University of
Colorado Boulder

2020
Ecosystem Trends Report

University of Colorado **Boulder**

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There is a critical need for all of us in Boulder county to understand how our ecosystems are changing in order to promote positive actions for the future of our local landscapes and communities.

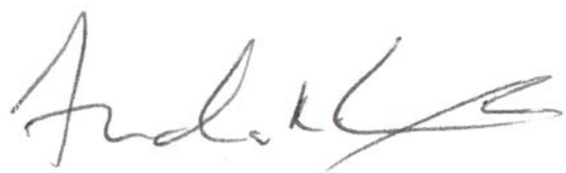
Executive summary

As the newly appointed Interim Director of the Center for Sustainable Landscapes and Communities, I am pleased to present the 2020 Ecosystems Trend s Report.

Boulder's immense environmental resources and commitment to stewardship are among the defining features of our community. Indeed, Boulder's leadership and innovation in this arena have inspired the efforts of communities around the nation. Yet we are acutely aware that the ecosystems around us are under threat from myriad pressures at local to global scales. It is this recognition that inspired this unique collaboration between the Center for Sustainable Landscapes and Communities at CU-Boulder, The City of Boulder, Boulder County, and the Community Foundation to bring you this critical and timely report.

The Ecosystem Trends Report represents several months of hard work and dedication on behalf of the project team, and the ongoing commitment of local researchers and community members who have for years been monitoring the health of our surrounding ecosystems. The report synthesizes diverse streams of evidence to reveal the current status of six categories of ecosystem health, including *climate, soil health, watershed health, air quality, biodiversity*, and *urban land cover*. Importantly, the contents of this report reflect conditions within our local community, and the data and categories were selected with the great input and guidance of local leaders and residents. As a result, this report offers new perspectives on the past, present, and future of our local ecosystems and empowers us with the tools to conserve and protect the landscapes that we hold so dear.

I want to thank the many talented professionals and community members who have made this report a reality—I am both humbled and inspired by your efforts. I look forward to the productive discussions that emerge from this report. Armed with this critical information, I am confident that the community of Boulder is ready and willing to meet the challenges that lie ahead in this time of unprecedented environmental change and that we will continue to lead in these efforts.



Amanda Carrico
Interim Director of the CSLC
University of Colorado, Boulder

Major TAKEAWAYS from the report

Climate

Boulder's climate is noticeably changing, with distinct increases in the number of hot days, as well as "wetter" late winter and spring wet periods, and "drier" summer and early fall dry periods over the past thirty years. The frequency and intensity of hail storms has increased over the past three decades as well.

Soil health

Land and farm management practices, such as low-to-no soil tillage and maintenance of high plant diversity on our open space grasslands, enhance the ability of our soils to store carbon and reduce the negative impacts of climate change. Providing greater access to water systems on small to medium-sized farms could increase the possibilities for reducing tillage.

Watershed health

Winter snowpack in our local watersheds provides Boulder's water supply, and benthic macroinvertebrates show that our creeks maintain high water quality. Urban growth and associated land cover change introduces pollutants to our water, so minimizing runoff from impervious surfaces helps to improve water quality.

Air quality

Boulder's air quality is influenced seasonally by emissions from multiple sources, including transportation and industrial natural gas production and processing. Winter air pollution is particularly noticeable. Local monitoring of air pollutant concentration allows for fine-grained measurements of air quality that can inform policy and regulatory measures.

Biodiversity

Boulder County supports an amazing variety of pollinator species, and local efforts to enhance pollinator habitat are growing. Black bears are common visitors to the city of Boulder and appear to be expanding eastward. Several species of birds of prey have declined significantly over the past 30 years, despite robust open space acquisition and management efforts.

Urban land cover

Boulder's urban tree canopy is at risk due to infestation of ash trees by the Emerald Ash Borer. Targeted tree planting efforts can help to replace these lost trees and their benefits. Tree canopy across the city of Boulder is equitably distributed, with rental housing locations having similar tree cover to owner-occupied locations.

FOR RESIDENTS

Boulder is rich with opportunities for action that can make a noticeable difference for our ecosystems, including cycling instead of driving, planting a pollinator garden, supporting efforts to monitor air quality, and getting engaged in community science projects to measure watershed health.

FOR BUSINESSES

Boulder's business community attracts employees, clients, and customers based on our high quality of life, which relates directly to air and water quality, urban green spaces, and a hospitable climate. Private sector innovations for environmental sustainability are critical to ensure Boulder remains a great place to do business.

FOR STUDENTS

The ecosystem trends described in this report offer many opportunities for new research and collaborative learning. Read and imagine how you can contribute to building knowledge about Boulder's ecosystems.

FOR ELECTED OFFICIALS

One of the core activities of the CSLC is to facilitate active and engaged public discourse on environmental issues relevant to our community. The topics included in this report were selected via public gatherings in 2019-2020 and thus offer a guide for environmental priorities in Boulder County.

About the report

There is a critical need for all of us in Boulder county to understand how our ecosystems are changing in order to promote positive actions for the future of our local landscapes and communities.

The Center for Sustainable Landscapes and Communities (CSLC) collaborated with the City of Boulder's Climate Initiatives Division in Fall 2018 to plan and host a one-day gathering on cities, ecosystems and climate change. One outcome of this vibrant and well-attended event was an identified need and motivation to regularly track and communicate the status and trends of Boulder County's ecosystems and ecosystem services.

WHY NOW?

Boulder County has a long history of community engagement with our local and regional ecosystems. Because our communities are increasingly connected with regional and global dynamics of environmental change, now is a critical moment to both understand and respond to those changes. The CSLC was identified as an ideal entity to engage students, faculty, and community members to collate information from diverse sources to produce the first-of-its-kind "Boulder Ecosystems Trends Report" in Fall 2020.

6 TREND CATEGORIES

Through several public gatherings in 2019-2020, the CSLC brought together CU students, faculty advisors, and community stakeholders to identify data types and sources relevant to current ecosystem status and trends. A long list of potential trends was vetted through community members and local land management staff, with the end result of a prioritized list of six categories of data types to be collated and synthesized for the 2020 trends report.

These six trend categories were chosen based on their relevance to local policy and management, the availability of high-quality data sources to inform the trend, and their direct impact on tracking environmental change. The six categories of trends identified for the 2020 report are: **climate, soil health, watershed health, air quality, biodiversity**, and **urban land cover.**

CLIMATE

Hail is getting bigger and more frequent for Boulder County residents

Hail storm events have increased in frequency and intensity, with the Boulder area experiencing more storms that produce larger pieces of hail than what has been on record for previous years. This has led to considerable damage to personal property, with homeowners, businesses, and growers feeling the effects in recent years.

Boulder County is part of the 'hail capital of North America', a region extending from the Front Range of the Rocky Mountains to the adjacent high plains where hailstorms are unusually common. Because of our elevation, we are closer to the freezing level in the atmosphere. This allows strong storm updrafts to reach the hail producing region of a cloud more frequently than in lower parts of the country.

Hail is a big part of the severe weather season in Colorado, and it is responsible for tens of thousands of dollars in damage each year to crops, homes, businesses and vehicles. During the period of 2017-2019, Colorado had the second highest total value of hail loss insurance claims in the nation.

Data collected on hail storms since the mid 1990's in Boulder County show that hail events are increasing in frequency, with towns across Boulder County seeing a sharp uptick in hail storms in the last few years (*Figure 1*). Additionally, hail size has also increased in recent years (*Figure 2*). Historically, hail storms frequently produced "penny-sized" hail (*See Table 1 for a breakdown in size categories*). But more recently, we have seen an increase in the frequency of large hail sizes, including half dollar, ping pong ball, and golf ball-sized hail events. Although not visually represented in the figures below, one apple-size hail event did occur in Superior 2018 - a highly unusual event.

Hand holding hail in a strawberry patch / Rbreidbrown via Wikimedia Commons

EXPLORE THE DATA

Hail events are becoming more frequent in towns across Boulder County

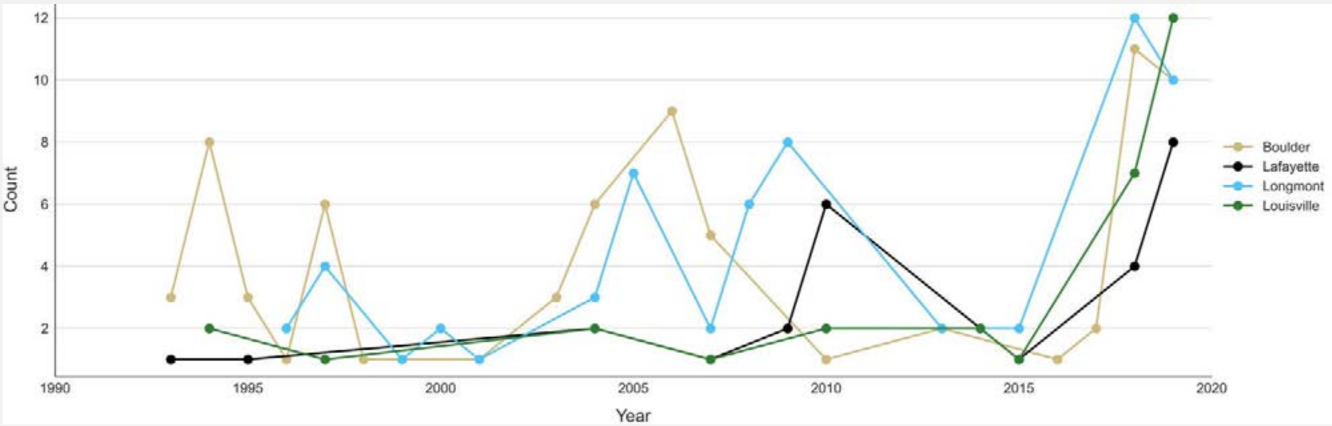
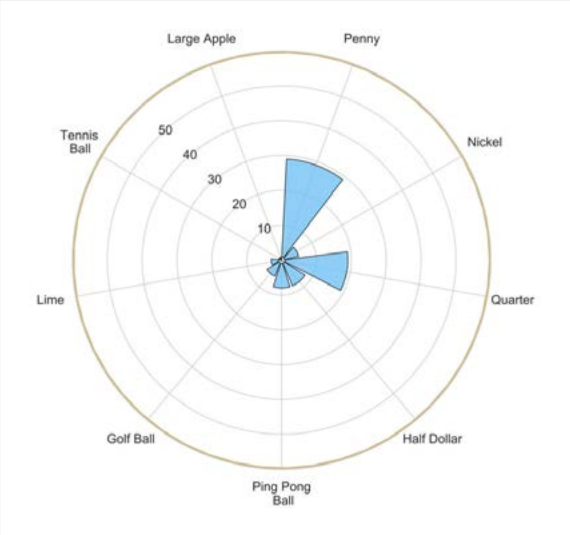
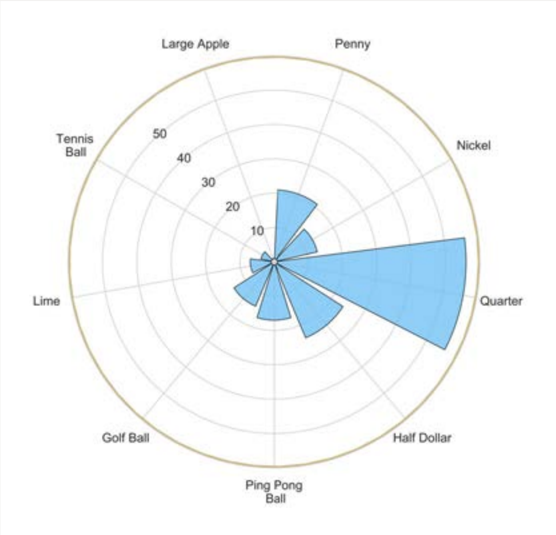


Figure 1. The number of hail events per year in the four most frequently hit towns within Boulder County. Towns include Boulder (gold), Longmont (blue), Louisville (green) and Lafayette (black). Over the last five years, hail events have increased in frequency for all four towns. For example, close to 90 hail events occurred in Boulder County in 2018 and 2019, which is 35% of the hail events recorded in the last 26 years. Note: multiple hail events can occur within a single day, so the number of occurrences could also be related to severity. *Source: NOAA's National Centers for Environmental Information Storm Events Database.*

The frequency of large hail is also increasing



Total count of hail sizes in Boulder from 1993-2005



Total count of hail sizes in Boulder from 2006-2019

Figure 2. Boulder County has only experienced nine of the fifteen size categories from 1993 to 2019. In order to evaluate changes in recorded hail diameters, the data set has been split into two groups, each representing 13 years (with 2012 being absent from the data). Across the county, the frequency and size have shifted in the last 26 years. *Source: NOAA's National Centers for Environmental Information Storm Events Database.*

Item	Size (inches)
Pea	0.25-0.375
Small Marble	0.50
Penny	0.75
Nickel	0.88
Quarter	1.00
Half Dollar	1.25
Ping Pong Ball	1.50
Golf Ball	1.75
Lime	2.00
Tennis Ball	2.50
Baseball	2.75
Large Apple	3.00
Softball	4.00
Grapefruit	4.50
Computer CD	4.74-5.00

Table 1. While Boulder County may get a lot of hail, **it is not typical for the area to experience the entire range of hail sizes** that are listed in Table 1. The county has seen 9 size variants out of the total 15. This scale has been developed by the Department of Commerce, NOAA and the National Weather Service to show the sizes of hail compared with representative objects to give a better sense of scale. These estimated equivalents are often used to describe hail as it occurs. This standardized process with 15 categories helps track the trends of hail across the country. *Source: Department of Commerce, NOAA, and the National Weather Service.*

RECOMMENDATIONS

With larger hail comes risks, especially to personal property

Support those suffering from hail storm losses. Concussive events during hail storms are possible, but more often than not, hail is most damaging to personal property. The agricultural sector in Boulder has suffered heavy losses from hail. The large pieces of ice break greenhouse windows, cause physical damage to field crops and fruit trees, and destroy farming equipment. When hail storms strike Boulder County, support our local farmers by continuing to buy their produce.

