak*) inflict additional stress upon freshwater marsh ecosystems, especially as they attempt to adapt to a changing climate. Invasives thrive despite disturbance and can outcompete native plants and animals for space and resources**, reducing the native biodiversity of the Potomac Watershed region (Virginia Department of Conservation and Recreation, 2021b).

HUMMOCKS

Beyond the normal high marsh zone are habitats called hummocks. Because they flood less frequently, hummocks can support larger trees and herbs. Species like the marsh blue violet (*Viola cucullate*), water hemlock (*Cicuta maculata var. maculate*), greenfruit clearweed (*Pilea pumila*), and false nettle (*Boehmeria cylindrica*) abide alongside ferns including the royal fern (*Osmunda regalis var. spectabilis*), cinnamon fern (*Osmunda cinnamomea*), and marsh fern (*Thelypteris palustris var. pubescens*). As water levels rise with climate change, these habitats will flood more frequently. Hopefully, hummocks will be afforded the space to migrate inland as tides rise (Maryland Department of Natural Resources, 2015, Chapter 4).

TIDAL FOREST

In the ecotones (transition zones) between these regularly flooded tidal marshlands and the upland forests are "tidal forests," which are dominated by a mixture of hardwood trees including ash, gum, and maple. The Potomac Watershed is unique in that bald cypress (*Taxodium distichum*) grows alongside these hardwoods. Atlantic white cedar (*Chamaecyparis thyoides*) can be found in rare stands as well. **Both Atlantic white cedar swamps and bald cypress swamps require extremely fresh, clear "sweetwater" to grow.** They were once much more common in the watershed area but are now considered regionally rare due to development and logging in the early 1900s (Maryland Department of Natural Resources, 2015, Chapter 4).

MARSH BIRDS

Located in the middle of the Potomac River in Washington, D.C. is Theodore Roosevelt Island, a natural park maintained by the National Park Service that features wooded trails and guided nature walks. No cars or bikes are allowed on the island, which is accessed from the western side via a footbridge from Arlington, VA. **Roosevelt Island was transformed back into a "real forest" in the 1930s by landscape architects who redesigned the rundown agricultural fields to mimic the natural ecosystems that covered the landscape before settler-colonial human interference. Consequently, the island is a birder's paradise.** It features species commonly found in freshwater swamps and tidal marshlands, like green herons and wood ducks. The National Park Service even supplies a brochure to keep track of all the birds you see (Potomac River Watch, 2016).

It is within these tidal forests that the American woodcock resides. This migratory bird is listed by the Maryland DNR as the species in greatest need of conservation within these ecosystems. Yet, the changing climate is likely to endanger the survival of these birds in a few ways (Maryland Department of Natural Resources, 2015, Chapter 4).

The American woodcock spends most of its time on the forest floor searching for food. It uses its long bill to probe the ground for earthworms and insect larvae found in the rich humus layers of soil. As such, the woodcock depends on consistent moisture to keep the soil wet enough for foraging. However, climate change is beginning to impact precipitation patterns in the Potomac Watershed region, causing the atmosphere to spill higher volumes of rainwater during more infrequent rain events. Earthworms cannot live in dry soils, so the woodcock is likely to struggle to find food during lengthening dry spells. Even when it does rain, it will fall with such intensity that it washes humus soil layers away rather than soaking into the ground. Thus, the bird's dietary complications due to climate change will simply inflict further stress upon the population already suffering from forested habitat loss due to development – which is already causing woodcock populations to decline each year (Salisbury University Environmental Studies Department, 2018b).

American Woodcock. Source: Fyn Kynd / Flickr

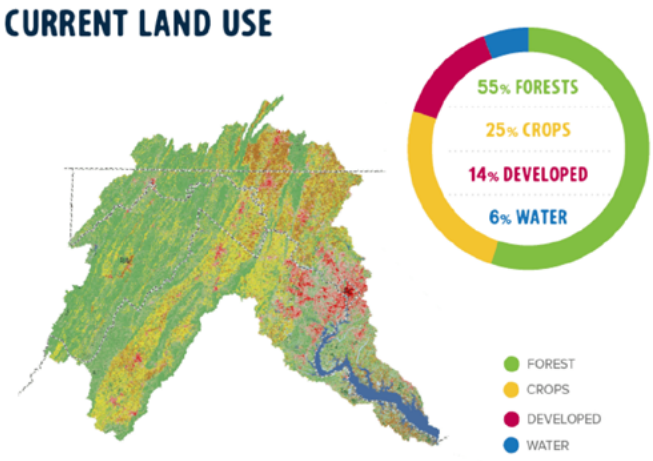
Generally speaking, for all migratory birds, **we are already seeing subtle shifts in the migration patterns of billions of birds as temperatures become warmer and more variable with climate change**. One 2020 study from the *Nature Climate Change* journal found that birds are migrating back home each spring about two days earlier every decade as a result of rising temperatures. During unusually warm seasons, birds can return even earlier. However, despite their earlier spring migrations, there is a growing discrepancy between the timing of bird arrival and the peak dates of spring blooms, berry ripening, and insect hatches that they depend upon for food. A *Forbes* article from 2020 states that "such a **mismatch in the timing of resource availability and the need for that resource can impact plants and insects as well as the birds that depend upon them**, and this asynchrony can lead to runaway population growth for some species — or to extinction for others" (Horton et al., 2020).

Visit *The American Scientist's* "Spring Budburst in a Changing Climate" for more information on how a warming climate is throwing off the timing of spring. The authors use Henry David Thoreau's 160-year-old field notes to compare the timing of spring activities between then and now.

AGRICULTURE AND FISHERIES

LAND USE IN THE POTOMAC WATERSHED

Although most of the land in the Potomac Watershed is forested (55%), agriculture also comprises a significant chunk of the land, amounting to 25% of the watershed's surface area. Developed land accounts for 14%, while water and wetlands make up the remaining 6%. Recently, the Potomac region has been witnessing a slight decrease in agricultural land as farms are sold and development slowly takes over the rural areas. Still, **agriculture remains the largest source of nutrient pollution to the Potomac River**, and consequently to the Chesapeake Bay. **By protecting forested areas and ensuring farmland is healthy and sustainable, we can improve water quality, increase the climate resiliency of our watershed, and have a thriving local food system that provides good jobs and good, nutritious food** (Potomac Conservancy, 2020).



Source: National Land Cover Database (NLCD), Multi-Resolution Land Characteristics (MRLC)

Credit: Potomac River Report Card, 2020

Aside from landscape diversity, agriculture plays a key role in the economy, livelihoods, and social fabric of the region. One third of Maryland's land is devoted to agricultural uses while the Virginia Department of Agriculture and Consumer Services cites agriculture as "the state's largest sector by far." Farming and farm product processing provide Virginia with 122,000 jobs and $27 billion in economic activity. In Pennsylvania, Franklin and Adams counties are important sources of cattle and cow milk, poultry, eggs, fruits and berries, melons, wheat, and corn for silage. The eastern panhandle of West Virginia is very productive as well, especially when it comes to corn, soybeans, and wheat. In addition, Berkeley County in West Virginia leads the state in fruits, tree nuts, and berry production while Jefferson is the top county for milk (U.S. Department of Agriculture, 2017; Boesch et al., 2008; "Understanding Virginia's Vulnerability," 2015; U.S. Department of Agriculture, 2016).

Fisheries also play a large role in the economy and livelihoods. The tidal stretches of the Potomac River and its tributaries provide a quality seafood and fishing sector. The catch includes herring, shad, striped bass, trout, blue crabs, clams, and oysters. Maryland is a national leader in harvesting blue crabs and soft clams, and its seafood businesses provides $600 million annually to the state's economy. This fisherfolk way of life is supported in the lower river counties of Charles and St. Mary's in Maryland, and Westmoreland, Northumberland, Stafford, and Prince William in Virginia (United States. Water Resources, 1951; "Maryland at a Glance," 2020).

INDUSTRIAL AGRICULTURE FUELS CLIMATE CHANGE & POLLUTES THE POTOMAC

Industrial agriculture is a huge contributor of greenhouse gasses, thereby playing a crucial role in the warming of our planet. Globally, agriculture contributes about 25% of all greenhouse gas emissions through both deforestation and unsustainable methods of cultivating crops and livestock (U.S. Environmental Protection Agency, 2021b). In 2018, the United States' agricultural activity alone emitted approximately 698 million metric tons of greenhouse gasses into the atmosphere: 12.3% as carbon dioxide, 36.2% as methane, and 51% as nitrous oxide (U.S. Department of Agriculture, 2020).

When forests are cleared to cultivate row crops, the carbon that is stored in the trees' and plants' biomass is released to the atmosphere as carbon dioxide. Tilling and overturning the soil also releases carbon dioxide into the air. While we tend to focus on carbon dioxide as *the* climate change culprit (since it is the most common human source of greenhouse gasses and persists in the atmosphere for hundreds of years), methane and nitrous oxide are actually much more potent (though they don't persist nearly as long in the atmosphere) because they absorb more heat energy than carbon dioxide. For instance, a molecule of methane is about 28 to 36 times more effective at trapping heat than a molecule of carbon dioxide – evaluated over the first one hundred years in the atmosphere. Methane is released from cattle ranches and dairy farms – quite literally – through cow burps and flatulence when cows are not rotationally grazed on grass. Nitrous oxide is 298 times more potent than carbon dioxide over one hundred years, and is produced as microbes in the soil break down fossil-fuel based synthetic fertilizers and manure that hasn't been aged or composted before being applied to crop fields (Helmenstine, 2020; Borunda, 2019; University of California, n.d.). Information from the EPA shows that 10% of 2019 GHG emissions in the USA came from agriculture, with the top sources including livestock (especially CAFOs), fossil-fuel based synthetic fertilizers and pesticides applied to agricultural fields, and tilling of soil (EPA, 2019). "Nitrous oxide and methane are produced from the decomposition of animal manures under low oxygen conditions. This often occurs when large numbers of animals are kept in a confined area (such as cows, pigs, and chickens kept on Concentrated Animal Feeding Operations – CAFOs), where manure is typically stored in large piles or placed in lagoons" (Ritchie, 2020). In addition to causing nitrous oxide and methane release, the storage of animal manure in large piles or lagoons on CAFOs often also causes pollution to surface waters and groundwater. Nitrous oxide – one of the strongest greenhouse gases – is produced when fossil-fuel based synthetic nitrogen fertilizers are applied to soils. This includes emissions from agricultural soils for all agricultural products – including food for direct human consumption, animal feed, biofuels and other non-food crops like tobacco and cotton (Ritchie, 2020). The use of fossil-fuel based synthetic fertilizers and pesticides contribute both to GHG emissions and to water pollution. Here in our watershed, industrial-style agriculture is the largest source of nutrient pollution to the Potomac River (Potomac Conservancy, 2020).

CLIMATE CHANGE IMPACTS AGRICULTURE AND FISHERIES

AGRICULTURE

While farming impacts the climate, the climate also impacts farming. In a 2008 report to the Maryland Commission on Climate Change, the Department of the Environment's Scientific and Technical Working Group (STWG) advised that the effects of climate change can be both good and bad for farming (Boesch et al., 2008).

CARBON DIOXIDE

For instance, carbon dioxide is an essential ingredient for photosynthesis, a process by which plants turn sunlight into both glucose for growth, and oxygen. Thus, an increase in carbon dioxide may have beneficial effects for some crop species. The STWG explains that "Plants respond differently to elevated carbon dioxide concentrations. **Cold-season and broadleaved weeds and cold-season grain crops, including wheat and barley, respond most dramatically to increased carbon dioxide. An increase of carbon dioxide concentrations to 550 ppm (the lower emissions scenario projection of carbon dioxide levels by late century) could increase the yield of these plants by 10-20%."** Meanwhile, "corn and many summer-weed grasses respond less dramatically to carbon dioxide enrichment, with corn yields increasing less than 10%." **Nevertheless, the stress of rising temperatures on plant reproduction can negate any beneficial effects from increased carbon dioxide** (Boesch et al., 2008).

According to the STWG, studies in Baltimore, Maryland, have found that **invasive weeds grow significantly faster under higher temperatures and carbon dioxide levels**. In fact, invasive weeds respond more to escalated carbon dioxide levels than the cash crops they invade. Because these levels are likely to be experienced within the coming 30-50 years, weed control may become an added challenge for farmers (Boesch et al., 2008).

TEMPERATURE

Additionally, the STWG revealed that crop production and the length of the growing season will increase with the initial rise in temperature. Yet, **while a shorter, milder winter and earlier arrival of the spring bloom may be welcomed, the overwinter survival of pest populations that have historically been killed off by the prolonged cold could also occur. Depending on the species, this could become detrimental to farmers' livelihoods and to the region's food security** (Boesch et al., 2008).

High temperatures can also result in pollination failure as the timing of spring insect hatches and budding are thrown out of sync. Additionally, **livestock animals will be affected through changes in extreme weather events, the frequency and duration of pest outbreaks, wildfire, plant and animal diseases, and anemia, as ticks become more abundant with the warming weather**. Heat stress hinders the ability of cattle and chickens to maintain a consistent body temperature (homeostasis), and as more energy is dedicated to internal heat regulation, less energy becomes available for producing milk or for reproducing and laying eggs (Boesch et al., 2008).

As the climate warms, southern cash crops like cotton will expand north to replace current, cooler-adapted crops. Indeed, the STWG states that "Plants that have an optimum range at cooler temperatures will exhibit significant decreases in yield… For instance, **the projected increase in mean temperature of 2 to 3°F (1.1 to 1.7°C)… could decrease corn and wheat yields by 8-14%." On the other hand, some crops like soybeans that have a broader temperature tolerance range will likely remain unaffected** (Boesch et al., 2008).

DROUGHT

Higher air temperatures cause more water to evaporate from the ground, reducing soil moisture required for seeds to germinate. And, while climate models predict annual precipitation to increase, it will manifest as more extreme weather events (washing away soil rather than seeping into the ground), and precipitation will likely be separated by weeks to months of dry spells, especially during summer and autumn. Thus, **by the latter half of the century, crop production is likely to decrease due to heat stress and lack of water during summer droughts.** "Under these conditions, farmers are likely to increase the use of irrigation—currently, just over 5% of Maryland's crop lands are irrigated—compounding the aquifer drawdown already taking place in some parts of the state," wrote the STWG (Boesch et al., 2008).

According to the Georgetown Climate Center, **"Half of Virginia's counties face higher risks of water shortages by mid-century under hotter, drier conditions**. These same at-risk counties produce $472 million in crops. Therefore, **Virginia farmers' livelihoods and the food supplies grown in these at-risk counties face greater threats from a changing climate"** ("Understanding Virginia's Vulnerability," 2015).

FISHERFOLK ON THE POTOMAC RIVER

Without a doubt, **one of the most iconic cultural symbols of the region is the blue crab**. Found on coffee cups, bumper stickers, and the Maryland driver's license, the blue crab is a staple of the State's identity, economy, environment, and food culture. Since time immemorial until today, the blue crab has been and continues to be an important food source for Indigenous tribes of our region, such as members of the Piscataway tribe, who continue to fish and crab in waterways across the Potomac River watershed, and are advocating for their treaty rights to fish and crab to be honored. Since the early nineteenth century, crabbing has provided stable livelihoods for thousands of families in the Chesapeake Bay area. Fisherfolk, shipbuilders, seafood restaurateurs, tourists, recreational fishers and crabbers were all drawn to what was viewed as an inexhaustible harvest in the region, and communities began to form around this way of life (Kenyon College, 2002).

Maryland Blue Crab, Ocean City MD. Credit: Elizabeth Ramming

Haley Decatur, now in her twenties, grew up on the banks of the Potomac River in a small town called Widewater, which is located in Stafford County, Virginia. "My family has been crabbing on the Potomac River since the late 1800s," she wrote in an email to the Potomac Conservancy. "Back then, there wasn't any other source of income on the Widewater Peninsula – you either farmed, made liquor, or crabbed and fished." She continued, "Some of my earliest memories consist of early mornings, watching the sunrise from the floor of my father's crab boat, wrapped up in the comforter from my bed. At the time, I had no idea that my daycare looked so vastly different from everyone else's."

Photo Credit: Virginia Sea Grant/Flickr

But the local environment has been changing over the past few decades. The Potomac River Report Card states that, **"population growth in suburban and rural areas – and the grey infrastructure to support it – are paving over natural landscapes and streamside forests. Roads, housing, parking lots, and other manmade, impervious surfaces are increasing and as a result, urban polluted runoff is steadily on the rise** (Potomac Conservancy, 2020)." Decatur noted, "When I was growing up, a lot of folks in Widewater were fishing or crabbing to make a living. As the years have gone by, it's become more built up; it's not like it used to be, in that regard." Trash, in particular, has become more of an issue every year, and Decatur often finds it stuck in her crab pots or washed up on shore.

Moreover, **climate change is projected to disrupt the region's blue crab population**. According to the University of Maryland's Center for Environmental Science, water temperatures in the Potomac River and Chesapeake Bay have been warming at an average rate of "0.67 degrees C (1.2 degrees F) per decade since 1985," and these warming trends were found in more than 92% of the Bay's waters – to include the Potomac estuary (University of Maryland Center for Environmental Science, 2015; Ding & Elmore, 2015). **Warming water threatens the existence of eelgrass, a crucial habitat for juvenile blue crabs.** These grasses become stressed when temperatures remain above 30°C (86°F) for long periods of time. Additionally, **the amount of dissolved oxygen in the water diminishes as temperatures warm, creating dead zones underwater where aquatic life cannot flourish** (Rowland, 2015).

Along the Potomac, Decatur has noticed shifts in the river's salinity. "When working on a boat in the water, the working conditions are heavily reliant on the weather. If it is a storm-heavy/rain-heavy season, the work is a lot harder and the crabs are a lot fewer, because the water gets too fresh." The scientific literature unanimously states that precipitation and the frequency of heavy storms is increasing as the climate warms. **"The more rainfall we get, the fresher the water becomes, disrupting the salinity that the crabs prefer. This keeps the crabs south longer, in saltier water, before they migrate up North into the Potomac River," she explained. "Everything is 30 to 40 days behind due to climate change and human disturbance."**

The health of the Potomac River is currently scored at a "B-minus" by the Potomac Conservancy, up from the "D" letter grade it received only 10 years ago. Still, it remains too polluted for safe swimming or for providing wholesome habitat (Potomac Conservancy, 2020). Unfortunately, as society grows more disconnected from our environment, its bruises may not be very apparent. But take it from Decatur: she has had a front row seat to the Potomac River her entire life. **"Truthfully, like a majority of other bodies of water right now, the Potomac River needs our help," Decatur wrote. "Not only with recycling, but reducing our waste in the first place.** Working on the water has really forced me to implement a sustainable way of living in my own life. I am pretty passionate about taking care of our environment, but **I truly think we need to step up our efforts."**

SOLUTIONS: AGRICULTURAL TECHNIQUES THAT REGENERATE NATURAL SYSTEMS, MITIGATE CLIMATE CHANGE, AND PROTECT WATER

While agriculture is currently a major source of the problems of water pollution and climate change due to harmful industrial agriculture practices, agriculture *could* in fact be a major part of the *solution* if we shift from industrial agriculture to agriculture that regenerates natural systems and is locally/regionally controlled. **Agricultural practices that regenerate natural systems (such as, for example, improving the health of the soil and planting food-bearing trees) help both to capture carbon in the soil and improve water quality.** Increasing soil carbon capture can both contribute to removing carbon from the atmosphere, and benefit farmers and ranchers, as it increases soil health and crop yields. Planting trees on farms can provide significant carbon capture and water quality benefits, while also providing shade for livestock, or providing food when fruit and nut bearing trees are planted. Creating and using compost to amend soil increases yields, stores the compost's carbon content in the soil, and also improves rainwater absorption of the soil, both retaining water on-farm to help crops and preventing stormwater runoff into streams and rivers that are the source of the water we drink. (Mulligan et al., 2021)

Agricultural practices and policies that would both lower GHG emissions and improve water quality include encouraging the reduction of and phasing out of fossil-fuel based synthetic fertilizer and pesticide use;

phasing out CAFOs and transitioning to pasture-raised livestock and rotational grazing of animals; re-integrating animals and crops in mutually beneficial systems; treating animal manure as the resource it is rather than as waste; composting animal manure before applying to fields as fertilizer; amending soil with compost; no till farming; bioswales; planting food forests; planting trees on farms to provide shade to livestock and/or create windbreaks to protect crops; planting streamside trees that produce fruit or nuts and protect water quality; use of perennial plants and cover crops to protect the soil; agroecology; and permaculture. Let's take a closer look at these solutions through agricultural practices that regenerate natural systems, protect water, mitigate climate change, produce healthy food, and create ecologically and economically sustainable livelihoods.

AGRICULTURAL BEST MANAGEMENT PRACTICES

"**Everything that happens on the land surrounding the Potomac affects its water quality.** Forested areas are home to the cleanest streams because trees and other plant life stabilize stream banks and naturally filter water before it flows into waterways. Destroying our forests weakens the land's natural defenses and increases pollution from nutrient and sediment runoff," the Potomac Conservancy stated in their 2020 report card. **Agriculture continues to be the largest source of nutrient pollution to the Potomac River.**

"Fortunately, **the use of best management practices (BMPs) in rural areas and on farmlands is slowly reducing the amount of nutrient pollutants entering the Potomac**," the Potomac Conservancy wrote. **Still, stronger efforts are needed.** Examples of **BMPs include creating riparian forest buffers by protecting and planting streamside trees, streamside fencing to keep livestock out of the forest buffer area and/or out of waterways, eliminating or reducing use of fossil-fuel based synthetic fertilizers and pesticides, no-till agriculture, amending soil with compost, restoring waterways, and cover cropping.** The calculated use of cover crops can control erosion by preventing wind and water from channeling soil into nearby streams. They also absorb extra nutrients, suppress weeds, and build up beneficial organic matter within the soil. Cereal rye, oats, and winter wheat grow well here in the Potomac region (Anne Arundel Soil Conservation District, 2018). Next, we will highlight one farmer in the Potomac River Watershed who is utilizing BMPs on his cattle farm, and discuss rotational grazing, one beneficial agricultural BMP.

SUNNY ACRES FARM

John Venskoske is a great example of a local farmer using BMPs to protect the health of lands and waters in our region. He owns a cattle farm called "Sunny Acres" in Frederick County, Virginia. "In 1947, we moved down here from Wheeling, West Virginia," Venskoske said in an interview with the Potomac Conservancy. "We had sheep, cattle, pigs, chickens – everything, you know – milk cows and beef cows… My dad was very conservation enthused, so we had a lot of ditching done." Drainage ditches help filter stormwater runoff and improve water quality while also providing a source of water for livestock (Anne Arundel Soil Conservation District, 2018). "We had ponds dug for water, three ponds dug, made for cattle water. And some of the lowland we had ditched, through government help, for drainage… I thought it was a good idea," he said. **"Two concerns of mine are clean water forever… and a place to grow our food."**

Through their waste, cattle can add large amounts of nutrients to local waterways, stressing the health of the entire system. Ditching ponds for cattle is a better alternative than allowing them to browse free-flowing water like streams or creeks. About **16 years ago, Venskoske contacted the Lord Fairfax Soil & Water Conservation District to discuss how to improve the water quality of Back Creek, a 60-mile-long tributary of the Potomac River which runs through his farm. The district worked with him to implement many soil and water conservation practices**, such as enhancing vegetation buffers that reduce runoff, thereby keeping the soil and its valuable nutrients on the farm's fields and out of Back Creek.

Over the years, Venskoske has added to his conservation measures. He has since placed Sunny Acres into a conservation easement to protect his land and the water that runs through it from development. According to the Potomac Conservancy, "protecting land in its natural condition is a long-term investment in the health of the Potomac." This can be done through conservation easements on private lands or through the creation of public parks or wildlife refuges. "Overall, land protection efforts in the Potomac region, from federal to local programs, are to be celebrated. Over 3.5 million acres, or 37% of total land area, are considered protected from development according to the Chesapeake Bay Program Partnership's Protected Lands Database. The EPA established a Bay-wide land conservation goal of 20% which the Potomac basin is far exceeding," the Potomac Conservancy wrote in its latest report card (Potomac Conservancy, 2020).

By entering into the conservation easement, Venskoske committed to completely exclude his cattle from Back Creek. The project was completed in 2014, and involved **fencing out his livestock from the stream and his pond, installing a new water system for his cattle, and creating a 35-foot riparian (tree and vegetation) buffer on each side of the creek.** "So, you know, now I've got two cattle crossings – one I put in ten or twelve years ago, and one I put in about six or eight years ago… so that the cows can't drink out of the creek anymore except when they're crossing it," Venskoske said. Cattle crossings provide controlled access for livestock to cross a stream, reducing streambank erosion and preventing nutrients and sediment from entering the water. Venskoske has protected a total of 6,150 feet of stream bank along Back Creek.

"And then, in this buffer along the creek, we planted trees. Oh, I don't know, we did like four-hundred-and-some trees around the one pond that I fenced off, and the creek," Venskoske added. **These streamside trees include a diverse arrangement of native, hardwood trees that further decrease the amount of soil erosion, sediment flow, and nutrient runoff into the creek. The streamside trees also sequester carbon from the atmosphere, filter and clean water before it enters the creek, and, once the walnut trees reach maturity, they'll also provide a source of food for Venskoske and his family.**

ROTATIONAL GRAZING

The United Nations estimates that livestock generate 14.5% of global greenhouse gas emissions (over half of the total agricultural emissions), and that cattle are responsible for more emissions than any other livestock animal (Food and Agricultural Organization, 2013). This is a result of both methane released from cow flatulence and carbon dioxide released when cows are not rotated on pasture.

First, the subject of cow flatulence: cows are ruminants, meaning they are designed to eat grass, not corn. However, they are fed corn and other grain fillers because it's cheaper – in particular because in the U.S., corn is subsidized by our government. It should come as no surprise, then, that a cow's gut cannot process corn as effectively as pasture grasses, creating a "bad case of industry indigestion," as Mother Earth News puts it. And rather than attempting to fix the cow flatulence issue by adding all kinds of supplements or fish oils to the equation, Mother Earth News writes that, "the better solution to the 'emissions' problem may also be the simplest: cows eat grass, emit less methane." In fact, scientists from Groupe Danone, the makers of Dannon yogurt, found that, "when they added omega-3-rich grasses to their feed year-round, the cows not only released less methane, but also produced about 10% more milk." These omega-3-rich grasses include plants like alfalfa and flax (Kimble-Evans, 2011).

On the other hand, cows that do feed in pasture can release carbon stores if they are permitted to eat the grass down to the ground. **Rotational grazing is one BMP that can help farmers decrease emissions from livestock, and also regenerate the soil. If cows are rotated between different areas of pasture, the health of the grass and soil can be preserved and even enhanced over the long run.** Meanwhile, carbon is kept in the ground instead of being released to the atmosphere. Moreover, with a rotational grazing system, there is no need to artificially fertilize the grass – the cows will do it, and their manure will be free of dietary additives.

One article from Michigan State University stated: "One [2017] study found that farms participating in sustainable agriculture practices like rotational grazing produced 19% fewer emissions than non-participating farms in the first two years, dropping to 35% fewer emissions after participating for longer than two years" (Michigan State University, 2018). Fortunately, many farmers in the watershed have adopted rotational grazing BMPs.

AGROECOLOGY

In the 1980s, agroecology, an ecological approach to agriculture, emerged as part of a rural social movement for food sovereignty, originating with peasant and indigenous agriculture in Latin America. According to master's research by Emmalee Aman and Jamie Pratt, these movements **grew throughout the 1990s, "building networks of farmers devoted to changing the social, political, cultural, and economic contexts that currently foster the growth of industrial agriculture and corporate control of food production"** (Aman & Pratt, 2014).

Agroecology incorporates elements of traditional ecological knowledge (TEK) and modern agriculture science to provide a sustainable and comprehensive method for producing resilient farming systems. TEK refers to the ever-evolving wisdom gained by indigenous and locally rooted peoples over hundreds of years by means of direct contact with their environment. The U.S. Fish and Wildlife Service explains that, **"this knowledge is specific to a location and includes the relationships between plants, animals, natural phenomena, landscapes, human beings, and timing of events that are used for lifeways," like agriculture or hunting and trapping** (Rinkevich et al., 2011).

The application of such traditional ecological concepts to farming does not require much outside input for achieving crop productivity. Agroecology does not depend upon chemical fertilizers or pesticides, as manure, compost, and cover crops deliver all the nutrients required to build healthy soil. "Planting is done in rotation with cover crops, incorporates plants that attract pollinators and pest predators, and benefits from integration with projects in animal husbandry. The system is biodiverse and resources like water and minerals are replenished with use" (Aman & Pratt, 2014). **Building biodiversity of soil microbes and including diverse plant genetics reduces a farm's vulnerability to pest outbreaks, superbugs, and extreme weather events fostered by climate change.**

FULL CELLAR FARM

The following story, from Aman and Pratt's research, is an example of how a local farmer in the Potomac River watershed transitioned from conventional farming to agroecological farming to leave the farm healthy and productive for future generations and to provide his family and community with healthy food. He also made the switch to agroecological growing to be more financially self-sustaining, and not depend on government subsidies to grow commodity crops that exhaust the soil:

Kip Kelley is the founder and owner of Full Cellar Farm in Jefferson, Maryland, in Frederick County about one hour's drive outside of Washington, D.C.

Since 2011, Kip has been transitioning 30 acres of his father-in-law's hilly land from commodity crops to a diversified, sustainable system. Together with his wife Sarah and three farm hands, Jimmy, James and Joe, Kip grows 20 acres of vegetables, 4 acres of hay, and 6 acres of chickens, turkey, and pigs in an integrated fashion. **Full Cellar Farm has diversified its income stream through selling at farmers' markets, a CSA, and wholesale.** Full Cellar Farm makes a point to sell at farmers' markets that accept SNAP (food stamps) and to sell wholesale to "Fresh Stops" that sell produce shares on a sliding scale. The goal in targeting these markets is to enable all community members to afford to eat healthy food.

Kip and his wife Sarah strive to keep their soil, water resources, crops, and animals healthy. The farm is not

certified organic, but most of the practices comply with the National Certified Organic program and follow agroecological principles. No synthetic or chemical fertilizers, pesticides, or herbicides are used. Instead, cover crops are used to prevent erosion and for nitrogen fixation, crop rotation keeps soil productivity high, and compost or composted chicken manure from the flocks kept on the farm fertilize fields. Drip irrigation has been installed throughout the fields to use water efficiently, and plants that attract beneficial insects that help with pollination and pest control compliment rows of vegetable crops. Kip is dedicated to a style of farming which cares for both the land and the larger community.

Kip stated that an agroecological style of farming has given him business security, because he's able to sell to a wide variety of people rather than only one or two grain elevators. He also feels **the farm is "over marketed" for vegetables and eggs and can't fully meet the demand for these products from a growing base of customers**. Kip appreciates that he has been able to establish friendships with his customers and to provide people with jobs. With more laborers on the farm, the land is better taken care of and the farm is really 'a place rather than just a property.' (Aman & Pratt, 2014)

Today, many community members wish to nurture their bodies and families with chemical-free foods and to protect our environment from harmful industrial agriculture practices. This trend in customer demand is changing how we think about food in the United States – leading to a promising new frontier for agroecology (Aman & Pratt, 2014).

PERMACULTURE

Permaculture is the second face of the same agroecology coin. Permaculture refers to the way we consciously *design* an agroecological system, which differs from conventional industrial agriculture in that it avoids the adverse social and environmental impacts of input-intensive farming (Tallarico, n.d.).

"It's just diversifying and really working with the plants to bring in the balance that's needed," said **Michael Judd, founder and principal designer of Ecologia Design in Frederick County Maryland**, a company focused on bringing edible and ecological landscapes to our region. "And then of course, **selecting the right species to grow makes a big difference too in the low input. So no, there's no reason for herbicides. There's no reason for pesticides,"** he said.

Can you imagine a world without synthetic fertilizers or pesticides? Most industrial farming operations can't, but that's because large fields of one crop – corn, wheat, soy... etc. – planted year after year, drain the soil of essential nutrients and lack the genetic diversity to fight diseases and pests; so consequently, they require the help of artificial additives. **"In the US alone, 324 million kg of 600 different types of pesticides are used annually, causing environmental and social costs reaching about $8 billion each year"** (qtd. in Aman & Pratt, 2014).

"Those are a lack of good design. **If you're using chemicals, you're lacking design**," Judd said.

Nearly twenty-five years ago, Judd was living in San Cristóbal de las Casas, located in the Central Highlands of the Southern Mexican state of Chiapas, when he unintentionally met an indigenous member of the Lacandon Mayan tribe. The Lacandon are the last of the Mayans who escaped the Conquistadors' forced Christianity by hiding in the heart of the jungle. For the last five hundred years, they've lived very simply and have kept their borders closed to outsiders. Their population consists of about six or seven hundred people now. "I followed him, and we finally started gesticulating and talking, and I realized that he was coming out of the jungle because he was quite sick," Judd explained (Reid, 2017).

The Lacandon rainforest spills across the Usumacinta River into Guatemala, but the jungle is disappearing due to cattle farming and logging: only about 10% of it remains intact. "It sounded like parasites, things in the stomach, because the forest had been getting cut and their natural spread out form of living had become concentrated more and more and more. So the cycles, the sanitary cycles were different," Judd said. "Anyway, I said I think I can maybe help, thinking of a compost toilet… I can do something that would help contain the human feces and things."