Share your hail stories! Your observations can contribute to scientific and societal understanding of the severity of hail storms. To report hail on social media, please include the time and location that the hail occurred, the size of the hail, and a photo with a measuring stick or item for comparison, if you have one. In Boulder County, report these to the National Weather Service Denver/Boulder forecast office: @ NWSBoulder

CLIMATE

"Hot" days in Boulder highlight concerning warming trend

Rising average temperatures have wider implications for Boulder, as residents try to adapt to recent, dramatic weather shifts that have been facing the area. While breaking record highs, Boulder also is dealing with a growing fire season.

While Colorado is best known for its winter landscapes, the state, including Boulder County, is endeared as a summer destination. This is partly connected to Boulder's climate, which offers an escape from the heat and humidity of other parts of the country. For example, Chautauqua started as a retreat offering respite from the heat of Texas summers.

But all of that may be changing, as average temperatures in Boulder County rise (Figure 2) and days above 90-degrees Fahrenheit become more frequent (Figure 1). Here we present 30 years of temperature data, rigorously collected by Boulder climatologists Matt Kelsch and John Brown, that highlight some concerning warming trends for Boulder County.

Rising temperatures, especially in summer months, can cause many different stresses, including heat-related illnesses for humans, rising water demands, crop losses within the agricultural sector, lengthening fire season, negative impacts on tourism, and greater pressures on species with low tolerance to heat. All of these consequences of rising temperatures place greater stress on local public health and businesses.

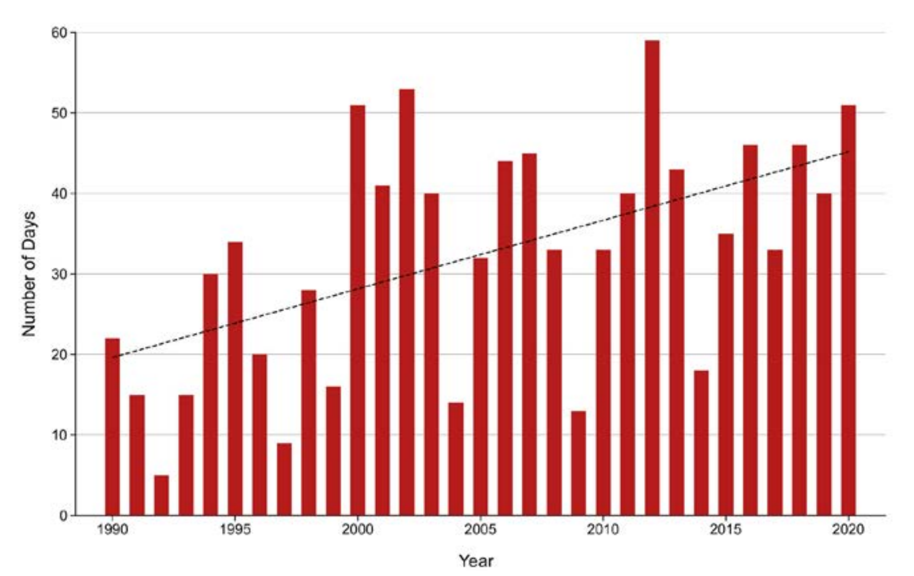
However, it remains unclear how much this warming trend is connected to climate change, and how long the trend may hold. Continuing to collect reliable data will be the key to understanding what these patterns mean for Boulder and will provide us with a better platform to guide policy and public advocacy.

Wildfires in Boulder, Colorado / Unsplash

EXPLORE THE DATA

Hot days (above 90°F) in Boulder, from 1990 to now.

Figure 1. The number of days above 90°F in Boulder, measured daily and summed per year, from 1990 to 2020. We can see natural, cyclical behavior for these average maximum temperatures (temperatures that rise and fall periodically). However, we can also see a warming trend (represented by the black dashed line) with the number of days with greater than 90°F temperatures generally rising over time. *Source: Data provided by Matt Kelsch, Associate Scientist IV at the University Corporation for Atmospheric Research (UCAR) and John Brown, NOAA's Earth System Research Lab.*



Monthly heat in Boulder, from 1991 to 2019

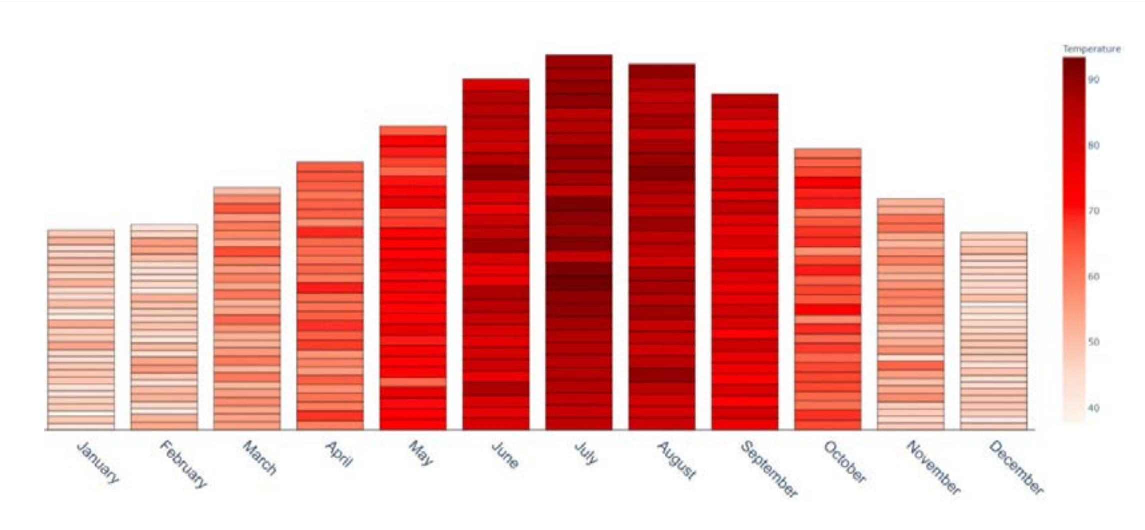


Figure 2. Average maximum temperatures, by month, from 1991 to 2019. Each vertical bar is divided into lots of little rows or horizontal bands, with each band showing the average maximum temperature (in °F) for that month in a single year. The bottom band of each vertical bar is the year 1991 and the top band of each vertical bar is 2019. On this graph, the higher the average temperature, the wider and darker are the bands in each vertical bar. Temperature fluctuations are what you might expect, with warmer months in summer and cooler months in winter. November is a great example of the type of variability we see in Boulder, with some years being quite cool (light peach, narrow bands) and other years being quite hot (orange to red, wide bands). *Source: Data provided by Matt Kelsch, Associate Scientist IV at the University Corporation for Atmospheric Research (UCAR) and John Brown, NOAA's Earth System Research Lab.*

RECOMMENDATIONS

Looking forward, how can we *address* human-caused changes in climate? And how can we *adapt* to the changes on the horizon?

Reduce carbon emissions

The main strategies to combat warming trends at the global scale are to reduce emissions of carbon dioxide related to human activities and to increase the amount of carbon stored or sequestered in our natural ecosystems. Emissions reductions can result from decisions and policies related to key energy, manufacturing and agricultural industries.

We can also each shift personal decisions that affect our daily emissions. Taking a measured approach to shifting our daily behaviors, such as driving fuel-efficient vehicles, cycling instead of driving, outfitting our homes and businesses with energy-saving appliances, using public transit when possible, and staying up-to-date on consumer products that contribute to climate change, can all have lasting impacts.

As residents of Boulder County, we can contribute to the development and implementation of policies at the local, state, and national levels that tackle emission sources that contribute to the rise in greenhouse gases. For example, the city of Boulder's Climate Mobilization Action Plan and Boulder County's Climate Action initiatives provide excellent guidance for actions to reduce emissions, such as reducing fossil fuel use in transportation, increasing energy efficiency, and reducing waste that ends up in landfills.

Enhance carbon storage

We can also contribute to efforts to enhance the carbon storage capacity of our natural ecosystems, often referred to as Natural Climate Solutions. Organizations in the city and county of Boulder have programs aimed at increasing carbon stored by soils on farmland as well as soils that support forests, wetlands, and grasslands. We can support policies and programs that advocate for the avoidance of land conversion as well as the restoration of degraded habitats to maintain or increase carbon storage in our natural ecosystems.

Adapt to changing conditions

As humans on a warming planet Earth, we need social action plans in place for adapting to the warmer temperatures that we will see in the years to come. This means designing infrastructure to navigate the rise in heat-related illness and educating the public about the elevated health risks. It is also crucial to streamline our cooling systems (for manufacturing/energy plants and A/C and refrigeration methods we use in our own homes) that are pushed to greater extremes during warmer months.

CLIMATE

Data shows Boulder's dry years are getting drier, while its wet years are getting wetter

Climate change is known to increase uncertainty when it comes to weather expectations - a trend we are seeing in Boulder County. Thirty years of precipitation data show that dry years are getting drier, wet years are getting wetter, and drought and flood events are becoming increasingly difficult to predict.

Knowing what to expect, in terms of annual precipitation, is helpful for our community. It helps growers plan their crops, ski lodges plan their season, and visitors plan their trip. But Matt Kelsch, *Associate Scientist IV at the University Corporation for Atmospheric Research (UCAR)*, and John Brown, at *NOAA's Earth System Research Lab*, have been tracking precipitation in Boulder daily for the last 30 years, and the data raise some complicated questions about Boulder's climate future.

The data, presented below, show consecutive years with significant departures from the 30-year average in annual precipitation. **The data suggest that our late winters and springs are getting wetter, while our summer months are getting drier (*Figures 1 and 2*).** It's unclear how much these changes are connected to climate change and how long this pattern may hold. Climate cycles typically run on decadal scales. However, cycles can be shorter, and much longer too.

Ultimately, this data set is a huge accomplishment and is pivotal to understanding climate trends in Boulder. However, the data raise more questions than they answer about our climate future, and it's clear that uncertainty is an increasing part of the equation.