Judd continued: "And he said 'okay,' and we went back up through this old dry riverbed for like four days into the heart of the jungle. Very few outsiders would come in, but they accepted me here, on a neutral piece of ground, and they said 'okay, you can build a compost toilet.'"

That experience changed Judd's life. "All of a sudden, I was living in this human habitat, that was also the jungle, and what – at first – just looked like a jungle. **After living with the Lacandon, I got to see how they interacted with the forest, and how they harvested their foods, their medicines, their fibers, you know, just how they integrated their lives by living with this dynamic perennial system.** And it blew my mind to see that we, as humans, as a species, can do this," Judd said. He had not studied permaculture or environmental sciences prior to this experience, but he said, "coming back out of the jungle and looking at the world anew, I could see how devastated [the world has] become agriculturally and industrially. You know, all these things now had a different understanding to me." **He saw that another way of living was possible.**

Once back in the States, Judd visited Earthaven Ecovillage, a permaculture community outside of Black Mountain, North Carolina, that was applying the same types of Traditional Ecological Knowledge that he had just experienced with the Lacandon Mayan tribe, but in the context of the United States. "So, it was this wonderful marriage of learning and working with indigenous peoples, and then coming back and discovering permaculture and weaving the two together," Judd explained.

Judd then lived in rural Nicaragua, where he started a few nonprofits focused on food security, and he'd go back and forth between the rural countryside of Nicaragua and New York City. After a while, he moved to the Catskills, to the Sivananda Ashram Yoga Ranch, where he helped start their practice of permaculture. Judd finally returned to his hometown in Frederick County, Maryland about ten years ago. He's since created a business, Ecologia: Edible and Ecological Landscapes, that tailors what he's learned from TEK and permaculture to fit the culture and ecology of the Potomac River Watershed. He helps individuals and homeowners' associations transform their urban and suburban yards into functional, beautiful, edible whole-systems that are patterned after natural systems and targeted toward site-specific landscape needs.

DESIGN EXAMPLES

FOOD SECURE SPECIES

Permaculture bodes quite well as a mitigating solution for climate change because it is efficient and resourceful. Its design boasts "low input for high output" species, meaning that permaculture utilizes what is already growing well naturally in the environment, rather than using plants that require added attention. "So, for us in our region, fruit wise, that would be pawpaw trees, persimmon trees, elderberry bushes, blackberry bushes; they do really well naturally so it wouldn't take a lot of effort to get great returns from them." In fact, the pawpaw (Asimina triloba) is the largest edible fruit indigenous to the United States. Pawpaw trees grow well along streams, and would be an excellent choice when looking to plant native food-producing streamside buffer trees. They are an adaptive species, and likely to remain a secure (and delicious) food source as the climate warms.

Two years ago, Judd co-created a nonprofit in Maryland called SilvoCulture, which is largely focused on planting **nut trees, another "low input for high output" family of plants**. "You've got the black walnut which does really well. The hybrid chestnuts do really well in our region… hickories, pecan – which is a [species of] Hickory," he said. Judd explained that, after all of his experiences, he believes nut trees will have the best benefit for all beings in the future, "And that, to me, is because they are long lived. **They live hundreds of years. They produce oils, fats, carbohydrates. They are really one of the most secure foods for many forms of life, not just humans.** So when I look into the uncertain future, I think, what might really stay and make a difference? And it's nut trees."

These types of food-producing perennial plants are largely self-sufficient; they do not need much tending to and they don't require the input of fossil-fuel based chemical fertilizers or pesticides. They can help take the pressure off of conventional agriculture, reducing climate change by reducing emissions. **The more food we produce locally, and regeneratively, the more we will be able to reduce the consumption of foods produced from extractive industrialized food systems, and the more we cut down emissions from transporting produce.**

Now, conservationists talk a lot about non-native species and how destructive they can become to the natural environment should they take over native plant habitat and become invasive. This is an extremely valid and urgent concern. But Judd provides a different perspective: "I don't subscribe to human made definitions about plants. I learn from plants; they are my guides. I watch and I learn from them and I see how they interact with their environment, and how their environment interacts with them. I also observe how our environment is rapidly changing and… how the plants, in Mother Nature, are responding to that change."

Indeed, we humans alter the land, exponentially grow our population, and dump pollutants and spew heat-trapping gasses into the atmosphere – and the Earth responds. Mother Nature responds. Some might call this survival of the fittest, or evolution by natural selection. "And I'm trying to follow those patterns, and learn from those patterns, not reject those patterns. The more we reject, the more we stay where we are. We're in the past while everything keeps moving forward. As a species, we need to look at how we start pairing plant species and moving forward quickly with the rapid change that's occurring. Nothing's invasive if you use it responsibly," Judd proposes. This is not to say we shouldn't try to maintain native plant diversity; but as far as food security goes, it might not hurt to incorporate productive, and adaptive species into our climate-smart agricultural management.

FOOD FORESTS

Food forests are a great example of how we can implement permaculture design to create low-input, high-output systems. "Now I should say that a food forest is not growing food *in* the forest. It's **growing food *like* the forest**. So, usually this is going to be on our lawn, in open sun," Judd explained. **Food forests are small patches, where an entire ecosystem is created** around a specific species. For example, if you plant a fruit or nut tree, you would then plant companion species that bring in beneficial insects to help balance the insect ecology and increase pollination. You would plant species that fix nitrogen in their roots. You would plant species that, when they die, they mulch the surface and feed the whole system.

"So instead of just planting your fruit tree out there [alone] with some mulching - which is going to make it very susceptible to disease, weeds, everything else - we create a patch… [with] these little companion groups to create a little food forest," Judd said. In effect, **food forests function as an ecosystem, providing the same types of beneficial services as a "real" forest: They increase pollination, decrease pests, create habitat, build up healthy soil, store carbon, filter air, filter and clean water, and remove pollutants from the environment, all while providing food for people and wildlife.**

WATER AS A RESOURCE

Permaculture works closely with water: by using good design, we can passively harvest water for alternative uses within our immediate landscape, while simultaneously preventing water damage to built structures. It is within this context that Ecologia Design assists its clients. “Here you’ve got water moving too quickly,” Judd demonstrates. “It’s going towards your house foundation. Let’s move that over to the side and then let’s capture it. And then let’s use that for a garden. Or, let’s use that for more fruit tree plantings, or berries,” he proposes. “I read the landscape and then I read the people, and ask ‘where do they overlap?’”

Bioswales, terracing, rain gardens, and other water-focused designs help to hold more moisture in the soil rather than allowing precipitation to run off. Judd explained that this “builds healthy soil and increases organic matter, which then sequesters more carbon [from the atmosphere],” helping to mitigate climate change. Moreover, water that seeps into the ground becomes filtered by soil microbes before re-entering the water table. Thus, **pollutants become effectively removed from waterways**.

The Potomac Watershed is predicted to see heavier rainfall, longer droughts, and more frequent storms as the climate changes. Bioswales are very resilient to these events. “They’ll help deal with increased rain. They’ll help deal with decreased rain. Whether it’s drought or flood, these systems are designed to slow, spread, and sink water into the ground so that we’re holding more in our soils, rather than seeing stormwater runoff,” Judd explained. “Grass is like green concrete. If you watch in a heavy rain, very little is absorbed. There’s not much organic matter. There’s not much soil depth for the water to even [sink] into on lawns, so it literally saturates very quickly and then sheets off,” he said. By designing a bioswale to follow the contour of the ground – like a mini terrace – water is not directed anywhere. Rather, it stops in its tracks and has a chance to sink into the soil, hydrating the water table the whole way down the slope. “And it begins to dramatically change the soil ecology, and thus the growth from that soil,” Judd added.

TAKE ACTION THROUGH DESIGN

As exemplified, **good design can revolutionize the health of any landscape, making our region more food and water-secure while helping to mitigate climate change.** Everyday residents of the watershed can practice permaculture at home “and ideally, you’ve got entire neighborhoods that work together on a collective design so that water is not building up,” said Judd.

SMALL BIOSWALE

A small bioswale, for instance, is quite simple and effective at removing toxins from the water, especially in the summer when it rains significantly. Most rooftops carry toxins, so if you insert a small bioswale just downslope of your downspout, and then add wood chips in the basin to attract fungi, water will collect and be filtered through the mycelium. The fungi will digest and neutralize those chemicals – even petrochemicals – preventing the pollution of nearby waterways and soil. “It’s such a win win win,” Judd exclaimed. “It’s very straightforward and very effective, and it’s something that we can all do individually. You know, if you’ve got a roof and you’ve got a downspout, there’s something you can do.”

PERENNIAL HABITAT

Planting perennial habitat is another great example of a simple, mitigative solution that individuals can tackle at home or in community. **Perennial habitat refers to longer lived plants and trees that will thrive for years and be productive without the need for much pruning or for artificial fertilizers or pesticides. “A fruit tree or a nut tree is going to feed all kinds of life, not just humans… It’s food, that’s what we all need. The whole ecosystem needs food. It needs to be fed,” Judd concluded.**

SOCIETY

CLIMATE AND ENVIRONMENTAL JUSTICE

The climate change crisis is not purely environmental or physical in nature. It is a problem that is so inextricably intertwined into the core issues of every global society and one that has no single culprit, and thus, no single solution. Here, we will look at climate change through the lens of ethics and morality, crossing the disciplines into the sociopolitical realm. We find **the burdens of climate change do not fall equally** amongst the population, making **this 'seemingly environmental' issue one that is inherently a social justice issue as well**. Because we are one with our environment, polluting the Earth pollutes people. Yet, **the people polluted most are those that society has marginalized – through institutionalized racism and economic hierarchy** – and valued least. In sum, environmental issues are social issues, and **a healthy environment is crucial for achieving social equity** (Munk, 2018).

ENVIRONMENTAL JUSTICE MOVEMENT

In the early 1980s, "environmental justice" (EJ) emerged as a concept of public concern in the United States. The movement that followed began as a reaction to the close proximity of toxic waste sites to communities of color, and as the movement grew, activists and academics used social justice principles – such as equity, human rights, access, and participation – to reframe the way we think about environmental issues (Munk, 2018). **The environmental justice movement brings attention to and tries to correct the fact that throughout the USA, communities of color and low-income communities are statistically more likely to have environmental burdens sited near them, and less likely to have access to environmental benefits.**

Many pinpoint the disaster at Love Canal as the beginning of a sequence of events that would spark environmental justice movements across the country. Love Canal, a town in New York, had been exposed to the dumping of tons of toxic waste in an abandoned canal from 1942-1953, causing unexplainable illnesses among its community members, along with chemicals leaching into backyards and local waterways in the late 1970s. Following these events, in 1978 President Carter declared Love Canal a federal health emergency and in 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act, known as the Superfund Act, which allows the U.S. Environmental Protection Agency (EPA) to investigate hazardous threats to public health and the environment. The Superfund Act called for a special tax on petroleum and chemical industries, which provided funds for the EPA's Superfund through 1995. In 1982, the EPA used the Superfund to clean up 60,000 tons of toxic soil from waste dumped along the highways of North Carolina in the late '70s by a company attempting to skirt requirements of the 1976 Toxic Substances Control Act, which made toxic waste dumping more expensive and required contaminated soil to be put in a landfill (Reimann, 2017; Kleiman, n.d.; U.S. Environmental Protection Agency, 2021a).

But, "Where does one put a heap of toxic earth, laced with a chemical *polychlorinated biphenyls (PCBs)* reputed to cause birth defects, skin and liver problems, and cancer?," posed one story from the Timeline blog at *Medium*. "The North Carolina government decided *to dump the 60,000 tons of toxic soil laced with PCBs* on politically neglected Warren County, North Carolina — the population of which was 65% Black. It ranked 97th of 100 for gross domestic product (GDP) value by county statewide. As of the 1970 census, 40% of the county's homes lacked indoor plumbing." The six-week protest that ensued was considered by Duke University to be "the largest act of civil disobedience in the South since Dr. Martin Luther King, Jr., marched through Alabama." Protesters were peaceful as they marched, held signs, and laid in the road to prevent the dump trucks from unloading their PCB-ridden soil in Warren County. Over 500 people were

arrested. It was this controversy that spurred environmental justice into an organized national movement (Reimann, 2017).

Across the US, people living in frontline environmental justice (EJ) communities routinely have higher levels of cancer – and in Louisiana, cancer is so prevalent from the high concentration of petrochemical operations that the 85-mile corridor along the Mississippi River between Baton Rouge and New Orleans has been nicknamed "Cancer Alley." **Frontline EJ communities also suffer most from asthma attacks due to the high levels of combustion byproducts being spewed into their air.** This includes particulate matter and volatile organic compounds (VOCs) like benzene and toluene, as well as plastic related pollution. What goes up must come down, and as pollutants settle in our air, water and soil, they can mutate DNA, impact reproduction and development, and cause other respiratory and skin illnesses. Moreover, many of these pollutants are greenhouse gasses, compounding the effects of climate change on our planet. **Climate change itself also disproportionately impacts communities of color and lower income communities.**

CLIMATE JUSTICE

Climate change is, in itself, an environmental justice issue because poor communities and communities of color across the globe and in the USA are disproportionately affected by the impacts of climate change. Internationally, the wealthiest countries emit the most carbon dioxide, and thus have the largest carbon footprints. But the poorest countries that contribute very little to global emission – such as small island nations like the Maldives and Fiji, coastal nations like Bangladesh and Vietnam, glacial-laden nations like Nepal and Tibet, and drought-prone countries such as those in Sub-Saharan Africa – feel the greatest impacts of sea level rise, melting icepack, extreme heat, and drought from climate change. Similarly, here in the U.S., high-income and White households typically have a higher carbon footprint, yet **the poor and people of color are impacted most by extreme weather events and air pollution** (Munk, 2018).

According to a new peer-reviewed study published in *Environmental Research,* **air pollution from burning fossil fuels (coal, natural gas, gasoline, diesel) is creating a public health emergency not only through fueling the climate crisis, but also caused about 8.7 million premature deaths globally in 2018**. That's more than HIV, tuberculosis, and malaria combined, and **accounts for nearly one out of every five deaths worldwide** – twice as many as previously thought. Overall, most of these deaths occurred in China and India. However, Western Europe, Southeast Asia, and parts of the U.S. Northeast and Midwest were hit hard too. According to a Natural Resources Defense Council (NRDC) article, Dr. Neelu Tummala, an ear, nose, and throat physician at George Washington University School of Medicine and Health Sciences, recently told *The Guardian*: "The air we breathe impacts everyone's health but particularly children, older individuals, those on low incomes, and people of color. Usually people in urban areas have the worst impacts" (Chaisson, 2021).

Over the past decade, the term "climate justice" has become more prevalent in U.S. news media (Munk, 2018). Climate justice begins with the idea that the adverse impacts of a changing climate are not felt equitably among people. A 2020 Yale Climate Connections article summarizes it perfectly: **"Low-income communities, people of color, indigenous people, people with disabilities, older or very young people, women – all can be more susceptible to risks posed by climate impacts like raging storms and floods, increasing wildfire, severe heat, poor air quality, access to food and water, and disappearing shorelines."** Undoubtedly, there is a direct correlation between civil rights and climate change (Simmons, 2020). **Research continues to demonstrate that the very same processes that are degrading the Earth and its systems are also exploiting low-income, indigenous, and communities of color.**

This is not coincidental. This is not happenstance. **This is the result of a western capitalist philosophy mixed with institutionalized racism: the result of a long history of policy and legislation designed explicitly to benefit White communities** (Cho, 2020).

To better understand *why* people of color and the poor are most affected by climate change and to explore specific actions toward climate justice in the Potomac River Watershed, we discussed the issue with one of the regional leaders of the environmental justice movement in the DMV, Dr. Sacoby Wilson.

Dr. Sacoby Wilson is an Associate Professor with the Maryland Institute for Applied Environmental Health at the University of Maryland (UMD), College Park's School of Public Health. He is also a member of the U.S. EPA National Environmental Justice Advisory Council, sits on the boards of both the Citizen Science Association and the Patuxent Riverkeeper, is Editor-in-Chief of *Environmental Justice*, a former board member of Community Campus Partnerships for Health, a Co-Founder of the DMV Environmental Justice Coalition and Founder of 17 for Peace and Justice, an environmental justice advocacy organization.

In an interview with the Potomac Conservancy, Dr. Sacoby Wilson explained how U.S. history and policy led to and continues to contribute to the disproportionate impacts of climate change on communities of color and poor folks. First, we have to look at how the United States as a country was established through the theft of Indigenous land and the enslavement of Black people. Then, we have to look at slavery: after the Emancipation Proclamation and the events leading to Juneteenth, Black folks migrated and settled in places near where they were formerly enslaved. "And unfortunately, after they were free, many of those Black folks, because they were not allowed to live in the White towns, had to settle in areas that were in the floodplain, in the flood zone, in the swamp," Dr. Wilson said. "Now fast forward to 2021," he continued, "that settlement pattern speaks to who's at risk from flooding associated with climate change and hurricanes."