Rain on a mountain road.
Photo by Zachary Spears / Unsplash

EXPLORE THE DATA

Annual precipitation in the city of Boulder, from 1991 to today

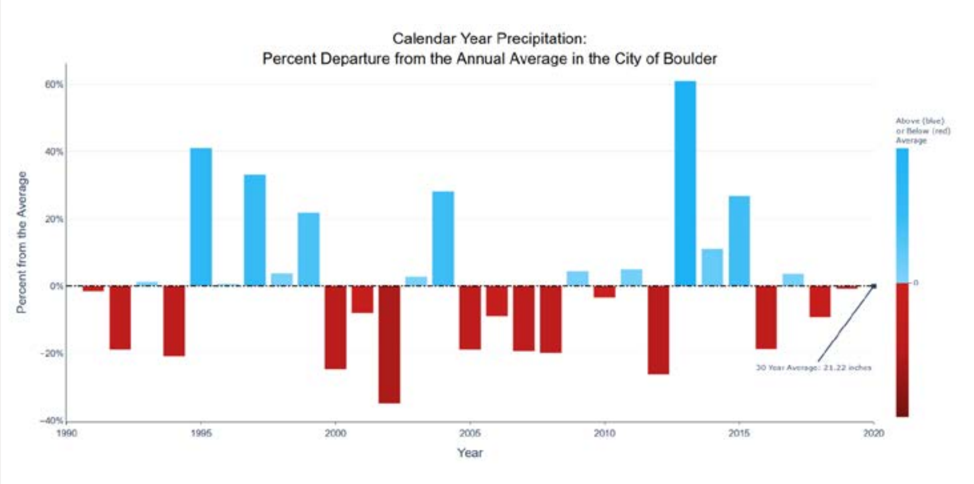


Figure 1. This chart presents the percent departure from the average in annual precipitation each year (0% represents 21.22", the annual average precipitation across the last 30 years). We can see consecutive "wet" years (i.e. years with significant departures above the average, represented by blue bars). For example, from 1995-1999, we had record-breaking highs in annual precipitation. And again in 2013, the year of the September floods in Boulder County, we saw a stretch of wet years that lasted until 2015. We can also see consecutive "dry" years (i.e. years with significant departures below the average, represented by red bars). A large portion of 2000-2010 was dry, which includes the severe drought of 2002. Dry years combined with high temperatures provide the ingredients for drought, which has important implications for the intensity of fires we will see in the years to come. *Data provided by Matt Kelsch, Associate Scientist IV at the University Corporation for Atmospheric Research (UCAR) and John Brown, NOAA's Earth System Research Lab.*

Monthly precipitation in Boulder, from 1990 to 2020

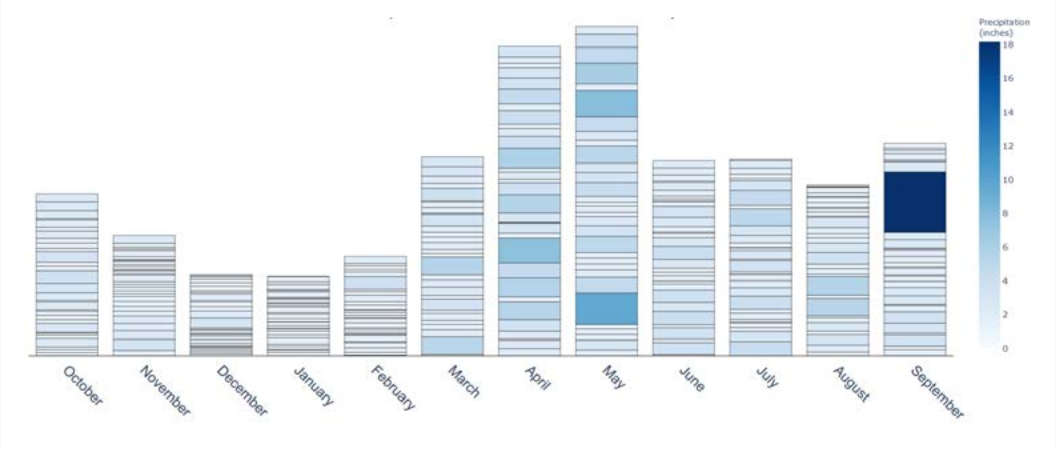


Figure 2. This chart represents monthly precipitation values measured within the city of Boulder from 1990 to 2020. Each vertical bar is divided into lots of little rows or horizontal bands, with each band showing the total precipitation (in inches) for that month in a single year. The band on the bottom of each vertical bar is 1991; the band on the top of each vertical bar is 2019. Notice the months are organized in an unusual order along the horizontal axis of the figure. This is what is known as the **water year**. The term 'water year' is used by the U.S.Geological Survey to calculate surface-water supply within a 12-month period, starting October 1st through September 30th of the following year. (Learn more about how the U.S. Geological Survey uses this measurement). These data highlight that precipitation is extremely variable among years, i.e. some bands are narrow, and some bands are wide. The more precipitation, the wider and darker the band. Note: Months with precipitation of 0 in any given year are not represented in this figure. *Data provided by Matt Kelsch, Associate Scientist IV at the University Corporation for Atmospheric Research (UCAR) and John Brown, NOAA's Earth System Research Lab.*

RECOMMENDATIONS

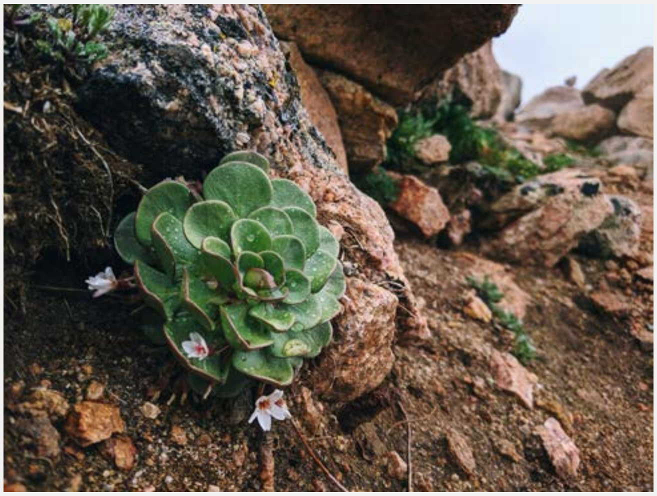
Stay informed on the impacts of precipitation trends and get involved in community science projects

At 30 years, the data set presented here isn't enough to quantify climate change or reliably predict our future climate. Thus, it is essential that we keep an ongoing record of precipitation and study emerging patterns.

To learn more about local weather phenomena and further understand how these fit into longer-term climate trends, educate yourself by reading the National Weather Service Denver/Boulder blog, with up-to-date information on Front Range weather.

You may also want to get involved in a community science project that tracks precipitation. A popular one that deploys volunteers across the country is the Community Collaborative Rain, Hail and Snow Network which reports a robust community database used by "meteorologists, hydrologists, emergency managers, city utilities (water supply, water conservation, storm water), insurance adjusters, USDA, engineers, mosquito control, ranchers and farmers, outdoor & recreation interests, teachers, students, and neighbors".

This general-interest community records and maps precipitation rates across the nation.



Rain in Boulder County / Unsplash

SOIL HEALTH

Plant diversity linked to higher levels of carbon storage in Boulder's grassland ecosystems

Scientists in Boulder County tested the relationship between plant species richness and carbon storage in the soil in grassland ecosystems. Data show that higher species richness is linked to higher percentages of organic soil carbon, on average, across all grassland types. This suggests that plant biodiversity, particularly in our native grasslands, provides important climate services.

Trees are highly celebrated for their ability to sequester carbon from the atmosphere, but soils play an even larger role in mitigating the feedback between terrestrial carbon and climate. Soils are the unsung hero of the carbon storage world, storing approximately 80% of all terrestrial carbon on Earth.

Carbon gets into the soil when plants and animals die and bring their carbon with them underground. Thus, scientists have begun exploring the connection between biodiversity above ground and carbon storage below. A 2018 study, published in the *Proceedings of the National Academy of Sciences*, found that plant diversity in grassland ecosystems had strong positive effects on soil carbon storage by increasing carbon inputs by plants and increasing soil microbial activity.

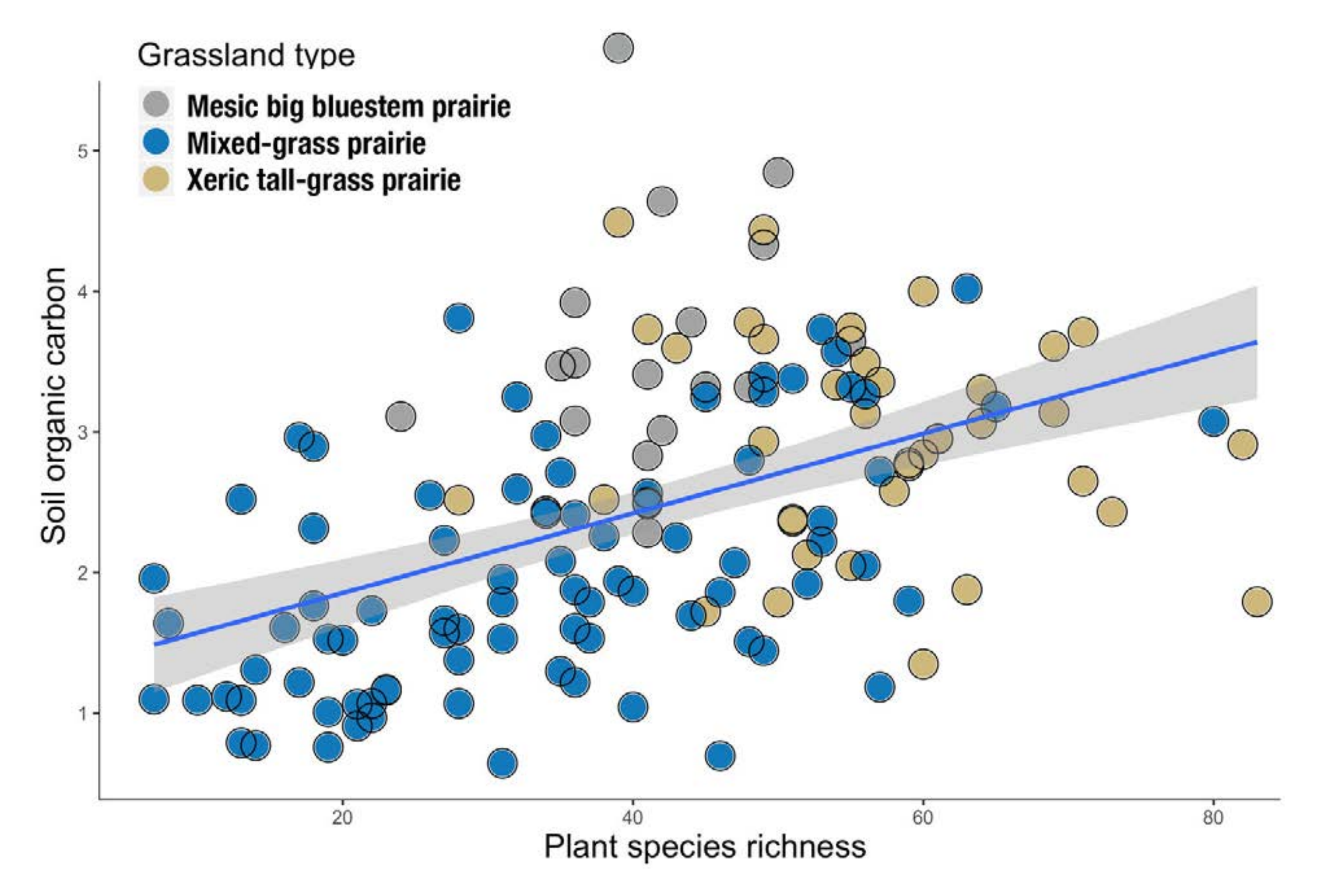
Scientists in Boulder County tested this relationship across three grassland types (**xeric tallgrass, mesic big bluestem**, and **mixed-grass**). Their data show that higher plant species richness is linked to higher percentages of organic soil carbon, but the relationship depended on the grassland type. This suggests that plant diversity plays an important role in mitigating atmospheric CO2 and regulating our local and global climate.

Another 2018 study suggests that grasslands are actually more resilient carbon sinks than forests because they are more resilient to droughts and wildfires. Thus, Boulder's native grasslands, and their diverse plant life, are an increasingly important force fighting for our climate future.

EXPLORE THE DATA

Plant species richness leads to higher carbon storage in the soil, across grassland types

Figure 1. Percentage of soil organic carbon versus plant species richness for three grassland types. Gray points represents the Mesic Big Bluestem Prairie, blue points represent the Mixed-Grass Prairie, and gold points represent the Xeric Tall Grass Prairie. Note that in grasslands where native species richness is higher, there is also higher soil organic carbon. *Source: Data was collected as part of the City of Boulder's Open Space and Mountain Parks grassland monitoring program and 2018-2019 externally funded soil monitoring. Data represents the 07/17/20 version of the data set, with a sample size of 141. Species richness was calculated as a count of all unique species, including native species, non-native species, and those not identified to the species level based on 2016 vegetation monitoring. Total percentage of carbon in the soil sample was determined using LECO furnace combustion CN analyses at the CSU Soil, Water, and Plant Testing Laboratory. Inorganic C was determined by Tracy Halward working at CSU laboratories by pressure transducer analyses.*



Get to know your grasslands

Grasslands, also known as prairies, are flat, fertile lands dominated by grasses. Prairie grasses, like those found in Boulder County, hold soil firmly in place, so erosion is minimal. Prairie grass roots are good at reaching water more than a meter deep, and they can live for a very long time. Grains are a type of grass, so the prairie grassland is perfect for growing grains like wheat, rye, and oats.

LEARN MORE ABOUT THE GRASSLAND TYPES INCLUDED IN THIS STUDY:

Mesic Big Bluestem prairie

Mesic tallgrass plant communities, dominated by big bluestem, little bluestem and switch grass, are associated with floodplains that are irrigated or naturally wet. In the Boulder Valley, mesic big bluestem communities occur in the South Boulder Creek floodplain and along ancient creek terraces. The largest remnants of Mesic Bluestem Prairie in Colorado occur in Boulder, separated from the mesic tallgrass prairie in the eastern Great Plains by hundreds of miles. The robust rodent populations occurring in this habitat type attract Swainson's hawks and other raptors that forage in grassland habitats. These grasslands provide habitat for several rare butterflies, including the Ottoe skipper and Arogos skipper. These species depend on tallgrass plant species and are considered rare and imperiled throughout the Great Plains. These grasslands also support many grassland bird species, such as bobolinks. *Photo by Bradford S. Slaughter.*

Xeric tall grass prairie

Before the steel plow, tall grass prairies stretched from southern Canada to northern Texas. They flourished in areas with rich soils and moderate rainfall. Some of the largest areas of upland tallgrass plant communities — dominated by big bluestem (Andropogon gerardii) — remaining in Colorado are in the Boulder area. These foothills tallgrass communities share similarities with the tallgrass prairies of the eastern Great Plains, but also have distinctive characteristics of their own. The Xeric Tallgrass Prairie includes several community types occurring in open meadows, savannas at the prairie-forest interface, and as matrix-forming grasslands on prominent mesa tops. Large, unfragmented patches of xeric tallgrass create seasonal habitat for a suite of grassland nesting birds, and are used seasonally by elk. Tallgrass prairie is considered rare and imperiled globally, and is one of the most endangered vegetation types in the world. *Photo by Caasi Saari.*

Mixedgrass prairie mosaic

At the forest-grassland interface or ecotone, mid- and short-grass prairie species blend with Rocky Mountain species to form a distinctive and localized set of plant associations. Diverse topography, soils and geology combine with climate to create habitat for grassland plant associations characterized by mid-height species such as western wheatgrass, needleand-thread grass, green needlegrass, New Mexico feathergrass, sideoats grama, little bluestem, and Rocky Mountain bluegrass. The mixedgrass mosaic supports a diverse fauna including uncommon species such as the shorthorned lizard, olive-backed pocket mouse, and several rare butterfly species. Large blocks of mixedgrass prairie provide habitat for numerous grassland nesting birds, the American badger, and elk. Much of the land inhabited by black-tailed prairie dogs in Boulder County is mixedgrass prairie. *Photo by Jan Huber / Unsplash.*

RECOMMENDATIONS

Conserve grassland ecosystems, and areas of high plant diversity, to encourage carbon sequestration and storage.

There is a clear relationship between plant diversity and carbon storage, but this relationship varies across grassland type. Mixed-grass prairies store the lowest amount of soil carbon, on average, and the Mesic big bluestem prairies store the most. The Xeric tall grass prairies had the highest levels of species diversity, suggesting their potential for future carbon storage.

These relationships between plant diversity and carbon storage in grasslands mandate conservation action.

Not only are these ecosystems endangered globally, they are providing a valuable service to our community in the form of carbon storage. We need to continue restoring and protecting grassland ecosystems to maintain this service and provide a home for threatened and endangered grassland species.

Learn more about the geologic history, ecology, species diversity, management, and monitoring of Boulder's grasslands in the Grassland Ecosystem Management Plan and in Boulder County's management plans and policies.

SOIL HEALTH

Many organic farms have high phosphorous levels, often exceeding recommended thresholds

Livestock manure is a readily available and cost-effective fertilizer, making it a key treatment in both conventional and organic farming. However, manure is also rich in phosphorous, which can leach into the water system and accelerate eutrophication. Data show organic farms have much higher phosphorous levels in their soil, many above the recommended threshold.

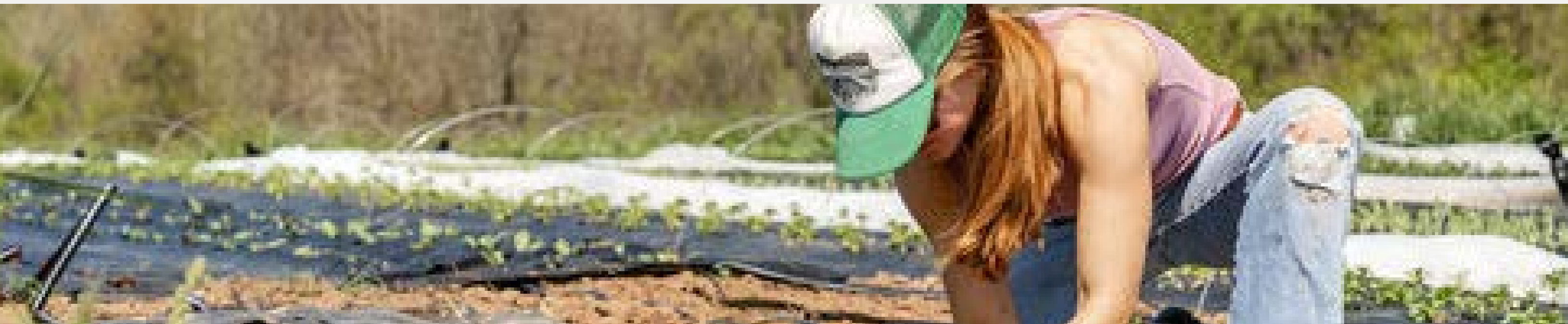
Livestock manure is a readily available and cost-effective fertilizer, making it a go-to in both conventional and organic farming. Manure provides important plant nutrients, like nitrogen, and can be an excellent soil conditioner. Properly managed manure applications recycle nutrients to crops, improve soil quality, and protect water quality.

Because organic farmers cannot use chemical fertilizers, they often apply large amounts of manure to boost their nitrogen levels. However, manure is also rich in phosphorous, which can build up in soils over time. Phosphorus is an essential element for plant and animal growth, but it also increases the biological productivity of surface waters by accelerating eutrophication. Because it causes increased growth of algae and aquatic weeds, as well as oxygen shortages resulting from their die-off and decomposition, eutrophication restricts water use for fisheries, recreation, and drinking.

Conventional farmers also apply manure but often in much smaller amounts, because they rely more on chemical fertilizers to supply crops with nitrogen. Additionally, many conventional farms have crop consultants that test their soil regularly and adjust the amendments to maintain soil health and nutrient levels.

Data from the Citizen Science Soil Health Project show that many organic farms in Boulder County have much higher phosphorous levels in their soil than conventional farms. In addition, phosphorous levels often exceed the threshold recommended for water quality protection.

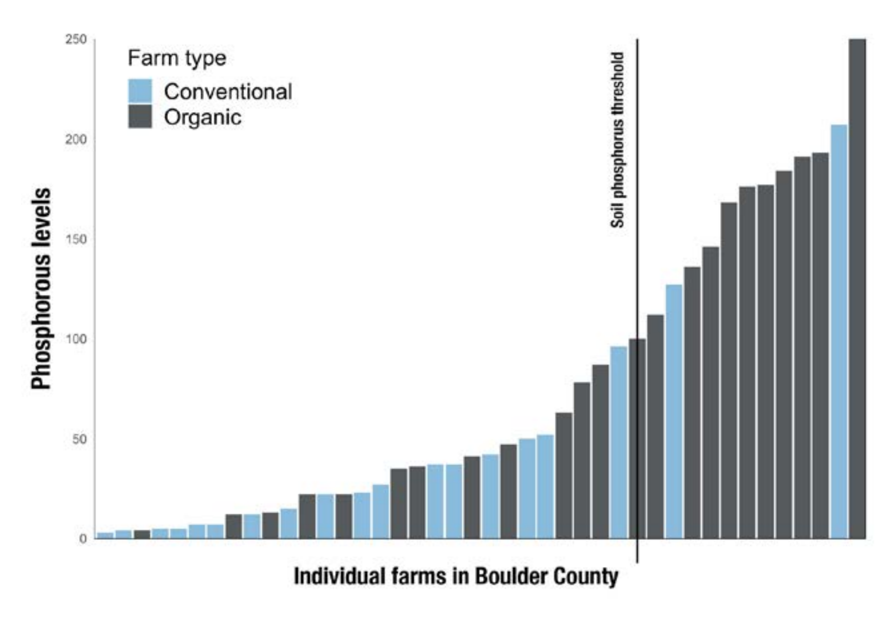
Here we explore the data and make recommendations for monitoring soil health in Boulder County. We suggest that Boulder County continue to help farmers regularly test and restore their soils, as well as incorporating legume cover crops and establishing buffer strips along fields, to absorb nutrient runoff.



EXPLORE THE DATA

Phosphorous levels in Boulder's soil: Conventional versus Organic farms

Figure 1. Phosphorus levels (mg P kg-1) in the soil of conventional versus organic farms. Blue bars represent conventional farms, while gray bars represent organic farms. Note that organic farms more often surpass the 100 mg P kg-1 recommended phosphorus threshold for water quality protection. *Source: Data collected from the Citizen Science Soil Health Project. Soil health was calculated from soil health tests and annual soil health scores for each participating grower, using the Haney/Phospho-Lipid Fatty Acid (PLFA) soil tests from Ward Labs.*



Percentage of farms at or above the recommended phosphorous threshold

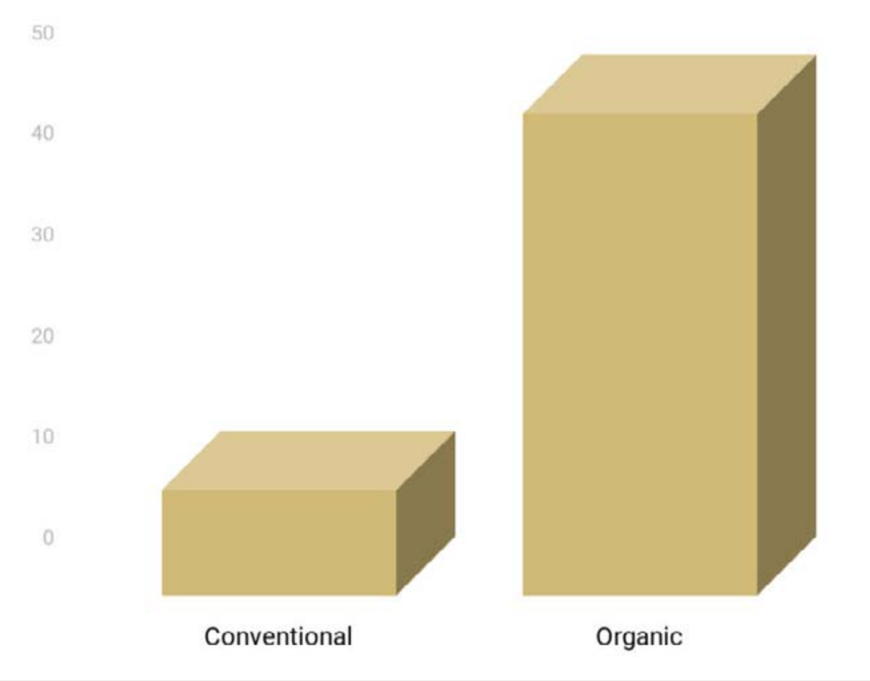


Figure 2. Percentage of farms at or above the phosphorus threshold, split by conventional and organic farm types. Only 10.5% of conventional farms, compared to 47.8% of organic farms, are at or above the recommended phosphorous threshold. *Source: Data collected from the Citizen Science Soil Health Project. Soil health was calculated from soil health tests and annual soil health scores for each participating grower, using the Haney/Phospho-Lipid Fatty Acid (PLFA) soil tests from Ward Labs.*

RECOMMENDATIONS

Partner with organic farms to improve soil monitoring and remedy unhealthy soils.

Large-scale and conventional growers often hire consultants to assess soil health and provide recommendations for fertilizer applications. These services include calculations for how much manure will be needed per acre of land and suggestions for application timelines.

Because they are often able to monitor nutrients in their soil through these consulting services, farms can avoid harmful buildups of phosphorus in the soil. However, many organic farmers cannot afford such services, and the soil testing kits readily available on the market have varying quality.