"Because of climate change, we're seeing more frequent, more intense hurricanes," said Dr. Wilson. "Look at what happened with Hurricane Katrina. Who was disproportionately impacted by Katrina? Well, a lot of folks of color, and low-wealth folks.... And New Orleans was highly segregated pre-Katrina. So, a lot of the wealthier White folks lived in higher elevation areas. Folks of color who were poor lived in lower elevation areas. Who was most impacted? Folks who were in lower elevation."

The same was true for Hurricane Harvey a few years ago. "It dumped 33 trillion gallons of rain in Houston. The Houston Ship Channel is one of the world's largest petrochemical corridors. Who lives permanently by that and is disproportionately impacted by those petrochemicals? Low-wealth folks, Latinx folks, Black folks, right? You know, a lot of people were impacted by Harvey. But the folks who were most impacted were people who are economically and socially vulnerable. People living in the hazards."

Historically, economic investment further exacerbated the impacts of climate change on communities of color. Again, let's rewind – this time to the 1930s and '40s. The Home Owners' Loan Corporation (HOLC), established in 1933, developed a neighborhood mortgage rating system which was soon adopted by the Federal Housing Administration (FHA), established in 1934. This system sectioned off neighborhoods based on race and ethnicity. So, White neighborhoods were placed in the green zone. They could easily acquire loans from the bank to fix up their existing homes and purchase new ones. Black, Indigenous, and People of Color (BIPOC) neighborhoods – regardless of wealth – were placed in red zones "redlined" and were unable to acquire loans because the HOLC and FHA considered them too risky to loan to. The banks assumed they wouldn't be able to pay back their loans, so BIPOC communities did not receive many investments ("Home Owners Loan Corporation," n.d.).

Here in the Potomac River Watershed, the impacts felt by climate change are not so much hurricane related as they are heat related. "The White neighborhoods that were not redlined, they got service investments, ecological amenities like trees, tree canopy, greenspace, green infrastructure," Dr. Wilson noted. Meanwhile, the redlined communities didn't have investments to plant trees or greenspaces. Moreover, "... **we built a lot of highways through Black and Brown communities. While White communities got a lot of trees and greenspace, communities of color got a lot of impervious surface.** So you have more concrete. You have more asphalt. What do concrete and asphalt do? They absorb heat. And they re-release that heat during the day and at nighttime," **creating what's known as the urban heat island effect**.

Fast forward to today. **“A recent study found that there’s an 8 degree Fahrenheit difference in temperature between redlined versus non-redlined areas,” said Dr. Wilson. Additionally, “because of the temperature trend with climate change, we’re getting record breaking temperatures, record breaking heat**, record breaking high heat days, more heat waves. So you already have more people of color in urban heat islands. And then you have increasing temperature and heat waves. I like to say, ‘heat waves are hell for the poor and the elderly.’”

Segregation wasn’t just driven by housing loans, but also by racial covenants, such as the G.I. bill. This bill, signed into law by President FDR in 1944, provided numerous benefits to returning World War II veterans. It provided people the opportunity to get their education and start the process of the American Dream. “The GI Bill was one of the biggest, most positive social programs in the history of the country… but those grants disproportionately went to White returning veterans, not people of color who also fought in WWII,” explained Dr. Wilson.

“And so this all informs today: areas that have poor housing infrastructure, too many impervious surfaces, poor sewer and water infrastructure, not enough trees, no tree canopy, limited greenspace. Past is prologue, right? **What’s happened in the past impacts the conditions and the risk that we see in communities of color now because of past policy.** It’s embedded racism in our housing policies, in our educational policies, in our economic policies, in our planning and zoning policies. Those things are all connected to the reason why some communities have higher risks related to climate change,” Wilson said. **This disproportionate burden is the result of not only our racist past (including intentional redlining), but also current permitting, zoning, and enforcement decisions that turn a blind eye to where pollution flows and who is exposed to it, and lack consideration of cumulative impacts.**

CEEJH LABORATORY

In 2011, Dr. Sacoby Wilson established the Community Engagement, Environmental Justice and Health (CEEJH) Laboratory at the University of Maryland (UMD) in College Park, Maryland. As stated on UMD’s website, the CEEJH Lab is focused on “providing technical assistance and research support to communities fighting against environmental injustice and environmental health disparities in the DMV [DC/Maryland/Virginia] region and across the nation.”

During the interview, Dr. Wilson explained that **CEEJH Lab is solutions-based. It is a science clinic that is action oriented and focused on getting science into the hands of the people in order to empower them to address their local environmental and health issues.** Furthermore, the lab helps advocate for “community science” by training community members how to collect their own environmental data using smartphone applications.

One huge focus of the CEEJH Lab’s research is air quality monitoring and building networks of hyper-local air quality monitors using local sensors. “We are building a network in Cheverly, Maryland, where now we’ve got some funding from Prince George’s County, the County Council, to build a network across all of Prince George’s County,” Dr. Wilson said. “We are starting to partner with the Maryland Department of Environment to do some co-location, to co-locate our sensors with their regulatory monitors.”

Air quality monitoring is important because many communities in the region have poor air quality due to industry and traffic – especially in the Washington, D.C. metropolitan area where commuter traffic is common. Highways and byways disproportionately run through communities of color and low-wealth communities, causing the air to become saturated with combustion byproducts that pose numerous environmental and human health risks. These include greenhouse gasses, particulate matter and volatile organic compounds, such as black carbon. Black carbon is emitted from coal-fired power plants and from diesel exhaust, and it contains harmful substances called polycyclic aromatic hydrocarbons (PAHs) which occur naturally in coal, crude oil, tar, and gasoline. PAHs can cause cataracts, kidney and liver damage, asthma and other respiratory problems, DNA mutations, and even lung cancer (Moorthy et al., 2015).

Another major CEEJH Lab project has been to work with the Center for Geospatial Information Science Team on UMD's campus to build geospatial tools that map communities that have environmental justice issues and also target resources. **One tool CEEJH Lab developed is called the MD EJSCREEN. "It is similar to the U.S. EPA EJSCREEN tool, but it's focused on Maryland," Dr. Wilson said.**

Using EJSCREEN, "you can locate who has the EJ (environmental justice) issues, see who's most impacted by climate injustice, right, and then have the *resources* to invest. You know they'll go from *unjust* sustainability to *just* sustainability. They'll go from *unjust* housing to *just* housing. *Unjust* mass transit to *just* transit. *Unjust* food infrastructure to *just* food infrastructure. *Unjust* green infrastructure to *just* green infrastructure. *Unjust* food and water infrastructure to, you know, *just*. To make that happen, you have to *invest* in those communities," he said.

"By investing in environmental justice communities, you help to ameliorate or address some of the exposure to health issues. Those investments could also make up for the years of communities being disinvested. It also may help with addressing the community impacts, like aggregate impacts of being dumped on for years. Some communities have had pollution for decades upon decades, and how has that impacted their health? How has it impacted the economic opportunity of those communities? How has it impacted the educational opportunity and the ability for folks to reach their full potential? **When you're exposed to pollution, that puts a cap on your potential,"** Dr. Wilson continued. "So, I'm really excited about those tools."

EXAMPLES OF EJ COMMUNITIES IN THE POTOMAC WATERSHED

Let's take a look at a few frontline environmental and climate justice communities in the Potomac River Watershed who are fighting for their human right to a healthy environment.

BLADENSBURG, MARYLAND

Bladensburg is a community located in Prince George's County, Maryland, whose population is predominantly African American and Latinx. They are also the second poorest Zip Code in Prince George's county, and seventh poorest ZIP Code in all of Maryland ("Map of 25," 2021). In addition to hosting a lot of industry – such as a school bus depot, a trash company, and the Ernest Maier, Inc. concrete block plant – Bladensburg is also traversed by loads of commuter traffic going to and from Washington, D.C. and the University of Maryland, College Park campus (Maryland Institute for Applied Environmental Health, 2019b).

Credit: Audrey Ramming / Potomac Conservancy

The Ernest Maier, Inc. concrete block plant has requested a special exception permit that would allow the construction of a new concrete batching plant on its property. However, many residents are opposed to this expansion because it would threaten public health and safety by increasing stormwater runoff, air and noise pollution, and traffic congestion. Moreover, many kids in the area walk to school amongst all this

traffic and industry, and are exposed to combustion byproducts such as nitrogen dioxide (an ingredient in the creation of tropospheric ozone, which is a greenhouse gas), particulate matter (PM), and many volatile organic compounds (VOCs) that can contribute to asthma and other more serious health conditions (Maryland Institute for Applied Environmental Health, 2019b).

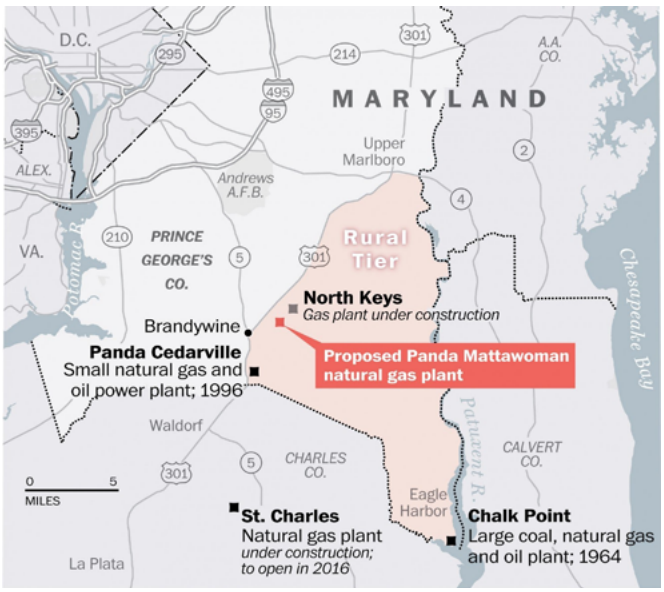
"The community was very concerned about a concrete facility that wanted to expand," explained Dr. Wilson. **Wilson's CEEJH Lab joined residents in partnering with the Port Towns Environmental Action group to help fight the expansion of the concrete plant. "We (CEEJH Lab) provided some research, some data on air pollution levels."** The lab used low-cost monitoring sensors to capture data on the extent of human exposure to PM and VOCs depending on the time of day (rush hour) as well as the proximity to heavily trafficked roadways and industrial activity near the concrete block plant. "This would inform their fight against the expansion of this concrete plant," Dr. Wilson affirmed. In addition, the CEEJH Lab participated in many public forums and workshops about air quality and public health. The lab has even trained community members in the use of these low-cost, real-time sensors to provide them the agency to collect pollution data themselves (Maryland Institute for Applied Environmental Health, 2019b).

Additionally, industry and heavy traffic are huge contributors of the thousands of tons of heat-trapping gasses emitted into the atmosphere every single second of every day. And while the commuters and industrial executives are the main contributors of these gasses, this is a prime example of how a low income community of color is hit the worst by the actions of the wealthy.

The community used the data provided by the CEEJH Lab to inform their testimony, and were successful in stopping the concrete plant from expanding. Still, many pollution threats remain for families in Bladensburg.

BRANDYWINE, MARYLAND

Brandywine is also located in Prince George's County, Maryland. It is an unincorporated community with no town council or mayor and its population is 74% Black (Data USA, 2018). According to the CEEJH website , "This lack of political representation has led to Brandywine being exploited by County leadership and state officials to act as a dumping ground for industrial hazards and locally unwanted land uses (LULUs) and a sacrifice zone for the rest of Prince George's County, the state of Maryland, and the Washington, D.C. region" (Maryland Institute for Applied Environmental Health, 2019a).



Credit: Laris Karklis, The Washington Post / CEEJH

Brandywine is plagued by three power plants within a 13-mile radius, one of which is a coal fired power plant. Additionally, two new gas-fired power plants are being constructed within a three-mile radius. They also have a coal ash landfill, a sludge lagoon, a concrete batching facility, and a Superfund site – which is an abandoned toxic waste site (usually that once supported an oil refinery or smelting or mining activities) – that the EPA has deemed too toxic to build upon, and thus has been added to a long list of sites awaiting government help for cleanup. Additionally, there are numerous mining operations that utilize explosives to extract aggregate material for construction. Heavy traffic, including big diesel truck traffic, also bustles down route 301 past Brandywine every day (Maryland Institute for Applied Environmental Health, 2019a; "Superfund sites," n.d.).

"They also have a coal ash landfill. When you burn coal, it creates ash and it sits on a landfill. **That coal ash landfill is by the community's only park – by the community's only playground**," Dr. Wilson added. "And so, there's a lot of concerns about the impacts from the power plants and the impacts from the traffic pollution." **Since 2016, the CEEJH Lab has been working with the BTB (Be the Bridge) Coalition, which is a community-based organization fighting for environmental justice, led by Kamita Gray.** Gray, has "spent the last six or seven years trying to fight against the power plants, just trying to fight for the community to be healthier and more sustainable and to get rid of the pollution sources," said Dr. Wilson.

The team has performed health impact assessments, provided testimonies, and even submitted civil rights complaints to the U.S. EPA Office of Civil Rights. In addition, their air quality monitors consistently capture real-time data on Brandywine's air pollution that both threatens public health as well as contributes to the buildup of greenhouse gases in the atmosphere (Maryland Institute for Applied Environmental Health, 2019a).

Testimonies provided by Dr. Sacoby Wilson, Kamita Gray, and other members of the community helped stop a special exception permit for the Brandywine Coal Ash Landfill. However, it was recently overturned in court, and must again be contested, noted Dr. Wilson.

BUZZARD POINT, WASHINGTON, D.C.

The CEEJH Lab also works with the Buzzard Point community in southwest Washington, D.C., which is 83% African American ("Buzzard Point Demographics," n.d.). They work with Rhonda Hamilton and other members of NeRAC (Near Buzzard Point Resilient Action Committee) on issues related to traffic, concrete facilities, electricity generation from the Pepco substation, and also the new D.C. United Soccer Stadium that's being built in the community. All these activities spew dust and pollutants into the air, contributing to greenhouse gasses as well as high rates of cancer and asthma.

An interpretation of what Akridge and Western Development's planned River Point project at Buzzard Point could look like. Credit: River Point Partners LLC / Interactive Zoning Information System

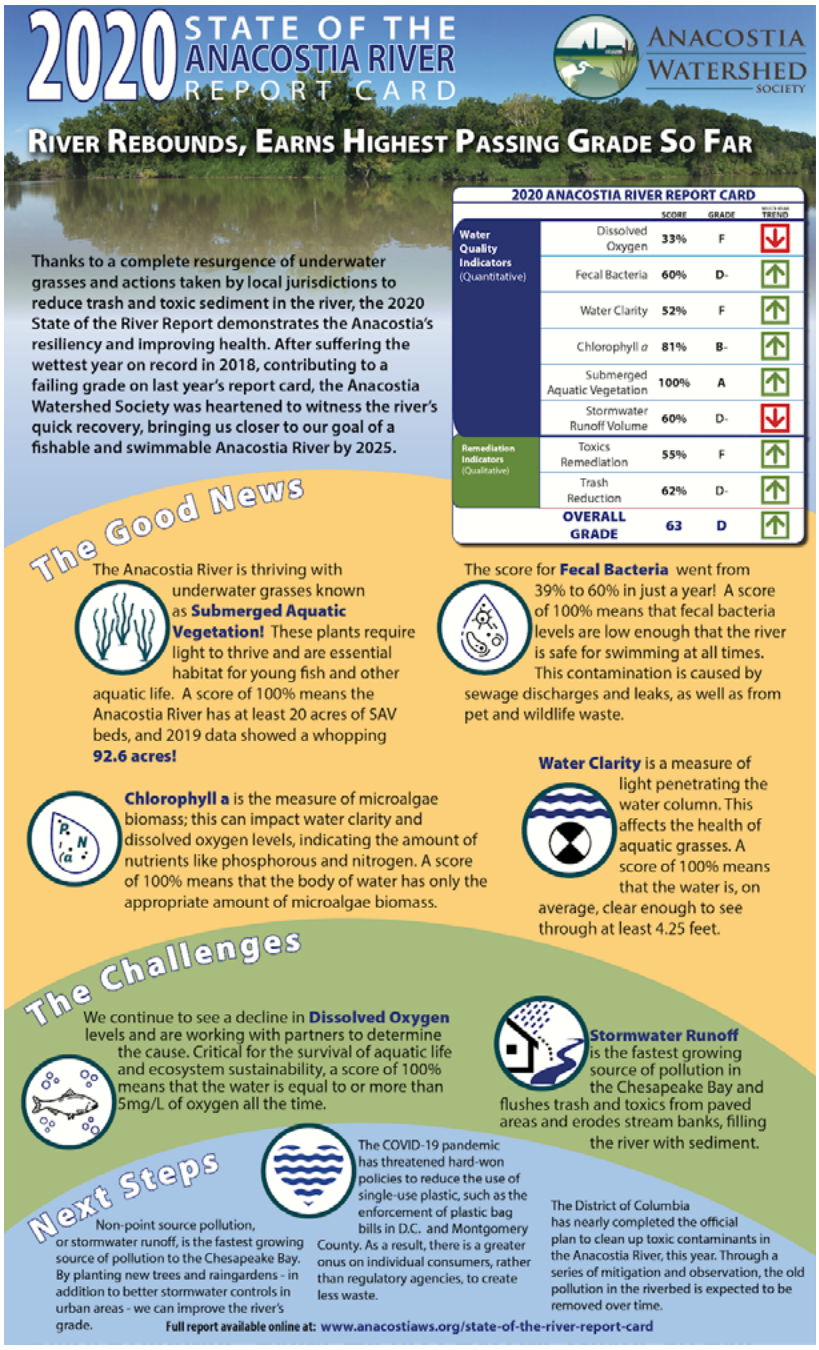
Additionally, Buzzard Point is located on the waterfront, where the Potomac and Anacostia Rivers meet. Due to climate change, Washington, D.C. is experiencing increased intensity and frequency of rainfall, which overloads stormwater systems and increases river height. **Flooding from storm surge and rising sea-levels is intensifying, putting communities like Buzzard Point that lie in the floodplain at risk.** In October of 2019, reports from the Commission on Climate Change and Resiliency (established in 2016) caused the D.C. Office of Planning to create a new section in their Comprehensive Plan – the land use document that guides city planning – aimed at transforming Washington, D.C. into a more climate-resilient city. As such, **Buzzard Point is currently in the process of flood-proofing its infrastructure by installing flood walls, integrating a living-shoreline resilience buffer, raising new residential buildings higher above the ground, and upgrading old developments** (Banister, 2020).