But without reliable and consistent soil testing, it can be difficult for farmers to make informed decisions about their fertilizer applications and avoid applying too much.

We suggest that Boulder County invest in monitoring systems for small and organic farms, to ensure all farms have access to quality testing for their soil.

Additionally, Boulder can help small and organic farms afford more costly alternative fertilizers (such as blood meal or fish fertilizer), which can help reduce the amount of phosphorus left over in the soil.

Boulder can also help growers incorporate legume cover crops into rotations to boost nitrogen but not phosphorus, so they apply less manure. Boulder can also help growers establish adequate buffer strips along fields, such as those used very successfully on Iowa farms, to slow and absorb nutrient run-off and protect waterways.

Healthy soil safeguards Boulder's potential for local, healthy foods / Unsplash

SOIL HEALTH

Tillage practices linked to poor soil health and reduced soil carbon

In Boulder County, tillage practices can be grouped into three categories: **conventional tillage** (*intensive, deep seasonal tillage like plowing or rototilling*), r**educed tillage** (*tillage that disturbs only a portion of the soil surface, like strip-till or chisel plowing*), and **zero tillage** (*no soil disturbance*). Data show that Boulder farms using conventional and reduced tillage had poorer soil health and less soil carbon compared to open lands (pastures, grasslands, forests, and orchards) with no soil tillage.

For many farms across the world, tilling soil is an essential part of farm practices. Tilling is the process of turning over old soil, in order to expose more nutritious, deeper soil for sowing new crops. For farmers, tillage is a way to solve problems. Tillage is used for seedbed preparation, weed suppression, soil aeration, turning over cover crops and forages, burying heavy crop residue, leveling the soil, incorporating manure and fertilizer into the root zone and more. However, in recent years, more and more farmers are switching to reduced-tillage practices. Since tillage fractures the soil, it disrupts soil structure, accelerating surface runoff and soil erosion. Tillage also reduces crop residue, which helps cushion the force of pounding raindrops, and disrupts the microorganisms in the soil, leading to poor soil health.

In Boulder County, tillage practices can be grouped into three categories: **conventional tillage** (intensive, deep seasonal tillage like plowing or rototilling), **reduced tillage** (tillage that disturbs only a portion of the soil surface, like strip-till or chisel plowing), and **zero tillage** (no soil disturbance). Data provided by the Citizen Science Soil Health Project, a grower-driven initiative that offers soil health tests and annual soil health scores for each participating grower, show that more intense tillage has a detrimental effect on soil health, because median soil health scores increase as tillage intensity decreases (*Figure 1*). Boulder farms using conventional tillage had the lowest soil health scores with a median score of 10. Boulder farms using reduced tillage had a better soil health score with a median of 13. However, lands with zero-tillage practices had the best soil health score with a median score of 20.

So why do farmers till the soil?

Farmers till to control weeds, loosen soil compaction, incorporate organic matter and fertilizers into the root zone, and prepare seedbeds. Organic farmers are especially dependent on plowing because they cannot use herbicides to control weeds. Most of Boulder's agricultural water is supplied by open irrigation ditches, which are lined with plants that drop seeds into the passing water. Many Boulder farmers flood irrigate their fields with raw ditch water, a traditional low-tech economical water application method. However, flood irrigation can compact the soil and introduce weed seed from open irrigation ditches, thus forcing farmers, especially organic farmers, to plow and cultivate more.

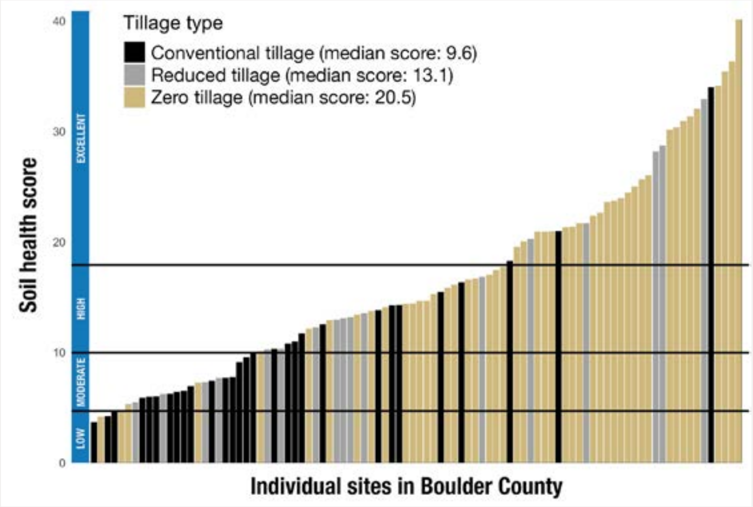
The importance of irrigation in a semi-arid landscape

Other water application methods like drip irrigation systems, sprinklers or pivot irrigation systems can solve weed-seed and compaction problems for farmers and lead to less intensive tillage. However, these systems require large investments in holding ponds, pumps, wells, piping, electricity, control systems, and more. Boulder farmers leasing city or county agricultural lands on short-term leases are unable to afford such investments. Thus, Boulder must continue to invest in upgrading water application systems, like holding ponds, pumps, and drip/sprinkler/pivot systems for farmers, to expand options for zero-tillage practices and safeguard soil health throughout the county.

EXPLORE THE DATA

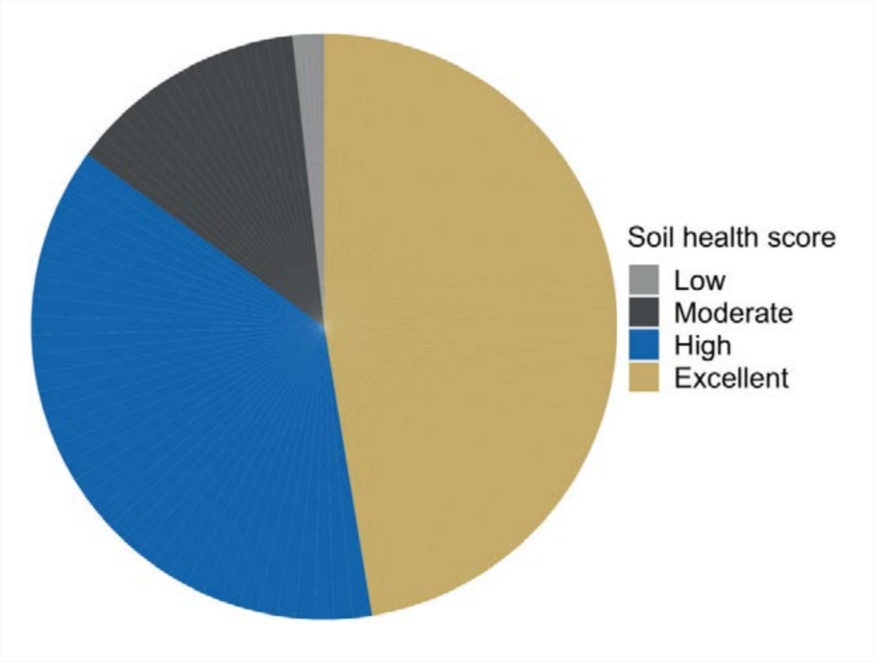
Soil health across tillage practices

Figure 1. Soil health for conventional, reduced, and zero tillage sites. Black bars represent **conventional** tillage farms, gray bars represent **reduced** tillage farms, and gold bars represent **zero** tillage lands (no-till farms but also other land types that have not been plowed, including perennial pastures, horse, cow pastures, orchard, golf courses, Christmas trees, and Open Space grasslands and forests). The black horizontal lines indicate health score thresholds, where health scores below 5 represent **low** soil health, scores between 5-10 represent **moderate** soil health, 11-17 represent **high** soil health, and scores 18 and above represent **excellent** soil health.
Source: Data provided by Elizabeth Black from the Citizen Science Soil Health Project. Soil health was calculated from soil health tests and annual soil health scores for each participating grower, using the Haney/ Phospho-Lipid Fatty Acid (PLFA) soil tests from Ward Labs.



Distribution of Soil Health Scores across Boulder County farms and Open Space lands

Figure 2. Percentages of sites on farms and open space lands with soils in each soil health score category. 5.3% of sites had low soil health scores (**light grey**); 20.2% of sites had moderate soil health scores (**dark grey**); 38.3% of sites had high soil health scores (**blue**); and 36.2% of sites had excellent soil health scores (**gold**).
Source: Data provided by Elizabeth Black from the Citizen Science Soil Health Project. Soil health was calculated from soil health tests and annual soil health scores for each participating grower, using the Haney/ Phospho-Lipid Fatty Acid (PLFA) soil tests from Ward Labs.



A little background on the 'Haney Test', which we use to calculate soil score:

All soil contains many small, easily-absorbed, plant-available molecules of minerals like soluble salts, trace minerals, inorganic nitrogen (nitrates), inorganic phosphorus (orthophosphates), and potassium. Soil has an inherent pH (acid/base balance) that determines how well some of these minerals are absorbed by plant roots.

Soil also contains soil organic matter, which is where soil microbes live, eat and die. Soil organic matter contains organic carbon, which microbes eat. Soil organic matter also stores organic nitrogen and organic phosphorus in large complex organic molecules which are not readily plant-available.

Soil microbes break down ("mineralize") some of these large organic molecules into small easily-absorbed plant-available molecules of nitrate and orthophosphate. As they work, soil microbes exhale CO2, measured as soil respiration.

Haney's Soil Health Score is a weighted sum of a soil's respiration plus the organic carbon and organic nitrogen that is available in the soil to feed both soil microbes and plants. A higher Soil Health Score means that there are more soil microbes, there is more food for them, and there are more soil nutrients available for them to break down and supply to plants.

Haney Soil Health measurement	**Definition**	**Role in soil health**
Soil respiration	The amount of CO_2 that is released in a 24-hour period from soil microbes	This metric represents the microbial activity of the soil, which is an excellent indicator of soil fertility
Water-extractable organic carbon	The amount of organic carbon extracted from the soil only using water	Since soil microbes use organic carbon, this metric is an indicator for soil quality
Water-extractable organic nitrogen	The amount of nitrogen that can be extracted by water (excluding inorganic nitrogen sources)	Soil microbes easily break down organic nitrogen to inorganic nitrogen forms that can be used by plants
Organic carbon: Organic nitrogen ratio	A comparison of the amount of water extractable carbon to water extractable organic nitrogen	This ratio represents the amount of microbial activity used for mineralization of nitrogen and phosphorus

Table 1. Variables contributing to the Haney Soil Health Score.
Source: table built with explanation from Midwest Laboratories.

Soil carbon in grassland sites with and without historic tillage

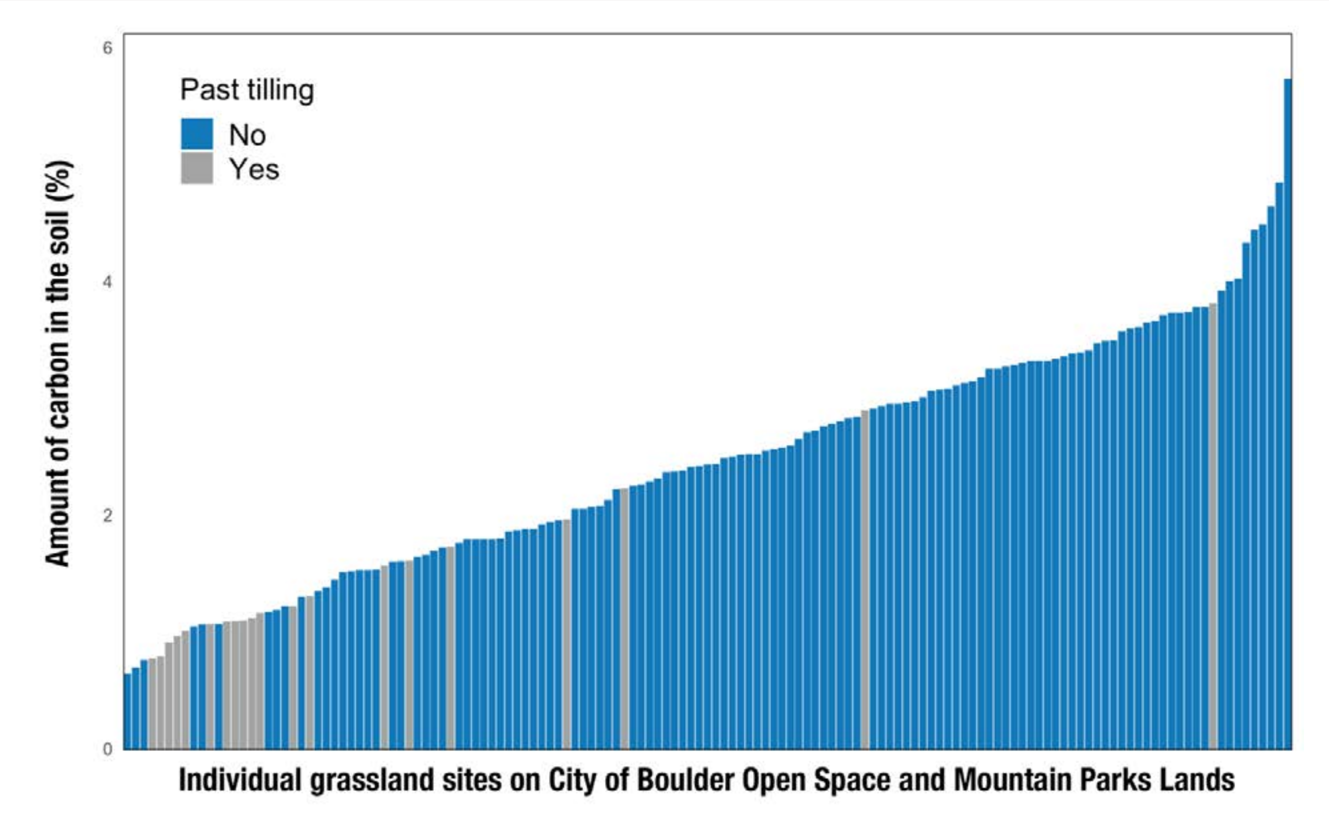


Figure 3. Percentage of organic carbon in the soil sample as determined by difference between the total carbon and inorganic carbon percentage. Blue bars represent grassland sites without historic tilling and gray bars represent grassland sites with historic tilling. Note that grassland sites without historic tilling tend to have higher percentages of organic carbon.

Source: Data was collected as part of the City of Boulder's Open Space and Mountain Parks grassland monitoring program and 2018-2019 externally funded soil monitoring. Data represents the 07/17/20 version of the data set with a sample size of 141. Total percentage of carbon in the soil sample was determined using LECO furnace combustion CN analyses at the CSU Soil, Water, and Plant Testing Laboratory. Inorganic C was determined by Tracy Halward working at CSU laboratories by pressure transducer analyses. Tillage data was derived by intersecting the transect locations with OSMP's 2018 Agricultural Layer depicting historic tilling or agricultural conversion. Note that some tilled sites have also received additional treatments to accelerate conversion from agriculture to native grassland such as seeding, planting and erosion protection.

RECOMMENDATIONS

Continue to upgrade water systems, so farmers have options for zero-tillage practices.

A pivot system is a movable pipe structure that rotates around a central pivot point connected to a water supply, pump, and electricity. For large farms, pivot irrigation systems are the most popular sprinkler irrigation systems in the world because of their high efficiency, high uniformity, ability to irrigate uneven terrain, and low capital, maintenance, and management costs. And because pivot irrigation does not compact the soil, unlike flood irrigation systems, pivot systems allow farmers to consider reduced and zero-tillage practices.

Boulder County provides some incentives for farms that are seeking access to improved water systems, enabling more of these pivot systems to be installed within Boulder County. However, pivots are often more appropriate for large-scale growers.

Smaller farms need smaller more complex systems and have less capital to allocate to upgrades, often leaving them with fewer solutions that don't involve tilling. Organic growers in particular have fewer alternatives available because tilling is a main source of weed control without the use of chemical herbicides.

With that in mind, a broader allocation of resources such as holding ponds, filtration systems, pumps, sprinkler/drip systems and electricity, to small and medium-sized farms that could benefit from these upgrades would improve the outlook for heavily tilled land within Boulder County. While there are many options to consider, pivot systems in particular would provide large farms with an effective management system to let their over-tilled soil recover.

RESOURCES: Waller P., Yitayew M. (2016) Center Pivot Irrigation Systems. In: Irrigation and Drainage Engineering. Springer, Cham. https://doi.org/10.1007/978-3-319-05699-9_12

A heavily plowed field ready for planting. Data show that plowing results in both lower soil health and soil carbon.

WATERSHED HEALTH

Benthic macroinvertebrates as an indicator of watershed health

Watersheds are a network of creeks, streams, rivers and lakes, and they are part of a nested system of watersheds. Watersheds can be small, like Left Hand Creek and Boulder Creek watersheds, or they can be large like the St. Vrain Creek watershed that contains them both. Watersheds contain far more than water bodies. They include the land that drains into the water bodies from rain, floods, or snow melt. Here we present data on two watersheds, Left Hand Creek and Boulder Creek watersheds, as an indication of Boulder County's watershed health.

While watershed health can be studied in many ways (such as looking at conditions of forests, cities, or grasslands), studying water in a creek is a great indicator of conditions in the creek and the surrounding land. In the creek, the Benthic Macroinvertebrate (BMI) community is a key indicator of water quality and can indicate the state of the watershed in general.

BMI are insects that naturally reside in our creeks and streams - the term 'macro' is used because we can see the invertebrates without a microscope. BMI come in the form of worms, snails, beetles and larvae, e.g. dragonflies. They are prey for both animals in the water, like fish, as well as animals that live by the water, like birds. They are also predators of other invertebrates. Additionally, they break down and recycle organic matter, such as plant parts (leaves and sticks).

BMI are one of many variables used to describe water quality because many macroinvertebrate species are sensitive to pollutants. Therefore, the presence or absence of these particular taxa can indicate the state of their ecosystem. From a BMI sample, scientists and land managers calculate a Multi-Metric Index (MMI) as an indicator of water quality and watershed conditions. The MMI score, *presented in Figures 1 and 2 and described in more detail below*, integrates multiple BMI community metrics. This score can identify disturbance in a water source that simultaneously can describe the state of our watershed.

While we only focus on MMI in this report, there are many different ways to use the BMI community to evaluate the health of water bodies and their watersheds.

EXPLORE THE DATA

Mapping MMI scores across Boulder Creek and Left Hand Creek watersheds, as an indication of watershed health.

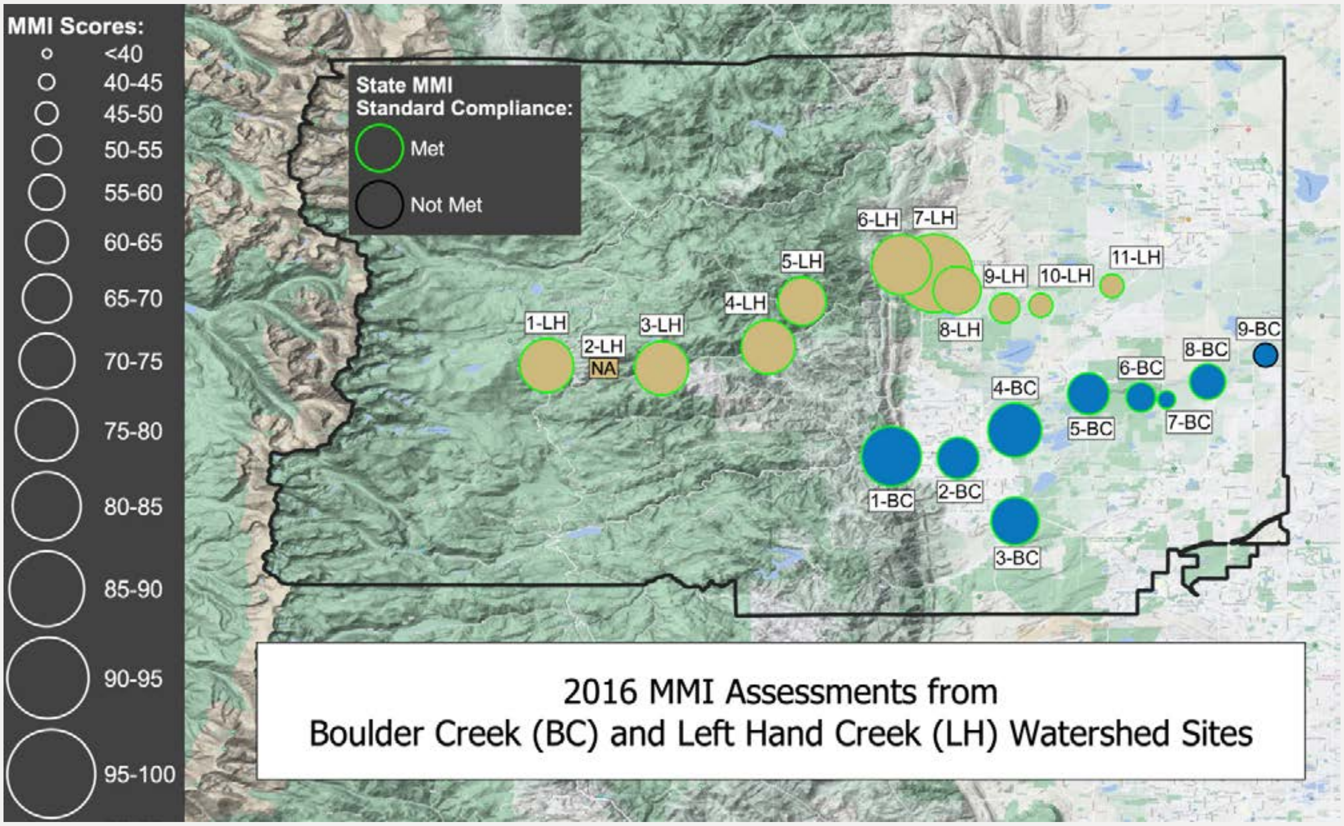


Figure 1. MMI Map 2016. MMI scores (Multi-Metric Index) measure the level of biological disturbance based on the composition of BMI (benthic macroinvertebrate) communities. These visible water insects in both Boulder Creek (BC) and Left Hand Creek (LH) are indicators of watershed health because they have predictable responses to disturbance. MMI scores give state regulators a quantitative method to assess water bodies based on these predictive responses. Acceptable MMI scores vary by location, but **overall, the higher the MMI score (the larger the circle), the better the BMI community, an indicator of watershed health.** In 2016, state acceptable MMI scores for Left Hand Creek sites were 50 in the foothills/high plains (6-LH to 11-LH), and 52 in the canyon (1-LH to 5-LH). All but one site met expectation. The 2-LH site is represented by 'NA' because there were too few BMI in the sample to calculate an MMI score. The low count of BMI at this site is likely due to poor water quality caused by acidic mine drainage from the Captain Jack Mine just upstream from the 2-LH site. Boulder Creek also met state standards at most of their foothills/high plains sites (1-BC to 9-BC), with MMI scores above 52. The two monitoring locations that did not meet the state criteria (7-BC and 9-BC) were further examined using the state's method. Site 7-BC was later found to meet the state's MMI standard (the green border), but 9-BC did not with an MMI score of 50.2 (represented by a black border). However, if 9-BC's MMI score was calculated using prairie as its location type, arguably more appropriate, then it too would meet the state's MMI score standard. *Source: Left Hand Watershed Center and the City of Boulder.*