However, these giant, new residential units are displacing the low-rise homes and affordable private housing is dwindling in availability. **Buzzard Point community members are concerned that once the neighborhood is flood-proofed and the toxins cleaned up, gentrification will push them out.** "We have to fight to ensure this neighborhood remains mixed income and culturally diverse, 30 to 100 years from now," said Kari Fulton, a member of NeRAC. A Truthout article wrote, **"Buzzard Point residents are working to defend their community. A campaign called "Clean this Place, Don't Displace," spearheaded by Kari Fulton and Rhonda Hamilton, aims to secure health safeguards for air quality, and protect public housing in the changing neighborhood.** Fulton's three-year-old son came up with the slogan" (Lockwood, 2017).

ANACOSTIA RIVER, WASHINGTON, D.C.

Every year, the **Anacostia Watershed Society scores the health of the Anacostia River based on terms of the Clean Water Act.** The goal is to reach an "A" letter grade, where the river is deemed healthy enough for swimming and fishing. **In 2020, the Anacostia scored a 63% (a "D"), which was the highest score to date.** A year prior, in 2019, the river scored a failing grade of 51%. This was likely due to record-setting rains from the summer of 2018, which brought tons of pollutants to the river from agricultural fields as well as from stormwater running off impervious surfaces like roads, parking lots, and roofs. The heavy streamflow during extreme storms also eroded banks of the river, washing sediments into the water (Anacostia Watershed Society, 2020).

The CEEJH Lab has done a few projects on the Anacostia, one of which was called **"Project RECREATE." Its focus was to address concerns about the exposure of recreationists to contaminants from Pepco's Benning Road facility, as well as other legacy pollution sites all along the Anacostia.** For another project, **CEEJH Lab partnered with the Anacostia Watershed Society to survey contaminants found in fish – an important concern for subsistence fisherfolk. Many low-wealth community members fish along the Anacostia to supplement for missing sources of protein. Others fish the Anacostia simply because it is a part of their culture.**



Credit: Anacostia Watershed Society

In 2018, the Anacostia Watershed Society started a MusselPower program to help improve the health of the river. Just as oysters filter water in brackish areas, **mussels filter water in freshwater systems**. One adult mussel can filter between 10-20 gallons of water each day. However, populations of freshwater mussels have greatly declined across the country due to the elimination of submerged aquatic vegetation by pollutants in many of the Potomac Watershed's waterways. Working with the Virginia Fisheries and Aquatic Wildlife Center, the Anacostia Watershed Society raised juvenile mussels in floating baskets in the Anacostia, and released nearly eight thousand into the river in the fall of 2019 (Anacostia Watershed Society, 2020).

What's any of this waterway cleanup got to do with the climate? Well, in the same way that forest fragmentation and invasive species disrupt the health of a land ecosystem and make it less resilient to the added impacts of climate change, pollutants and runoff disrupt the health of an aquatic ecosystem and make it less resilient to the added impacts of climate change. So, if a stream or river, like the Anacostia, were to already have an impaired ecosystem with poor water quality, the added effects of climate change could compound the threat and be quite detrimental to the plants, animals, and people that live there. According to a study in Nature Communications, "associated decreases in other stressors (e.g. pollution, fragmentation) could offset some warming effects, paying climatic 'debt' with increased environmental 'credit'" (Vaughan & Gotelli, 2019).

However, those who are most impacted by pollution and climate change have historically not been included in the mainstream environmental movement. "I think it's something to remember," **Dr. Wilson noted, "...that when you think about rivers and streams, we have to clean them up so that *everybody* can access them and make sure that there's equity and access in natural amenities...The Anacostia's being cleaned up, but there are a lot of folks who've been disconnected from the Anacostia, because they were never *invited*." Those that live along the floodplain of the river are largely people of color and low-wealth communities, yet those who feel welcomed to join in conservation movements to protect that resource are largely White, wealthy folks. "People of color have long been excluded from environmental policy and conservation—creating blind spots that perpetuate inequality,"** according to a *National Geographic* article.

Dr. Wilson continued, "Sometimes environmental resources conservation has been seen as a predominantly White issue. And a lot of folks of color who like nature, who go out, who canoe, who paddle, who fish, are not just subsistence-based, they recreationally fish. So, we have to make sure, when we do engagement and we talk about our rivers and streams, that we're engaging folks, not assuming that people of color are not interested, or don't use those resources. We have to do a better job of building those relationships," he said.

For decades, many low-income communities and communities of color have been fighting for their basic human rights to breathe clean air, drink clean water, eat nutritious food and live a safe, healthy life. Although these communities are on the frontlines of environmental disaster, they have historically been left out of conversations and decision making around the very environmental issues that are directly affecting their lives. Part of **environmental justice is not just outcomes, it is also process – the full and meaningful involvement of those most impacted, in decision making processes**. Frontline environmental justice communities, people of color, women, other-abled people, and low-wealth communities who are most impacted by climate change and other environmental issues need to be given a seat at the decision-making table, rather than being on the menu. **Those who are most directly impacted by environmental injustice and climate change are the experts both on the problems and the best solutions within their specific communities.**

EAST RIVERDALE-BEACON HEIGHTS, MARYLAND

East Riverdale-Beacon Heights is yet another community in Prince George's County, Maryland, that is experiencing the unjust effects of climate change. **The majority of residents are Latinx and African American, live below the poverty line, and many live within a floodplain – which is only increasing in size as rains become heavier and river levels rise.** Residents can advocate for the county to implement green infrastructure techniques, such as permeable pavement, retention ponds, blue walls, green walls, and urban tree plantings to help alleviate risk from flooding (Delcid et al., 2019).

"If you look at flooding, you look at heat waves, you look at hurricanes, you look at droughts, you look at forest fires – you **look at any climate related perturbation – those folks who are most socially vulnerable, or economically vulnerable, will always be hit first, worst, and most. And unfortunately, folks of color are disproportionately in those categories," explained Dr. Wilson.**

JUSTICE PARK, FAIRFAX COUNTY, VIRGINIA

Justice Park is a Fairfax County Park Authority owned park that serves the 22041 zip code, the **zip code with the highest socioeconomic disparity in Fairfax County.** While the park is located in the more affluent 22044 zip code, it is surrounded by the low-income 22041 zip code, whose community members primarily reach the park by walking to it. The high school across the street from the park is expanding and looking for space for more parking. There is **currently a proposal to install 90 parking spaces on two acres of the parkland, losing green space and adding more paved surface in a low-income community** already suffering from disparities, who need green space the most. Community members have expressed frustration about lack of community engagement on the part of Fairfax County Public Schools (FCPS) and Fairfax Park Authority, who have been working together on the proposal to pave 90 parking spaces on the public parkland. Residents said they were not informed about the proposal to put a parking lot on public park land, and weren't given an opportunity to comment. Community members feel the deal is being done by a secret handshake between FCPS and the Park Authority. Adding insult to injury, all the amenities the community was promised would be added to the park in the 2009 Master Plan – a network of trails connecting the eastern and western halves of the park, and a garden area - the community still hasn't been provided, and instead, they are facing a proposal to take two acres away from their local park to build a parking lot. Several community members have noted that preserving the park would further Fairfax County's goal to promote equity. Other residents noted the park is adjacent to a Resource Protection Area, that paving more areas would exacerbate stormwater runoff, and that the land was once owned by African American families who were descendants of slaves. **As of early May 2021, local residents are still in the process of fighting to protect the park as a community resource** and prevent two acres of it from being paved as parking lot.

PIMMIT HILLS, FAIRFAX COUNTY, VIRGINIA

Pimmit Hills is a **low-income community of color** in Fairfax County **currently fighting a pipeline project that is being rerouted through their neighborhood**. This is the only neighborhood which the pipeline is being rerouted through- it will be kept along its original route for the rest of the pipeline's reconstruction process along Rt. 7 in Fairfax. **The community has asked for an EJ review but has not gotten one as of early May 2021.**

MOUNT CLINTON, VIRGINIA: NEW COMMUNITY PROJECT CLIMATE FARM

The New Community Project Climate Farm is an example of **climate justice *solutions* led by those most impacted by climate change** – in this case, immigrant climate refugees with traditional ecological knowledge of regenerative agriculture methods from their home countries. This intersectional project is a 6-acre agricultural research center for carbon farming and food production methods suitable to Rockingham County in the Shenandoah Valley of Virginia. According to an article by Lars Akerson in the Harrisburg Citizen, the farm just got started in March 2021 with a four-year funding commitment from the New Community Project, and is led by five part-time employees, all of whom came to the US as climate refugees. Irma, from Latin America, has been coordinating urban farming and sustainability initiatives for the past eight years, while Abraham Tesfamariam – whose parents were small farmers in Eritrea – was recruited into the project due to his local fame as a prolific gardener who shares the bounty from his yard and his knowledge of growing food with his neighbors. **The farm's coordinating team of five has developed a site plan for the 6-acre farm that will feature a variety of carbon farming methods: silvopasture livestock grazing, a multi-layer food forest, a forested streamside buffer zone with fruit-bearing pawpaw and persimmon trees and medicinal plants, annual-perennial regenerative cropping, multifunctional hedgerows, and a community garden for recent immigrants who lack access to farmland.** The team already has commitments from Guatemalan, Eritrean, and Congolese groups interested in plots of the large-scale community garden on the farm. Each family or community until will be able to tend a substantial section as they wish while using organic methods, cover crops, and highlighting their own agricultural

traditions that are also methods of climate farming. The team hopes to cultivate relationships with other landholders to establish land and water protections and regenerative agriculture beyond the boundaries of the farm. Once established, the climate farm hopes to hold seasonal festivals onsite, where visitors and volunteers will be able to see regenerative agriculture farming based on traditional ecological knowledge in practice and share its bounty. These exchanges will allow for rich learning, not only about land, soil, and ecological management, but also about the deeper social, emotional, and spiritual aspects of conservation that exist among various communities. This is an excellent example of investing in an intersectional community-led project for climate justice solutions led by those most impacted.

SOLUTIONS: POLICY AND INVESTING IN COMMUNITY-LED PROJECTS

POLICY SOLUTIONS

Change is slow, but communities across the country are seeing wins on the environmental justice front. "I think a great win recently has been with the (Presidential) executive order on climate change; I mean, think about the positive implications, the ripple effects," said Dr. Wilson. The states can now use the federal model as an example and replicate the bill at the state level.

Another federal example of a policy solution to address environmental and climate justice is **Environmental Justice for All Act of 2021, which was crafted through a process spearheaded by environmental justice leaders** who represent some of the very communities this bill is meant to support. This is significant, as **achieving environmental justice requires the full and meaningful involvement of those most impacted in decision-making processes**. If passed, the bill would:

> Enable residents or groups to sue in court for projects that use federal funds or resources and engage in environmental discrimination;
>
> Strengthen the National Environmental Policy Act (NEPA), requiring federal agencies to consider the views of Black, brown and indigenous communities impacted by disproportionate pollution when permitting decisions are being made for new projects;
>
> Create a fund using new fees on oil, gas and coal industries to aid communities that are transitioning from greenhouse-gas dependent industries;
>
> Direct federal agencies to create a working group on environmental justice compliance and enforcement and develop environmental justice strategies and annually report on implementation;
>
> Require federal agencies to seek Tribal government input in the NEPA process, and to ensure that Tribes be invited to serve as cooperating agencies for proposed actions that might impact their reservation lands and sacred sites;
>
> Codify an existing grant program to ensure more equitable access to parks and recreational opportunities, prioritizing projects and recreational opportunities that benefit underserved urban communities (Garcia, 2021).

Across all levels of government (federal, state, local), getting our society closer to environmental justice will require: Laws that require environmental decision makers to think about environmental justice implications of their decisions and consult with affected communities before approving projects; the full and meaningful involvement of those most impacted in decision-making processes; consideration of cumulative impacts of pollution; zoning law changes to prevent "sacrifice zones"; and investing in communities that have been marginalized.

Locally, an EJ win was achieved when **Virginia recently passed HB704 / SB406, which directs state agencies to examine the effects of proposed regulations on environmental justice and develop policies that advance environmental justice.** It creates a basic environmental justice framework for the Commonwealth, requires the Governor's Secretariats to create agency-specific environmental justice strategies, and requires state agencies to incorporate environmental justice into their regulations and policies. The bill Declares that it is the policy of the Commonwealth to promote and carry out environmental justice; that before taking certain actions, state agencies must assess the potential impacts of the actions on low-income communities, communities of color, and other vulnerable populations; authorizes state agencies to amend proposed regulations, policies and other actions to reduce or eliminate disproportionate impacts to these communities; requires each State Agency to develop an agency-specific policy to promote environmental justice; authorizes each State Agency to adopt regulations to implement their environmental justice policy; and creates an interagency working group to coordinate the implementation of the Commonwealth's environmental justice policy.

In Maryland, environmental justice leaders are advocating for the passage of a similar bill to direct state agencies to examine the impacts of proposed regulations on environmental justice and develop policies that further environmental justice.

In August 2020, a group of **Maryland environmental justice leaders wrote and submitted an EJ letter to Governor Hogan, which includes 22 specific EJ solutions** for the state of Maryland to implement:

1. **Maryland Department of the Environment (MDE) needs to have an Environmental Justice Plan**

   MDE and other agencies should be required to develop an environmental justice plan that has metrics to track progress and ensure that performance standards are included in the job performance of all staff in implementing the EJ plan

   Require all state agencies to use the Maryland EJ SCREEN tool in permitting, enforcement, and other relevant decisions

   Require that all state agencies have a division who helps them implement and track their work on implementing their environmental justice plan

   Require that the state develops an interagency workgroup, similar to the federal interagency working group on environmental justice that works in concert with the Environmental Justice Commission

   Require enhanced community engagement for all permitting processes for all state agencies

2. **Maryland's Environmental Justice and Sustainability Commission must be re-chartered**

   A need to expand authority for the Commission to allow it to appropriately insert itself in the decision-making processes of agencies who control the levels and location of pollution sources in Maryland

   Establish a permanent working group within the Commission dedicated to understanding and mitigating the effect of cumulative impacts of pollution faced by low income populations and communities of color

   Draft language that compels the Commission to work with EPA to ensure that it can review all project(s) that fall under NEPA regulations to ensure environmental assessments (EAs) and Environmental Impact Statements (EISs) are proper. Also, allowing the Commission to verify NEPA requirements involving public notice, public involvement, and consideration of alternatives

   Draft language that gives the Commission authority to review all Finding of No Significant Impact ("FONSI")

Draft language that gives the Commission authority to encourage public input regarding environmental assessments (EAs) and to work with EPA in providing opportunity for public participation to occur prior to the draft of the EA

The Commission must be open to, and committed to, hosting their quarterly meetings around the State, not just in Baltimore, MD. These meetings should be used as listening sessions so that constituents can share their environmental justice concerns. Currently, seats on the Commission appear to be filled by people who live in or around Baltimore where it is convenient to attend Commission meetings. If the Commission was properly representative of Maryland frontline communities, a rotation of meeting locations would be not only necessary but would encourage participation by more Marylanders.