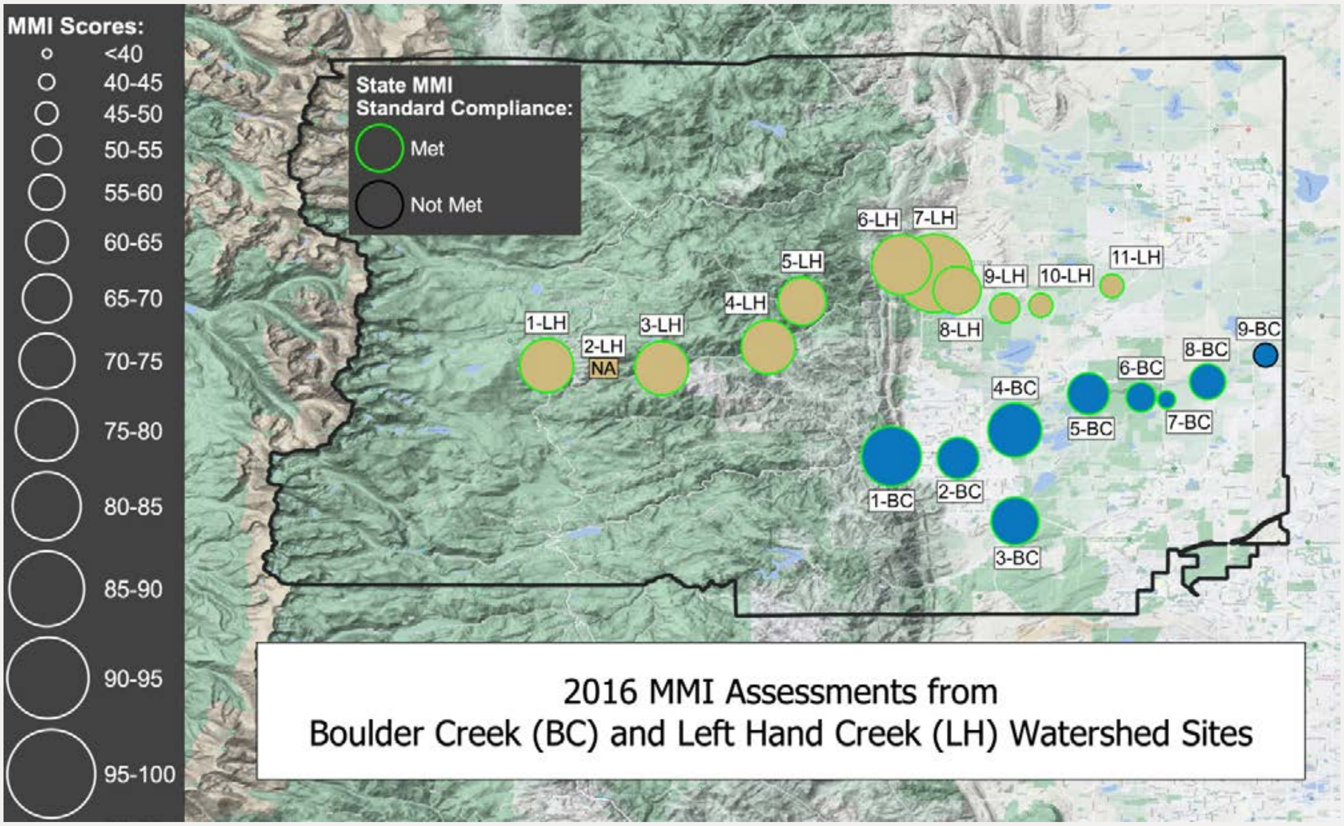


Figure 2. MMI Map 2018. MMI score standards were updated in 2018. The updated scoring process shifted Boulder Creek's acceptable MMI score to 45.2 at all sites, while Left Hand Creek's acceptable scores remained the same at 52 in the canyon and 50 in the foothills/high plains. Colors and abbreviations in this figure remain the same as in Figure 1 (LH gold and BC blue). Boulder Creek met state standards at 100% of their sites in 2018. In 2018, 73% of Left Hand Creek sites met state standards, and included the site 2-LH. There are two likely sources of perturbation in Left Hand Creek. In the canyon, just above site 2-LH, Captain Jack Mine continued to impair water quality. Moreover, the mine had a release prior to this sample that created acidic conditions with metal deposits causing fish kills and a decrease of sensitive BMI for miles downstream. Events like this can cause low MMI scores as it did at 2-LH (MMI 46.5). Downstream in the foothills/plains, 8-LH and 9-LH BMI samples may have been impacted by dry periods or low to no flow conditions. Low stream flow or available water reduces BMI habitat quality and is likely more concentrated with nutrients or other pollutants that may lower MMI scores from 2016 to below state standards (8-LH and 9-LH with MMI scores of 29.7 and 40.8, respectively). All three sites that did not meet the state standard are represented with a black border. *Source: Left Hand Watershed Center and the City of Boulder.*

POSSIBLE REASONS FOR LOW MMI SCORES

The influential factors of BMIs' community status are both natural (e.g. floods or wildfire) and anthropogenic (e.g. urbanization or agriculture).

Disturbances can impact water quality at the local scale and have a much wider impact on the watershed. For example, mines can release toxic substances into waterways that can disrupt BMI habitats, reflected in low MMI scores. In other locations, it is possible that low stream flow, either natural or from water diversion (e.g. for drinking water or agricultural needs), can cause stress in BMI ecosystems. Other potential disturbances include nutrient deposition from agriculture (*anthropogenic*) and post-fire runoff (*natural*). Disturbances can also vary in scale, impacting BMI locally or for long distances. For example, the fires of October 2020 may be visible in future MMI scores for Boulder County watersheds.

RECOMMENDATIONS

Support organizational and public action for watershed health.

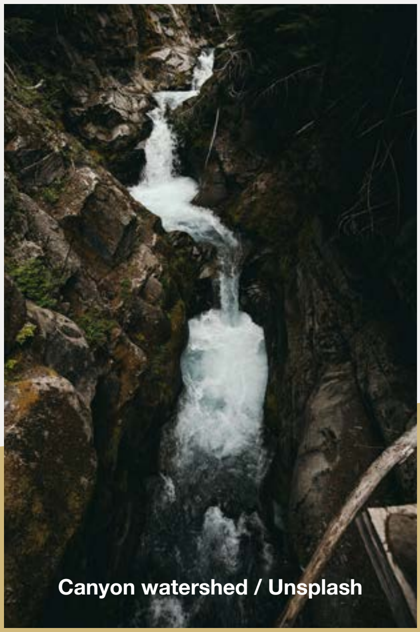
Left Hand Watershed Center will continue to monitor and assess watershed health and use data collected to inform future management recommendations and actions. This includes a new effort to work with stakeholders throughout the St. Vrain Basin, including the city of Boulder, to develop a shared basin-scale adaptive management framework.

Incorporating forests into adaptive management is also a critical next step, particularly given the recent local fires. In all of their work, the Watershed Center engages the community in science, stewardship, and place-based participatory learning.

The city of Boulder conducts routine water quality and biological monitoring along Boulder Creek, implements stream restoration projects, and engages in collaborative education and outreach programs. These initiatives aim to minimize the city's impact on water quality and improve both surface water conditions and watershed health for the greater Boulder Creek watershed. To find out how you can help protect your watershed, visit Keep it Clean Partnership.

To learn more about the Watershed Center's community science, stewardship and education programs, visit the Left Hand Watershed Center website.

Benthic macroinvertebrate / Freepik



Canyon watershed / Unsplash

Mosquito larvae / Freepik

WATERSHED HEALTH

Snowpack – vital for our way of life and for healthy watersheds

The snowpack that accumulates each winter in Boulder County has a huge influence on the quality and quantity of water that we'll have to use over the course of the summer and fall, and how full our streams and rivers will be to support aquatic ecosystems.

Snowpack is defined in the dictionary as "a seasonal accumulation of slow-melting packed snow." To those of us who live and work in the semi-arid landscapes of Boulder County, snowpack is essential for providing the water we need to drink, swim, water our crops and lawn, and use for industrial purposes, as well as supporting our diverse and productive wetland, stream, and riparian ecosystems.

Boulder County contains the St. Vrain and Boulder Creek watersheds, and sits within the larger South Platte River Basin, which covers most of central and eastern Colorado, from the Continental Divide west of Boulder to the Nebraska border. The Natural Resources Conservation Service (NRCS), a federal agency with offices in each county, gathers data on snowpack to predict spring runoff and summer streamflow amounts. These are typically reported as a percentage compared to the median snowpack, derived from the data from all years in the data set.

In Boulder County, the NRCS uses several SNOTEL ("SNOw TELemetry Network") sites, including one near Niwot Ridge in the mountains of western Boulder County, to estimate snowpack for the St. Vrain Creek and Boulder Creek watersheds. The figures below show that the accumulation of snowpack in these two adjacent watersheds is fairly similar, except for two months of the year.

In particular, for the St. Vrain Creek watershed, January is far more variable than other months across the 30-year period and in 2007, the January snowpack exceeded the median snowpack by about 200%. In addition to the five months of the year tracked for the St. Vrain Creek watershed, the Boulder Creek watershed contains data for the month of June, which is the most variable month of the data set (*Figure 1*). Since 2015, snowpack has generally been higher than the median for the 30-year period for both watersheds.

EXPLORE THE DATA

30 years of snowpack data for the St. Vrain and Boulder Creek watersheds

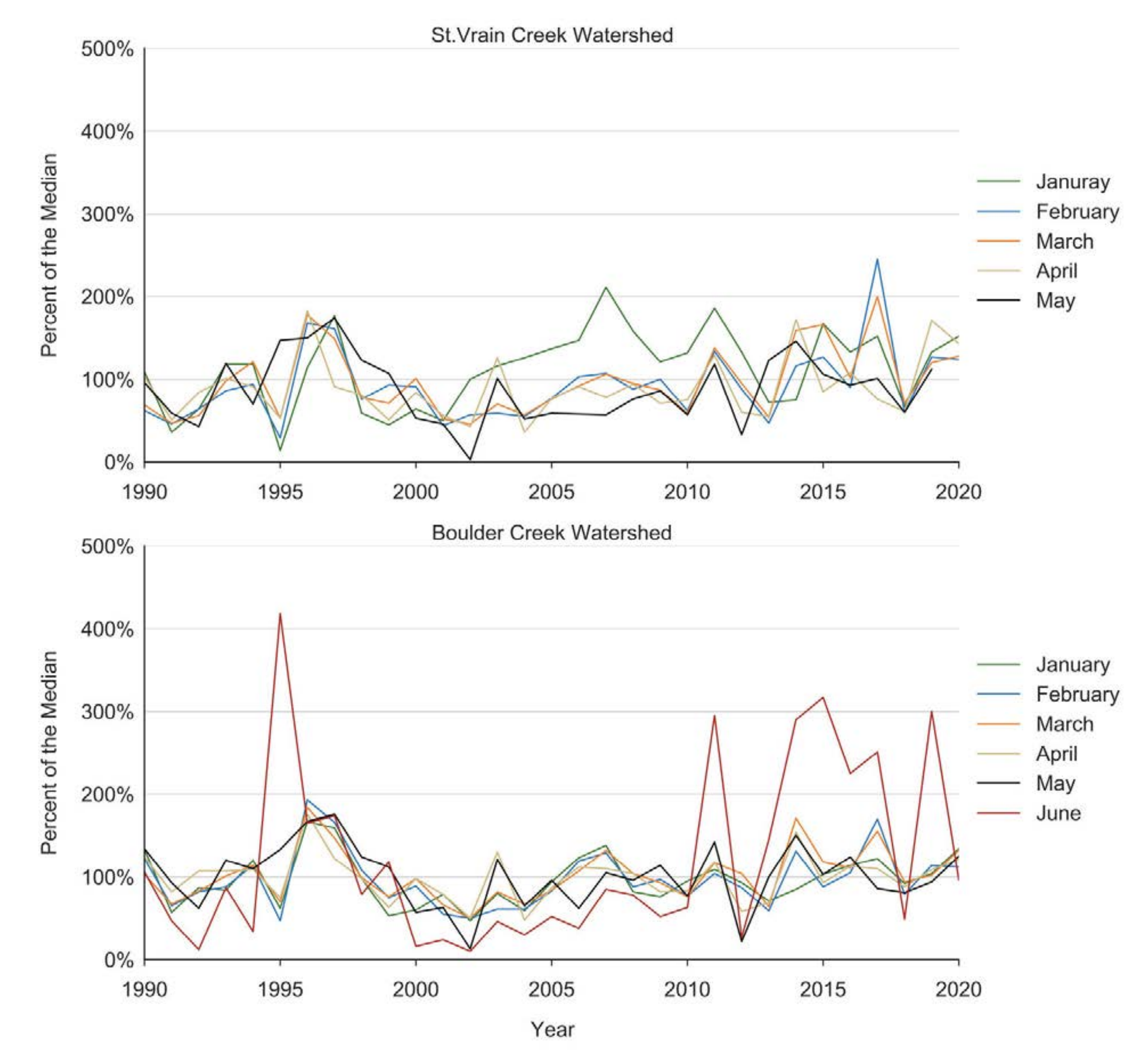


Figure 1. Snowpack data (percent of the median) for the St. Vrain (upper panel) and Boulder Creek (lower panel) watersheds, from 1990 to 2020. For each year of the data set, the value of snowpack depth plotted for that month represents the departure from the median value for that month over the entire data set. The USDA Natural Resource Conservation Service uses several SNOTEL sites to calculate the St. Vrain Creek and Boulder Creek watershed snowpack. The seasonal patterns of snowpack in these two adjacent watersheds are remarkably similar. However, only the Boulder Creek data set contains snowpack data for the month of June. *Source: USDA NRCS Colorado data from several SNOTEL sites.*

ABOUT THE DATA

30 years of snowpack data for the St. Vrain and Boulder Creek watersheds

SNOTEL's snowpack data are associated with watersheds (St. Vrain Creek and Boulder Creek, in this case) because a large majority of the water that enters those watersheds comes from snowpack. A large portion of runoff comes from snowpack too, which can be good and bad. The good kind of runoff is the kind that fills our reservoirs, keeps creeks and rivers flowing, and provides enough water for people upstream and downstream.