3. **The Governor's Office must show greater commitment to addressing systemic racism and advancing environmental justice**

Develop and release an Executive Order on Environmental Justice and COVID-19 to address disparities like your peer North Caroline Governor Roy Cooper did

Support the passage of a new bill that directs state agencies to examine the effects of proposed regulations on environmental justice and develop policies that advance environmental justice just like HB704/SB406 that passed in Virginia in 2020

Support the passage of a bill that requires all county governments to identify environmental justice communities and incorporate environmental justice into their general plans as California did with SB1000

New mandatory duties for agencies like MDE that compel the agency to listen to the voices on the Environmental Justice Commission and to take the representatives of affected communities seriously

Cumulative Impact Assessments must be part of permitting processes of all state agencies particularly MDE, Department of Transportation, Department of Planning, Department of Natural Resources, Department of Agriculture

MDE and other agencies including the Public Service Commission, Department of Transportation, and Department of Natural Resources should receive additional oversight from the legislature in their implementation of the Brandywine EJ civil rights complaint settlement

Modify the current Maryland Environmental Policy Act to include stronger language on compliance with Title VI of the Civil Rights and require environmental assessments (EAs), environmental impact assessments (EIAs), and environmental impact statements (EIS) to include cumulative impact analysis and health impact assessment, allowing adequate opportunity for public comment before final determination.

Pass the Community Healthy Air Act and conduct a peer reviewed study of actual emissions from Concentrated Animal Feeding Operation exhaust fans

Pass new legislation to establish environmental benefits districts in areas with high environmental (in) justice scores, with sustainable funding

Require that MDE and other state agencies use air quality data collected by residents through community science or citizen science if available in decision-making

Independent enforcement authority solely dedicated to ensuring that violations of environmental laws in environmental justice communities are enforced and illegal pollution is mitigated and environmental hazards eliminated (Phillips, Wilson, Ashanti, Borrero Krouse, Brookes, Inzerillo, Tutman, Payan, and Reed 2020).

Additionally, funding is needed to fund each state and county agency with staff for a division focused on environmental justice within each of the various agencies.

INVEST IN COMMUNITY-LED PROJECTS TO PLANT TREES AND FOOD FORESTS

Funding the planting and maintenance of trees and food forests in historically redlined communities and frontline EJ communities - with community leadership on what to plant where, and creation of green jobs that benefit local community members – will both address environmental/climate justice and capture carbon.

We can **plant trees in communities that do not have tree canopy to provide shade and reduce the heat island burden. Trees also filter pollutants from water, filter pollutants from the air and reduce carbon dioxide - the most excessive greenhouse gas**. "A lot of communities with climate change issues in urban areas don't have tree canopy. **It's not enough to plant the trees, there have to be dollars invested to make sure there's maintenance of the trees," explained Dr. Wilson.**

"In the state of Maryland, heat related morbidity, heat related deaths: we've had those increase over time (with the increase in extreme weather from climate change)," said Dr. Wilson. "Baltimore (as well as the Washington, D.C. metropolitan area) has a higher percentage of heat related morbidity – hospitalizations and heat related deaths. Why? Because Baltimore and D.C. have a lot of impervious surfaces. People don't have trees or tree canopy and they don't have air conditioning. That is a recipe for disaster."

Not every community has the resources for tree canopy management. **We can advocate for funding for tree planting and tree management jobs** in our towns, counties, states, and federally. "You know, a great thing you could do is to **have folks living in the community get trained to plant the trees, do landscape design, and also landscape management. They'd also get paying jobs to do maintenance. So, they'd have ownership over it... it's going to be more sustainable; it's going to be better buy-in, and people will see the multiple benefits of having more tree canopy."**

Urban Forests = Cleaner, Cooler Air / American Society of Landscape Architects (ASLA)

One example of a bill that was recently passed to provide funding to plant and maintain trees is Maryland's "Tree Solutions Now 2021" bill, which includes a provision creating dedicated funding of $15 million per year to plant and maintain 5 million trees in Maryland by 2031, including planting 500,000 trees in historically redlined urban communities.

Through the Chesapeake Tree Canopy Network, over 25 Potomac Watershed communities have completed tree canopy assessments in which they may set goals for percentage of tree canopy and assess current canopy cover using Network's *i-Tree Landscape Tool*. The *i-Tree* software is free from the U.S. Forest Service and enables each community to measure benefits of their respective tree canopies, including reduction in stormwater runoff and air pollution, and energy savings. For example, the Washington, D.C. Urban Forestry Division (UFD) of the District Department of Transportation (DDOT) uses these tools along with community scientist volunteers to create an inventory of trees in the D.C. public parks, manage inspections, removals, and plantings, and coordinate over 13,000 work requests per year using GIS tools to group work requests by area to improve workload efficiency. UFD also provides information to the public with maps of tree maintenance schedules and developed additional interactive tools on the history of the D.C. tree canopy and identification of 60 of the city's tree species, even down to a particular tree on a particular street (Chesapeake Tree Canopy Network, 2021; T. Phillips, 2020).

We can also invest in communities to transition empty lots to food forests, which is not growing food *in* the forest, but growing food *like* a forest. **Dr. Wilson noted that food forests in communities, "could address the stormwater runoff issue, the heat issue, the air pollution issue, the noise issue, and of course the food issue**, right? Especially for folks in communities that don't have supermarkets and grocery stores."

Individuals, foundations, and organizations can also donate to and support EJ organizations led by those most impacted.

PUBLIC HEALTH

While the gravity of the climate justice section above demonstrates how a warming climate disproportionately affects the health of communities of color, low-wealth communities, and other folks who are most marginalized in US society, we now turn to the *overall* effects on human health for the population as a whole, as it relates to heat stress, air quality, vector-borne diseases, and water quality.

HEAT STRESS

In the Potomac Watershed, the number of summer extreme heat days expected to exceed 35°C (95°F) will continue to rise throughout the century – and certainly, as the frequency of extreme heat days increases, so too does the probability that there will be a successive number of these days, leading to more severe heatwave events. **By 2050, the Potomac region is expected to experience about seven heatwave events per summer, lasting upwards of ten days or more** (Boesch et al., 2008).

Heat stress can result in a range of illnesses such as heat cramps, fainting, heat exhaustion, heatstroke and even death. Barring cramps, these illnesses arise due to the body's failure to regulate its internal temperature. Normally, our bodies sweat and our blood vessels dilate in an attempt to release heat, but when air temperature and humidity increase, it becomes harder to endure. Both the elderly and young children are at an increased risk of heat-related illness as they are inherently less able to regulate their internal body temperatures. Moreover, the dangers of heat stress to those living in urban areas are compounded by the heat island effect, whereby asphalt and concrete drive daytime temperatures even higher, and stored heat keeps nighttime temperatures warmer as well. As the climate warms, the necessity for air conditioning will escalate, especially in urban areas, and even more so in urban areas that lack sufficient shade from tree canopy. Climate injustice thus becomes more apparent as those living on streets without sufficient tree canopy, as well as in buildings without air conditioning, are largely people of color and of low economic status. Ironically, increased use of air conditioners will also increase the demand for electricity, further accelerating the emission of greenhouse gasses responsible for the heightened warming in the first place (Boesch et al., 2008) if we don't transition our electricity to renewable energy.

SOLUTIONS: HEAT STRESS

Solutions for adapting to a warmer future while lowering health risks include effective, community-wide early warning and response plans for heat-waves; guaranteed air conditioning units for every home (ideally powered from renewable energy sources); and improved education regarding the importance of drinking enough fluids, wearing light and loose-fitting clothing, and limiting sports, construction work, and other strenuous outdoor activities during dangerous heat events. **Counties and states can help cool our cities and keep people safe by strengthening urban forestry programs; passing land use ordinances to increase tree canopy, green streets and sidewalks, and other nature-based solutions; and updating building codes to promote green walls** (Boesch et al., 2008; U.S. Environmental Protection Agency, 2008).

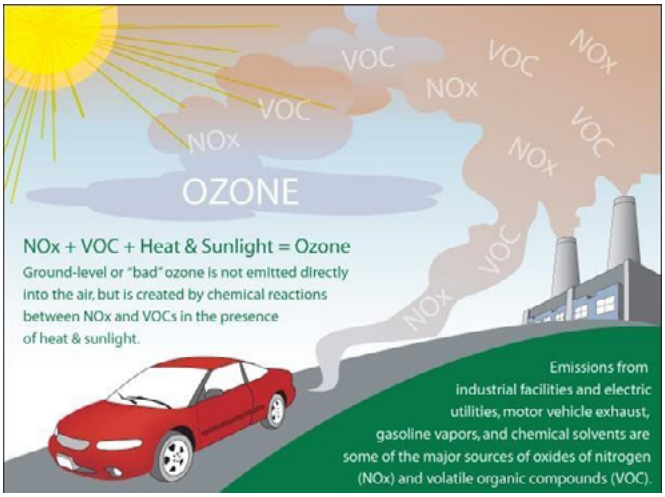
AIR QUALITY

More frequent and extreme heat events also promote the formation of smog, a lung-irritant, while longer summers, extended growing seasons, and even storm events can exacerbate pollen and other airborne allergens that fuel asthma and allergies and take a toll on public health.

OZONE

The dominant component of smog pollution is ozone. In the stratosphere, located ten to thirty miles above ground, ozone is crucial as it shields Earth's surface from the sun's harmful ultraviolet rays. However, in the troposphere – the lowest layer of the atmosphere in which we live – ozone is quite dangerous. **This "ground level" ozone can affect human health by irritating the respiratory system. Ozone reduces lung function, exacerbates bronchitis and emphysema, aggravates asthma by increasing sensitivity to allergens, and inflames and damages the lining of the lungs, sometimes leading to chronic obstructive pulmonary disease, permanent scarring of the lung tissue, and even death** (Environment, Health and Safety Online, 2021). Many areas of the United States are currently affected by ozone levels that exceed national standards, and a 2020 American Lung Association report found that Washington, D.C., Maryland, and Virginia rank twentieth in the country for residents most at risk of illness from ozone pollution (Center for American Progress, 2020). Furthermore, ground level ozone also destroys vegetation and habitat, and is responsible for approximately $500 million in diminished crop production annually (Environment, Health and Safety Online, 2021).

Ground level ozone, itself, is not something that is emitted directly by human activity. Rather, it is a secondary effect of chemical reactions between human-sourced nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. While NOx are naturally produced from lightning, volcanic eruptions, and biological decomposition in soils, an additional **24 million tons are emitted annually through combustion processes from cars, trucks, and other vehicles, as well as from power plants, cement factories (adjacent to communities of color within the Maryland-Washington, D.C. area), and other industry**. VOCs are released from the incomplete combustion of fuel (caused by insufficient oxygen and/or temperature), as well as from building materials such as paint and adhesives, cleaning products and aerosols, and the burning of biomass (University Corporation for Atmospheric Research, 2017; Boesch et al., 2008).



Source: U.S. Environmental Protection Agency

Ozone formation requires high atmospheric temperatures to spark the chemical reactions, which is why ozone alerts do not occur during the winter months, even though NOx and VOC emissions remain just as high. Thus, as the climate crisis continues, longer summers – which could last half the year by the end of the century – and more frequent and extreme heat waves could spell disaster for human health by initiating more ground level ozone events. In addition, trees release VOCs more quickly when the air is warmer, and gasoline evaporates faster when it is hot outside. "Under climate change, and just in warmer conditions in general and in sunnier conditions, you get ozone forming faster," Jeffery Dukes, director of the Perdue Climate Change Research Center, told the Indianapolis Star. "And then of course you have greater concentrations of it, so you have more smog, worse air quality and all the health effects that come along with that," he said (Boesch et al., 2008; Snabes, 2020).

Additionally, **climate change is likely to** decrease the frequency of weather fronts that bring wind and rain associated with low pressure systems, **causing stagnant, high-pressure systems to last longer**. Therefore fewer, but heavier, rain events will occur as warming air acquires more moisture before it pours. **"With high pressure, there is no mixing, so the air becomes dirty like standing water"** National Weather Service Meteorologist Alex Tardy told Spectrum News 1. "It's like putting a lid on the cooler air below and it traps pollution, ozone, and particulates" (Bennett, 2020; Boesch et al., 2008).

SOLUTIONS: OZONE REDUCTION

Fortunately, we have the capacity to reduce ground level ozone and improve air quality, even in a warming world – we just need the will power.

Policy solutions that will address the root causes of ozone with systemic solutions include: phasing out power plants that burn fossil fuels (coal, methane gas, etc) and shifting to renewable energy; investing in high-quality, reliable public transportation; switching public transportation vehicles and government-owned vehicles to "clean fleet" vehicles that are not powered by gasoline, diesel, or natural gas; investing in truly clean vehicles; and Smart Growth to create mixed-use, walkable, bikeable, and public transit-friendly neighborhoods. Companies can contribute to reducing ozone pollution, smog, and GHG emissions by allowing telecommuting / work from home as often as possible to reduce or eliminate commuting and associated emissions from vehicles.

Individual actions such as greening your commute by biking or taking public transportation, limiting engine idling, using environmentally safe paints and cleaning products, conserving electricity, and avoiding burning leaves and other lawn debris (especially on days when ozone is expected to be high) can all help reduce NOx and VOCs and, therefore, the formation of ground level ozone. By taking steps to address climate change directly, like exchanging gasoline and diesel vehicles for electric cars, we can reduce the amount of ozone producing chemicals in the atmosphere, and improve air quality and public health at the same time (AirNow, n.d.; Snabes, 2020).

As ozone is one of the six common air pollutants identified in the Clean Air Act, the EPA has a set of national and regional rules for reducing emissions of the pollutants that form ground level ozone. Most of these rules deal with vehicle and transportation standards, regional haze and visibility rules, and regular reviews of the National Ambient Air Quality Standards (NAAQS). The latter fluctuates, especially when presidential administrations change hands. The EPA then works with states to determine which areas do not meet the national standard; after which states will draft a state implementation plan (SIP), that details the measures it will take to improve the air quality in those areas. Air quality forecasts are often provided with weather forecasts, but you can check the ozone levels and other daily air quality information for your area on AirNow, a partnership of the EPA, National Oceanic and Atmospheric Administration (NOAA), National Park Service, NASA, Centers for Disease Control, and tribal, state, and local air quality agencies (AirNow, n.d.; U.S. Environmental Protection Agency, 2021c).

ALLERGENS AND ASTHMA

Globally, the presence of asthma has risen over the decades, by 8% between 1997 and 2007 and then by 19% between 2007 and 2017. Research suggests that this could signal climate change, as the body's immune response detects a change in the behavior of allergens early on. Indeed, allergens, like pollen, mold and fungal spores, are mobilized by climate-induced changes in temperature, thunderstorms, and flooding.

HEAT

According to a February 2021 study in the journal of Geophysical Research Letters, **climate change is making summers hotter and longer**, while shortening the other seasons, and by 2100, summers could last half the year. In just sixty years, from 1952 to 2011, summers have already expanded by seventeen days in the Northern Hemisphere. This is critical, as "this is the biological clock for every living thing," the study's lead author, Yuping Guan, told NBC News. Indeed, extended summers could throw many things out of whack, including the synchrony between pollinators and spring budding, "false springs" that lure crops out early only to be wiped out by a temperature drop later on, and the burden of allergens on human health (Chow, 2021; Wang et al., 2021).

Longer summers, in addition to increased atmospheric carbon dioxide levels, provide plants the opportunity to produce more pollen over a longer growing season, causing increased concern for allergy sufferers. A study by the U.S. Department of Agriculture in 2011 found that the ragweed season had extended by upwards of a month since 1995, and experiments show that doubling carbon dioxide increases ragweed pollen production by as much as 90% due to enhanced photosynthesis (Daniel, n.d.).

According to a 2020 study in the Chinese Medical Journal, **extreme heat, itself, can also trigger asthma symptoms by "stimulating thermosensitive bronchopulmonary C-fiber nerves" (Deng et al., 2020), which is a fancy way of saying that heat can cause people's airways to constrict.** A study in Kentucky showed that asthma patients experienced a 112% increase in airway constriction when hyperventilating warm air as opposed to a 38% increase when hyperventilating room temperature air (Deng et al., 2020).

THUNDERSTORMS

Around the world, severe thunderstorms have been repeatedly, albeit sporadically, reported to trigger asthma attacks. **Although still being investigated, sufficient epidemiological evidence supports the hypothesis of "thunderstorm asthma," a phenomenon wherein strong storms "can concentrate pollen grains at ground level and provoke the release of allergenic particles in respirable size after their absorption of water," (Deng et al., 2020) causing an inflammatory response in peoples' airways.** In other words, more pollen grains are present in flowing, humid air. Moreover, fungi, including asthma triggering mold species like *Alternaria* and *Cladosporium*, reproduce in hot, humid conditions (such as before a thunderstorm), and like pollen, their spores can be made ambient by storm winds, making the lot of them easier to inhale into the respiratory tract (Daniel, n.d.).

FLOODS

Fungal spores are often found in greater concentrations in the environment (such as in buildings and the atmosphere) following severe floods, as persisting damp humid environments favor their reproduction. **With flooding becoming more common in the Potomac region, fungi -including mildew, molds, rusts, and yeasts - are likely to become more prevalent, especially in homes in low-lying flood prone areas often occupied by communities of color. Mold can persist for months after flood exposure, lengthening the duration of asthma symptoms.** Mold can even affect the structure of buildings as it releases enzymes that break down cellulose, the structural component of wood (Deng et al., 2020).

Unequal Impacts

"In communities of color, we have higher rates of asthma," said Abel Olivo, the Executive Director of Defensores de la Cuenca (Defenders of the Watershed). He continued, "For children who go to school, certainly those who have English as a second language, or who are predominantly Spanish speaking at home, as I was when I was growing up, school was hard. **It was hard for me because I didn't understand, necessarily, the structures, the systems, and bilingual education wasn't a thing, you know, when I was younger. So, layer on top of that asthma, or some other disease [or] ailment that makes concentrating hard already.** You know, like, 'This stuff, this material is hard for me. **Oh, and I can't breathe. I can't concentrate....** Well, I must be dumb.'" And then, he said, "you start to think of yourself in that regard, and then the moment comes when you make a decision, 'Well, I'm just gonna drop out and get a job.' **That speaks to your long-term standing, your long-term earning potential, when you limit your educational opportunities based on environmental conditions, based on your health, based on these things are out of your control."**

Solutions: Allergens and Asthma. The authors of a *Chinese Medical Journal* study recommend that urban planners consider solutions that reduce the amount of air pollutants and allergens afflicting the public. For instance, buffer zones of two to three hundred meters could be established between high-traffic and

residential or recreational areas to reduce toxic exposure to air pollutants like ozone. This is especially pertinent in frontline environmental/climate justice communities most exposed to heavy traffic and industry in the region. Counties might also consider planting "non-allergenic plants in public and private green areas, pruning hedges before flowering or pollen emission, and consulting maps of pollen levels before planning public events'' (Deng et al., 2020). Health departments could also create early warning systems in which allergy-prone individuals are alerted to risky weather conditions, such as heatwaves or thunderstorms during the watershed's pollen season (Deng et al., 2020).

"You know, public health costs are tremendous in lower resource communities because of higher rates of chronic diseases," Olivo said. So, investing in communities of color to mitigate these extreme weather events, which are becoming more and more frequent, will ultimately be worth it for municipal governments as it will "help save money on the back end."

VECTOR-BORNE DISEASES

Vector-borne diseases are transmitted by organisms that carry disease-causing bacteria or viruses from one host to another. **Warmer and longer summers are allowing mosquitoes, ticks, and other disease carrying pests to expand their range**. Additionally, because winters are becoming shorter and warmer, these pests are able to survive and reproduce, increasing their population size whereas before, the cold would prevent reproduction. **The viruses they carry are also fostered by climate change, as higher temperatures can shorten a virus's incubation period** (Cohut, 2020).

MOSQUITOES

Over the years, the number of mosquito-borne illnesses has increased across the world. In March 2019, a team of international researchers published a study in Nature Microbiology explaining that the ranges of two main disease carrying species, *Aedes aegypti* (the yellow fever mosquito) and *Aedes albopictus* (the Asian tiger mosquito), are predicted to expand with warming temperatures, thereby threatening half of the world's population by 2050. In the United States alone, the yellow fever mosquito has spread northward at a rate of about 150 miles per year over the past five to ten years, and could reach as far north as Chicago by 2050 (Kraemer et al., 2019). **In the Washington, D.C. metro area, bug-bite season now lasts an average of 152 days, an increase of 37 days since 1980** (Fritz, 2019).

Mosquitoes thrive in hot, humid conditions. The Asian tiger mosquito, for instance, prefers a temperature range of 10-35°C (50-95°F) and a relative humidity of at least 42%. Indeed, as the region becomes warmer, more moisture is evaporated into the air, increasing the number of humid days. This is worrisome given the recent rise in Zika virus cases in the United States. Zika was once confined to South America and the Caribbean, but has since spread through travel to the United States. It provokes mild symptoms for most people who contract the virus, but can be dangerous for pregnant mothers as it is known to cause severe brain damage and birth defects in newborn babies. Despite the name, both the Asian tiger mosquito and the yellow fever mosquito, of the *Aedes* genus, are valid transmitters of the Zika, dengue and chikungunya viruses, which all cause symptoms of fever, rash, and severe muscle aches. Though dengue and chikungunya are not so common in the United States, they still make an appearance every now and then, and **the Zika virus is likely to spread faster in warmer environments** (Fritz, 2019).

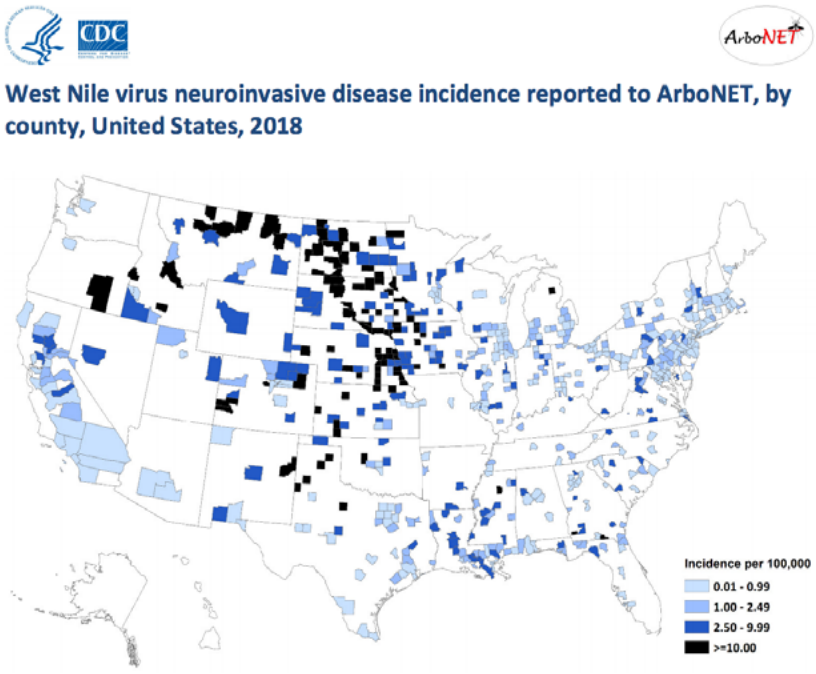
West Nile virus has become the most common mosquito-spread disease in the United States, as well as in Canada and Europe, since 1999 when it first arrived in North America. Medical News Today articles from the summer of 2020, note that **"Many scientists have since argued that climate change is the most significant factor contributing to the spread of the West Nile virus to the U.S. and around the world. At present, the EPA lists the West Nile virus as an indicator of climate change."** Further, models suggest that "the optimum temperature for [West Nile] transmission is 24–25°C (75.2–77°F)," and in a study from the eLife journal, authors note that, "we might expect a net increase in transmission of West Nile virus in

response to the warming climate, even as hot temperatures suppress transmission in some places" (Cohut, 2020; Kingsland, 2020; Shocket et al., 2020).

While there have been several reports of West Nile virus in these *Aedes* mosquitoes, they are not considered a primary vector of this disease. Instead, mosquitoes of the *Culex* genus are considered to be the main transmitter in the United States, as well as across the globe (Colpitts et al., 2012). {**In 2012, West Nile set a record in the United States, with 5,674 people infected, and of those infected, almost 300 died**} (Fritz, 2019). The authors of a 2016 paper in WIREs Climate Change suggested that, {"Above-normal temperatures have been among the most consistent factors associated with [West Nile virus] outbreaks"… This has been found in both the Americas and Europe, for both of the main West Nile virus strains" (Hoover & Barker, 2016). The *Georgetown Climate Center* concurs, noting that, "A warming climate exacerbates public health threats like infectious diseases and air pollution in Virginia. West Nile virus and Lyme disease (addressed in the next section), once extremely rare, now present increased health risks across the state" ("Understanding Virginia's Vulnerability," 2015).

The West Nile virus belongs to the same family of viruses as Zika, dengue, and yellow fever, and is sourced from the blood of infected birds. Though humans do not typically experience any symptoms, some individuals may experience inflammation of the brain and central nervous system. According to Dr. Maria Cohut's 2020 article in *Medical News Today,* "Data from the CDC (Center for Disease Control) indicate that **in 2019, 958 people across the U.S. had contracted West Nile virus. The virus affected the brain and central nervous system in 626 (65%) of these people**" (Cohut, 2020).

In 2018, there were about three times as many cases of West Nile virus nationwide, with the greatest concentration in the eastern United States – likely because it was such a rainy, humid year. Let's break that down to the approximate Potomac Watershed level: in 2018, there were 2,647 cases of West Nile virus reported to the CDC across the United States. By state, Virginia reported 47 cases, West Virginia reported two, Pennsylvania reported 130, Maryland reported 45, and Washington, D.C. reported 13, for a sub-total of 237 cases. **Of those 237 infected individuals, the West Nile virus affected the central nervous system in 177 (75%) of cases** as follows: Virginia 38; West Virginia 2; Pennsylvania 95; Maryland 35; and Washington, D.C. 7 (Centers for Disease Control and Prevention, 2020b). Unfortunately, there is currently no cure for the virus, so rather than treating the disease, doctors must manage the symptoms (Cohut, 2020).



Source: ArboNET, Arboviral Diseases Branch, CDC

Although West Nile virus is the most common mosquito borne illness in our area, malaria is the most common disease associated with mosquitoes. However, while malaria was common in the United States in the early 20th century, it was eradicated by 1950 through the use of insecticides, drainage ditches, and other measures (Beaubien, 2017). Today, approximately two thousand cases are reported to the CDC each

year in the United States, but those are mostly associated with travelers returning from tropical locations. Malaria is transmitted by *Anopheles* mosquitoes carrying the parasite, *Plasmodium falciparum*, which requires temperatures to be greater than 20°C (68°F) to complete its life cycle. However, *Plasmodium vivax* is an alternative strain of the parasite that is able to accomplish its life cycle in lower temperatures (Centers for Disease Control and Prevention, 2020a).

SOLUTIONS: MOSQUITO-TRANSMITTED DISEASES

Simple measures can be performed locally by individuals to dampen the risk of mosquito-borne infections. **Eliminating breeding grounds by reducing places for standing water to collect**, such as in discarded tires or empty planting pots, is one extremely effective measure. **Mosquito traps** can also be effective, and quite interesting to learn about too, because different species of mosquito are attracted to different stimulants. Some are more attracted to lighter or darker colors (dark colors absorb heat and signal a warm body to prey upon) while others are more enticed by smells like lactic acid (produced from sweat) or smelly bacteria that live both between our toes and in limburger cheese (Webb, 2015).

"Yet these interventions are akin to symptomatic treatments — they aim to keep the effect under control, but **what about [addressing] the cause?**," Maria Cohut mentions in her 2020 Medical News Today article. **We are again pointed back to climate change mitigation strategies, such as nature-based solutions, green infrastructure, renewable energy, and the need to reduce greenhouse gas emissions.** "Changes to ecological cycles are bound to affect insect populations and other vectors," notes Cohut. "In turn, this is likely to change how diseases spread. But **humans can control our impact on the environments that we inhabit, and that is, perhaps, the most crucial step in ensuring that we do not accelerate the arrival of another future health crisis**," she wrote (Cohut, 2020).

Example of a mosquito trap. The hanging blue cooler contains enticing aromas that attract the mosquitoes, while the white bucket contains a fan that draws in the curious pests as they get close. Credit: Scott Zona / Flickr

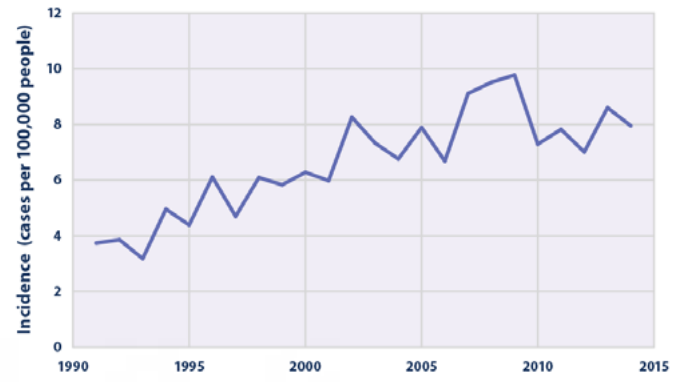
TICKS

Lyme disease is the most prevalent vector-borne disease in the United States and has become even more rampant over the past decade. In 2016, Pennsylvania led the country with over 12,000 confirmed cases of Lyme disease. The pathogen responsible is a bacterium called *Borrelia burgdorferi*, which is transmitted to humans via tick vectors (Dumic & Severnini, 2018; DCNR, 2018). **Lyme disease** is characterized by the bullseye that arises at the site of the tick bite. **If left untreated, it can progress to cause migraines, fever, fatigue, and skin rashes. Severe cases lead to joint pain, numbness in the hands and feet, heart palpitations, or nervous system failure**, such as Bell's palsy, a form of facial paralysis (Centers for Disease Control and Prevention, 2021).

In the northeast, the deer tick (*Ixodes scapularis*) is the main vector. The main host of the bacterium is the white footed mouse, but birds and other small mammals such as chipmunks can also act as reservoirs. As many as one hundred deer ticks can be found on a single mouse. And while deer do not carry this bacterium, they are important in the life cycle and spread of deer ticks. It takes about two years for a deer tick to complete its life cycle. Larvae hatch from eggs in the spring, and during the summer they feed on small mammals, like the white footed mouse, where they first contract the bacterium. The larvae enter dormancy during the winter, emerging the next spring as nymphs, hungry for a meal. It is during this second summer that the bacterium can be transmitted to humans. After their meal, the nymphs molt into

adults, and if the adult tick survives the second winter, it will seek another host, usually a deer, on which to gorge before dropping to the ground to lay its eggs (Dumic & Severnini, 2018).

Scientific studies have indicated that climate change is a key perpetrator of Lyme disease, though the magnitude of its impact remains unclear because many environmental and human factors, like changes in land use, alter the distribution of ticks, making it difficult to study climate change as an isolated variable (Couper et al., 2021).



U.S. Reported Cases of Lyme Disease (1991-2014). Source: EPA

While it is true that cold winters can freeze ticks to death, studies have shown that only about 20% of the population dies off (DCNR, 2018). Plus, scientists believe that ticks can synthesize a natural antifreeze within their cells that helps protect from the cold. Ticks that have found a host animal can usually survive the winter on their conquest's body heat, but host-less ticks must burrow under leaf litter or snow for insulation from the winter cold, which makes them more susceptible to freezing. Some scientific studies hypothesize that the cold is not necessarily what kills them, but rather big, frequent temperature shifts. Conversely, **mild winters can propagate the tick population, and following a mild winter we can expect to see *more* ticks come springtime**. Although extreme heat can cause tick mortality, consistent 21-32°C (70-90°F) days can support reproduction and lead to an increase in population size (Big Blue Bug Solutions, n.d.).

Tick survival depends upon both temperature and humidity. **Because ticks thrive with moisture, tick populations will rise as the climate gets wetter in both winter and summer.** A 2020 study in the journal *Global Change Biology* notes that, "Studies have found that warming temperatures at high latitudes contribute to quicker tick development rates, increased survival, and range expansion, suggesting that milder winters would be associated with increasing Lyme disease incidence, with the largest effects observed in cooler regions, as we also detected in this particular study." Evidently, warming temperatures typically tend to increase transmission rates along the northern, cold edge of a vector's range limit, which, in the case of deer ticks, just so happens to be right within our Potomac Watershed region (Couper et al., 2021).

Because the range of ticks has expanded to areas where they have previously been unable to survive, the EPA has used the rate of reported Lyme disease cases as an indicator of climate change. In addition, a 2018 study in the *Canadian Journal of Infectious Diseases and Medical Microbiology* found that for a future warming of 2°C (3.6°F), "the number of Lyme disease cases in the United States will increase by over 20% in the coming decades." Moreover, **urbanization and fragmentation of forests have allowed for the population explosion of deer and mice** (also known as "edge species" because they can adapt easily to landscape change and therefore thrive at the edge of human disturbance). **Forest fragmentation and habitat loss has also brought these animals, along with their tick parasites, right to our doorsteps, creating the perfect soup of hosts, in the perfect mellowing climate, for the deer tick – and consequently, for Lyme disease** (Dumic & Severnini, 2018; K. Ambrose, 2019; U.S. Environmental Protection Agency, 2020b).

SOLUTIONS: TICKS AND LYME DISEASE

In the spring and summertime, and increasingly during milder winters, individuals venturing outdoors should wear tick repellent, tuck pant legs into socks, wear light-colored clothing so that ticks stand out better, shower upon return to check for ticks, and wash and dry clothes on the high heat setting. Within our counties, **reducing the amount of fragmented landscapes by encouraging the protection and creation of larger patches of forest can help draw tick host species away from our backdoors.** Other nature-based solutions include **encouraging natural predators of tick host species, such as owls and black rat snakes, who eat mice, chipmunks, and rabbits**. It is also important that we improve preparedness and response by health professionals and policy makers, and raise public awareness of the increasing dangers of ticks and Lyme disease (DCNR, 2018; Dumic & Severnini, 2018).

WATER QUALITY

ALGAL BLOOMS AND RIVER HEALTH

In the Potomac Watershed, **nutrients from agriculture and urban industry, most notably nitrogen and phosphorus, make their way into the region's rivers and streams**. The enrichment of nutrients in an aquatic system, known as eutrophication, is detrimental to its underwater ecosystems. Exacerbated by warming water temperatures, **added nutrients support the growth of algae, which block sunlight from reaching bottom dwelling plants**, preventing them from photosynthesizing. Because oxygen is a byproduct of photosynthesis, **bottom waters and the organisms that live there become starved of oxygen**. Additionally, as these underwater plants die, and as the surface algae (which have very short life cycles) die and sink to the bottom, the process of decomposition by microbes further strips the water of oxygen, **leading to dead zones where aquatic animals like fish and blue crabs cannot thrive**. Additionally, **some species of algal blooms, like cyanobacteria, release harmful toxins to the surrounding environment which, at high enough concentrations, can threaten the health of both aquatic and human life** (Solomon et al., 2019).

Cyanobacteria, commonly known as blue green algae, are quite genetically diverse, and therefore can thrive in a range of geographies, from the supraglacial ponds of Antarctica to the thermal springs of Yellowstone National Park. They can tolerate huge environmental changes in temperature and salinity, and therefore are utterly resilient to anthropogenic climate change. Cyanobacteria were actually among the first organisms to efficiently photosynthesize and played a big role in the creation of Earth's early atmosphere. Recently, cyanobacterial toxins have been studied for their anticancer potential in human cells (Zanchett & Oliveira-Filho, 2013).

However, cyanobacterial toxins can be harmful to both invertebrates and fish. Studies from the United Kingdom have found that fish mortality during cyanobacterial blooms were the result of gill, digestive tract, heart, kidney, and liver failure. These toxins can bioaccumulate up the food chain, occurring in greater concentrations in the liver, kidneys and muscles of larger fish – like catfish, trout, or shad. **Humans can be exposed to cyanobacterial toxins not only through drinking water, but also by eating contaminated fish**. Symptoms include skin irritation, kidney and liver damage, gastrointestinal disturbances, and even cancer, among other things (Zanchett & Oliveira-Filho, 2013).

Washington, D.C.'s Department of Energy and Environment (DOEE) staff urges the public to utilize the EPA's national "bloomWatch app, which allows users to easily capture photos and GPS location data of potential algae blooms using a smartphone or tablet and then share data with other community scientists and DOEE staff" (Washington, D.C. Department of Energy and Environment, n.d.).

Fifty years ago, the Potomac River was so polluted that blankets of bright green algae would coat the water's surface every summer. In 1971, *The New York Times* referred to it as "an open sewer calling itself a river." The Anacostia was also in bad shape due to decades of poor sewage management, littering and illegal dumping, and one study even found that two out of every three catfish were plagued with tumors. Erin Garnaas-Holmes, who works for the Clean Water Fund, told *American University Radio* in 2019 that the Anacostia "has been the poster child for a degraded urban waterway for decades." In fact, in 1971, the EPA pressed Washington, D.C. to pass a law to ban swimming, and even wading, in the Potomac, Anacostia and Rock Creek waterways – wherein violators would receive a $300 fine or spend ten days in jail (Fenston, 2019b). Fines can still be awarded to violators who swim in these rivers.

Due to high levels of pollution, it remains illegal to swim or wade in the Potomac River. This photo was taken along Section A of the Billy Goat Trail in the Chesapeake & Ohio (C&O) Canal National Historical Park near Great Falls in Montgomery County, MD. Credit: Audrey Ramming / Potomac Conservancy

Credit (Top): Washington, D.C. Dept. of Energy and Environment (DOEE)

Credit (Bottom): U.S. Environmental Protection Agency (EPA)

Thankfully, **billions of dollars have since been poured into cleaning up the Potomac River, Anacostia River, and Rock Creek waterways, but they remain too polluted for fishing or swimming**. A 2019 study in the *Environmental Monitoring and Assessment* journal asserts, "The tidal fresh portion of the Potomac, into which the Anacostia flows, is also characterized as highly turbid and eutrophic with frequent blooms of the cyanobacteria *Microcystis*... Moreover, late summer conditions throughout the river included hypoxic (oxygen-poor) waters... and consisted of a high amount of (pico)cyanobacteria" (Solomon et al., 2019).

The *Potomac Conservancy* scored the Potomac River at a "B minus" in 2020, while the *Anacostia Watershed Society* gave the Anacostia River a "D;" and these scores truly represent an increasing trend in the health of these two rivers. The Anacostia Watershed Society maintains a goal of a "fishable and swimmable Anacostia River by 2025," but Garnaas-Holmes jokes that the biggest challenge might instead be, "Convincing people that we're actually getting towards a space where you can stick your hand in and pull it out and there will be more than just the skeleton left" (Fenston, 2019b; Potomac Conservancy, 2020; Anacostia Watershed Society, 2020).

Many waterways across the United States are not qualified to support fishing or recreation both in and on the water, as they fail to meet the standards of the Clean Water Act instated in 1972. Most are just too concentrated with bacteria like [E.coli] or cyanobacteria from harmful algal blooms. **Currently, residents in the Washington, D.C. metropolitan area are part of this statistic, and therefore can only**

participate in what's known as "limited-contact water recreation" activities – such as canoeing and kayaking, boating, and *recreational* fishing (Fenston, 2019b; Wilson, 2014).

***Subsistence* fishing, however, poses a big health risk to its participants, who are often low-income individuals or people of color.** These vulnerable populations "are often most susceptible to adverse health effects because of their differential exposure to multiple environmental contaminants, psychosocial stressors, socioeconomic disadvantage and lack of access to quality health care" (Wilson, 2014). The EPA estimates fish consumption rates among subsistence fishers to be about 142 grams a day, eight times higher than that estimated for the general population (Wilson, 2014).

In an interview with the Potomac Conservancy, **Abel Olivo, executive director of Defensores de la Cuenca (Defenders of the Watershed), spoke of Latinx communities along the Anacostia River: "Knowing that that level of consumption is above the recommended weekly, monthly levels to safely consume the fish, it's a concern.** You know, because there are folks who catch the fish who feed it to their families [and] may have young ones that are more susceptible to the levels of toxins or contaminants in the fish that impact cognitive development. And again, you talk about long term effects – cognitive development is a huge one in terms of little kids." Olivo's organization is starting a fishing program in conjunction with the Anacostia Riverkeepers, called Fishing in Faith, that aims to engage people in talking about water quality issues.

SOLUTIONS: ALGAL BLOOMS AND RIVER HEALTH

Swimmers are itching to get back into the water, and city leaders are discussing relaxing the decades-old swim ban as river health improves. And we are indeed getting there. **DC Water's Clean Rivers Project, which is a massive infrastructure project designed to capture and clean wastewater before it reenters D.C.'s rivers (discussed under** *Extreme Weather*), **expects a 98% reduction in combined sewer overflow by 2023, which will reduce nutrients available for algal growth.** Plus, projects geared toward **restoring** river sediments and **underwater grasses** have been underway; and **as of 2019, the Anacostia Watershed Society has reintroduced thousands of native freshwater mussels to aid in water filtration and algal cleanup** (Anacostia Waterfront Trust, n.d.; Farrington, 2019).

In the meantime, the Anacostia River Pool Feasibility Study has drummed up ideas for what swimming in the river could look like – once it has been deemed safe enough to do so. The Anacostia Waterfront Trust has partnered with SmithGroup, an architectural, engineering and planning firm, to begin sketching ideas: "The 'pool' could be a full-size lap pool, a shallow splash pad, a deep pool safe for diving, or something that includes all of these," as stated on The *Anacostia River Pool's* site. "The goal of the swimming facility will be to allow people to swim or wade directly in the clean river water without filtration" (Anacostia Waterfront Trust, n.d.; Fenston, 2019b).

POLLUTED RIVERS EXHALE GREENHOUSE GASSES

Climate warming, together with nutrient pollution, helps promote the growth of harmful algal blooms like cyanobacteria; but conversely, **polluted rivers surprisingly emit large amounts of greenhouse gasses into the atmosphere, further fueling climate change** (Keegan, 2021).

In 2021, a team of scientists in Hong Kong studied fifteen of its waterways, only to find that **the more polluted a river was, the more greenhouse gasses it emitted**. And this is true globally. The **underlying reason is ultimately due to how people utilize the land. "Rivers receive large inputs of carbon and nitrogen from the landscapes they drain,"** Sophie Comer-Warner, a biogeochemist and research fellow at University of Birmingham, told *BBC Future Planet*. **Discharge from CAFO-style livestock farms, industrial agriculture runoff, untreated wastewater, stormwater, and sediment accumulation all contribute to river water pollution.** Upon entering the river, the myriad forms of carbon and nitrogen are received by microbes and are subsequently broken down through respiration, releasing carbon dioxide, methane, and nitrogen dioxide in the process (Keegan, 2021).

Worldwide, polluted rivers exhale approximately 3.9 billion tons of carbon annually, about four times more than the aviation industry – an impressive number considering how little of Earth's surface rivers cover. Rivers in urban environments tend to be particularly polluted, emitting greenhouse gases at nearly four times the rate of rivers in rural areas, mostly because of wastewater contaminants. Eighty percent of the world's wastewater is still released directly into the environment. Yet, while the magnitude of carbon emissions from rivers is small relative to that of fossil fuel combustion, its impact should not be ignored, especially in the fight to mitigate climate change. Moreover, because the world's urban population is still ever-growing, the contribution of rivers to climate change will likely continue to grow as well (Keegan, 2021).

SOLUTION: REDUCE RIVER POLLUTION AND RESTORE RIVERS

Cleaning up and **restoring our rivers drastically helps to lower the rate of GHG emissions from rivers**. Research estimates that when river quality is improved, its global warming potential reduces in magnitude by two to ten times. **Minimizing or eliminating the use of fossil-fuel based pesticides and fertilizers on agricultural fields, sports fields, and lawns; protecting and planting forested streamside buffers along waterways to separate them from livestock and crop fields, as well as the use of bioswales and cover crops can all help to prevent nutrient pollution from entering riverine systems. Improved wastewater treatment and storage** in urban areas – such as through DC Water's newly installed stormwater capture infrastructure by means of underground holding tunnels – **can also help reduce river pollution**. At the national and international level, policies like the United States' Clean Water Act, the EU Green Deal, and the EU Water Framework Directive, can also help mitigate nutrient flow to rivers and reduce their climate change impact (Keegan, 2021).

Poor water quality also impairs the health of an aquatic ecosystem, making it less resilient to the added effects of a changing climate. According to a study in *Nature Communications*, "concomitant decreases in other stressors (e.g. pollution, fragmentation) could offset some warming effects, paying climatic debt with accrued environmental credit" (Vaughan & Gotelli, 2019).

TOP SOLUTIONS

SYSTEMIC SOLUTIONS

The changing climate affects our waters, wildlife, and quality of life. It also contributes to more intense storms that deliver a greater volume of rainwater than in the past. We must work with Mother Nature and employ nature-based solutions to reduce greenhouse gas emissions, mitigate the impacts of climate change, and adapt our communities to the changing climate and more extreme weather conditions.

Here are some recommendations to help address the impacts of climate change in the Potomac River watershed:

Protect forests, promote forest connectivity, and fund the planting of trees. One of the most cost-effective solutions for both clean water and climate change is trees. Streamside trees, also known as riparian forest buffers, capture carbon and filter polluted runoff before it enters our local streams and drinking water sources. We must continue to strengthen forest protection laws at the state and local level and advocate for increased public funding to plant and maintain trees in our communities. In addition, we must prioritize the planting and maintenance of trees and food forests in historically redlined communities and frontline environmental justice communities, and involve the community in decisions related to these project.

Reduce polluted runoff and flooding through green infrastructure. Trees, bioswales, rain gardens, rain barrels, green curbs, and other nature-based solutions can help reduce polluted runoff and flooding in our neighborhoods. To mitigate the effects of increased rainfall in the future, we must use more green infrastructure to naturally absorb and filter excess stormwater and prevent polluted runoff and combined-sewage overflows. Green infrastructure creates jobs, beautifies neighborhoods, protects our waterways, and provides shade to address the urban heat island burden.

Transition from industrial agriculture to regenerative agriculture. Farmers must have sufficient technical assistance and financial support to implement river-friendly farming practices that regenerate natural systems. Well-managed farms can sequester carbon, protect water quality, produce nutritious food, and generate sustainable livelihoods.

Embrace river-friendly, smart growth planning at the county level. The population of the DC metro region is projected to grow by 2 million people by 2030. We need to pursue a strategy of "growing up, not out" to accommodate this growth in a way that is sustainable. This approach includes identifying conservation areas to protect healthy forests, stream-side tree buffers and river-friendly working lands; limiting development's footprint, which will leverage existing infrastructure and reduce the demand for cars and vehicle miles driven on an annual basis; investing in the redevelopment of existing city centers; and changing planning and zoning laws to mandate green infrastructure.

Transition from fossil-fuel dependent energy to renewable energy. We must encourage the transition away from energy created through the extraction and burning of fossil fuels, and incentivize renewable energy, such as solar and wind. Solar installations should be sited in a way that is compatible with both clean water goals and climate change mitigation goals. Placing solar panels over surfaces that are already impervious (buildings and parking lots) is ideal. Removing forests or disrupting productive farmland to install solar is counter-productive to clean water and conservation goals.

Prioritize equity in decision making. Climate change impacts everyone, but communities of color and low-wealth communities experience a disproportionate share of environmental burdens in this country and our region. In addition, communities of color and low-wealth communities are less likely to have the environmental benefits of parks, trails, and other green spaces. We must require decision-makers to consider environmental justice implications, to invest in frontline environmental justice and historically redlined communities, to meaningfully involve affected communities during decision-making processes, and to prioritize community-driven solutions. Those who are most directly impacted by environmental injustice and climate change are the experts both on the problems and the best solutions within their specific communities.

These recommendations focus on nature-based solutions which are some of the most reliable, viable, and cost-effective methods of carbon sequestration. Solutions like protecting forests, planting trees, green infrastructure, and regenerative agriculture not only help combat climate change, but also contribute to healthy lands, waters, and communities. Truly reducing greenhouse gas emissions will require systemic and systematic changes to energy production, transportation infrastructure and the way a number of business sectors operate, including agriculture.

INDIVIDUAL ACTIONS

Here are some effective and affordable measures you can employ at your home and business to reduce greenhouse gas emissions. A big area is around energy consumption and sourcing. You should ask your energy provider about how you can get your electricity from renewable energy sources. You should also consider you vehicle choices and how much you drive, since the transportation sector is a large contributor of greenhouse gases.

You can also replace hard surfaces on your property with pervious pavement. For example, permeable pavers have open cells of gravel, moss or grass that filter rainwater, allowing it to seep back into the groundwater rather than running off into nearby waterways, bringing all kinds of pollutants with it.

In addition, you can plant a rain garden, which is a collection of native shrubs, perennials, and flowers planted along a natural slope. These gardens absorb stormwater runoff from driveways, roofs, lawns, and patios, preventing it from overloading nearby streams. They also filter up to 90% of pollutants and chemicals and 80% of sediments from stormwater before it joins the water we drink. Rain gardens can help sustain groundwater which, in turn, results in increased streamflow during dry periods, creating a better habitat for fish and other flora and fauna, and more water availability for sustaining life.

Finally, rain barrels capture water runoff from roofs and store it for later use on lawns and gardens. They also help reduce the amount of stormwater runoff from your property. It is important to remember that roof water can carry pollutants and bacteria, so before applying rain barrel water to your garden, make sure to add about one ounce of household bleach to 55 gallons of water about a day before watering, and make sure to water the soil (which acts as a filter system), not the plants directly.

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