The bad kind of runoff is when snow melts and carries potential pollutants, such as nutrients from lawn fertilizers, pesticides from lawn and garden chemicals, petroleum by-products from vehicles and roadways, and bacteria from human and animal waste into our surface water and groundwater.

The types of land cover in a watershed strongly influence the quality and amount of runoff.

As the human population in Boulder County has increased over the past several decades, the area of impervious surfaces has also increased, which shifts the amount of "bad" runoff and may influence watershed health. For more information, see the companion watershed health story in this report focused on urban population growth.

RECOMMENDATIONS

Get involved in measuring snowpack!

There is a vibrant community-science project aimed at local measurements of snowpack in mountain regions across North America, called Community Snow Observations.

Join the activities of the Boulder-based organization Protect Our Winters, which is focused on motivating the outdoor community to implement actions to minimize the negative impacts of climate change.

Manage your residential landscape to reduce "bad" runoff, by minimizing your use of lawn and garden pesticides and synthetic fertilizers, and by reducing the area of impervious surfaces, such as driveways and walkways.

When you're installing a new patio, path, or driveway, try using surfaces that permit drainage, such as permeable or porous pavers.

WATERSHED HEALTH

Boulder County's human population has increased nearly 600% in the last 70 years, with implications for watershed health.

The types of land cover in a watershed strongly influence the quality and amount of runoff. As the human population in Boulder County has substantially increased over the past several decades, there have been dramatic changes in land cover and land use, both of which may influence watershed health.

The human history of Boulder County can be traced back several thousand years to Paleo-Indian hunter-gatherers whose activities and livelihoods are revealed in the presence of archaeological sites.

By about 500 years ago, groups of Ute, Cheyenne, and Araphaho peoples resided in Boulder County, and riparian areas such as Boulder Creek were particularly important wintering grounds. In the mid 19th century, gold and silver deposits began to be exploited by European settlers, leading to the establishment and growth of mountain towns in western Boulder County, such as Gold Hill, Caribou, and Nederland.

During that period, the city of Boulder grew to support the mining industry and the city of Longmont developed primarily as a center of agricultural activity. The 20th century was a period of rapid population growth in Boulder County, fueled by the post WWII economy, the establishment of several US government laboratories and high-tech industries, and the growth of the University of Colorado.

Between 1950 and 2020, the population of Boulder County increased from about 48,000 residents to just over 330,000 residents; an increase of nearly 600% (*Figure 1*).

EXPLORE THE DATA

Boulder County human population size, from 1870-2020

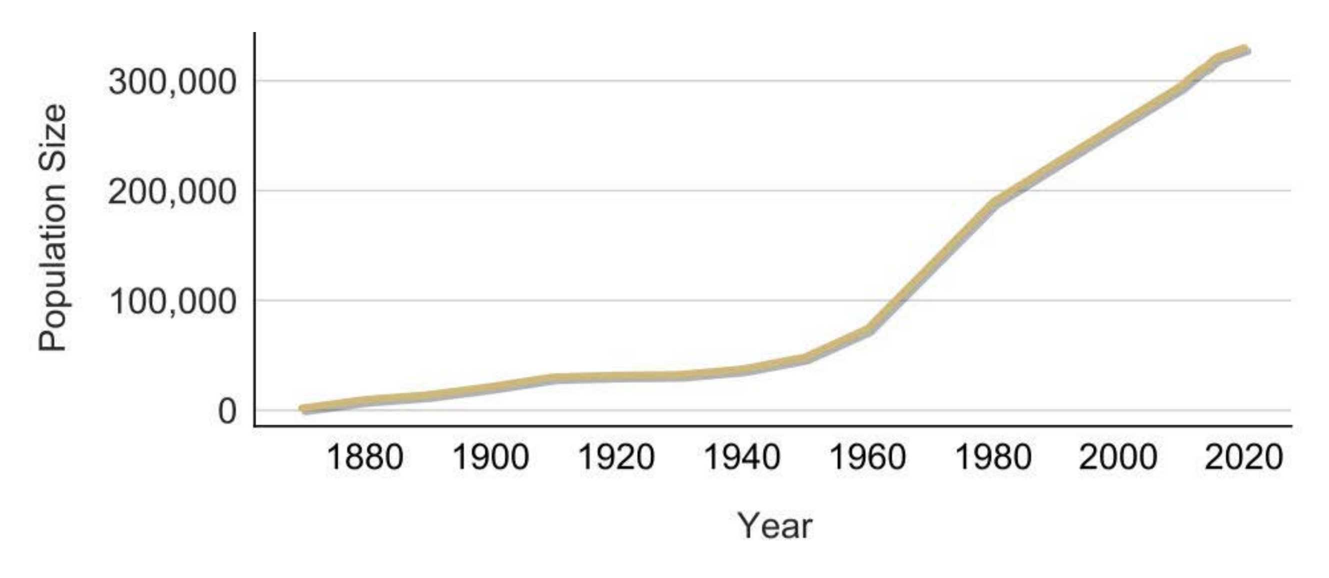


Figure 1. Boulder County human population size from 1870-2020. Source: https://worldpopulationreview.com/us-counties/co/boulder-county-population

The increase in the number of Boulder County residents clearly translates into more houses, roads, schools, and commercial infrastructure to support our communities. The maps shown below (Figure 2) display the areas of annexed urban land cover in the cities of Boulder, Longmont, Superior and Louisville, which have all increased substantially between 1950 and 2020.

These increases in urbanization result in greater area of impervious surfaces and new forms of inputs to surface water and groundwater in Boulder County.

Although the relationships between urban land cover and watershed health have not been extensively studied in Boulder County, we know from other urban centers that increasing urbanization can impact the watershed via greater inputs of potential pollutants in runoff, such as nutrients from lawn fertilizers, pesticides from lawn and garden chemicals, petroleum by-products from vehicles and roadways, and bacteria from human and animal waste that may move into our surface water and groundwater. **The increase in human population may also increase the probability of human-ignited forest fires, which may also influence watershed health.**

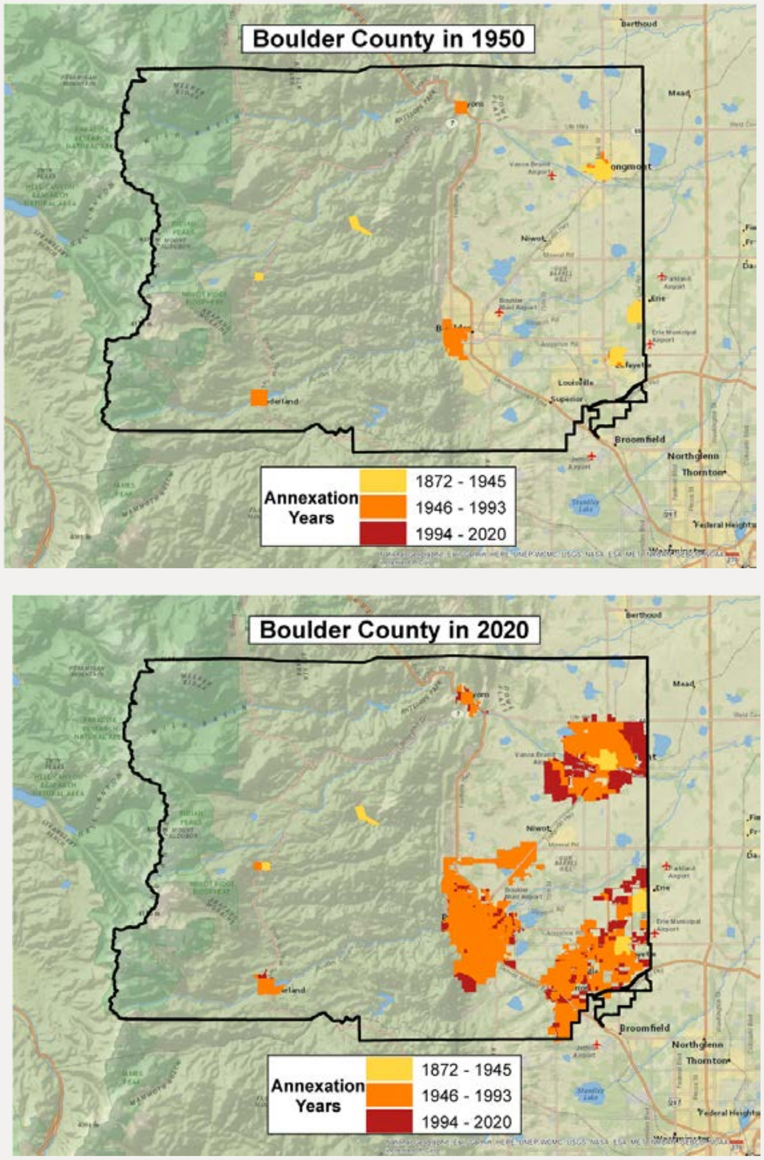


Figure 2. Urban land cover in Boulder County in 1950 (left panel) and 2020 (right panel). Yellow, orange, and red polygons represent areas annexed from 1872-1945, 1946-1993, and 1994-2020, respectively. *Source: Data compiled by Boulder County Land Use Department staff from city of Boulder data and recorded ordinances for Longmont, Lafayette, Louisville, Lyons, and Superior.*

RECOMMENDATIONS

Boulder County must continue to prioritize ethical, sustainable population growth.

Boulder's population is projected to continue to grow over the next few decades. Efforts that prioritize ethical, sustainable population growth are likely to provide a continued, high quality of life for Boulder residents.

Urbanization typically results in more concrete and more built structures, but there are ways to increase population density while decreasing per capita human impact.

Relevant to watershed health, it's important to support activities that minimize or reduce urban land cover and impervious surfaces.

For example, converting lawns to pollinator gardens or other native landscapes, as well as decreasing the area of impervious surfaces in your residential landscape, will reduce potential pollutants that flow into nearby creeks and streams.

AIR QUALITY

Boulder's ozone concentrations frequently rise above air quality standards

Numerous factors contribute to the rise of harmful ozone levels in Boulder. Ozone is not directly emitted from human-made sources, but forms in our atmosphere under certain conditions. Colorado is struggling to meet air quality standards, despite regulations in place on oil and gas emissions throughout the state.

Ozone formation happens differently depending on where in the atmosphere it is found. When it is formed high in the stratosphere, it acts as a protective barrier that shields the Earth's surface from harmful ultraviolet radiation. Weakening layers of ozone in the upper atmosphere raise concerns for public health experts. With more radiation exposure, there is a potential for the rise in skin-related cancers and eye damage from increased levels of UV light. However, when we talk about *regulating* ozone concentrations, we are mainly concerned about **tropospheric level ozone.**

When ozone concentrations build up in the troposphere (*the atmospheric layer that sits just above the Earth's surface and reaches a height of approximately 10 km*), they have negative impacts on health, particularly for respiratory processes, leading to cellular damage in plants and animals.

HOW IS 'GROUND-LEVEL OZONE' FORMED?

According to the EPA, ozone is formed through "chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOCs)." Ozone occurs from a combination of VOCs from oil and gas emissions and NOx from urban and industrial emissions. Both sectors contribute to total ozone production on high ozone days, although industrial emissions contribute somewhat less to ozone on average.

OZONE LEVELS IN COLORADO

The generation of emissions from local oil and gas industries has more than doubled since 2000, with the City of Denver exceeding the National Ambient Air Quality standard for over a decade. Because of Boulder's geographic location and proximity to the Denver metro area, the conditions are right for locally generated pollution and poorer ambient air quality to stagnate over the city.

Ozone is a **secondary** pollutant source, which means it requires specific conditions in the atmosphere to form, and is found in its greatest concentrations in the early afternoon.

The EPA National Ambient Air Quality standard for ozone is set at 0.07 ppm (*this is referenced as a black horizontal line in the figures below*). VOCs from oil and gas emissions, together with urban and industrial emissions, contribute to around 60-80% of the total ozone production on high ozone days. Atmospheric data from the Boulder Reservoir does show that ozone levels peak each year in the summer months (*Figure 1*), with some of these levels exceeding the EPA's air quality standards. How we regulate these emissions will largely determine our ability to curb ground-level ozone.

EXPLORE THE DATA

Maximum daily ozone levels (ppm), measured at the Boulder Reservoir

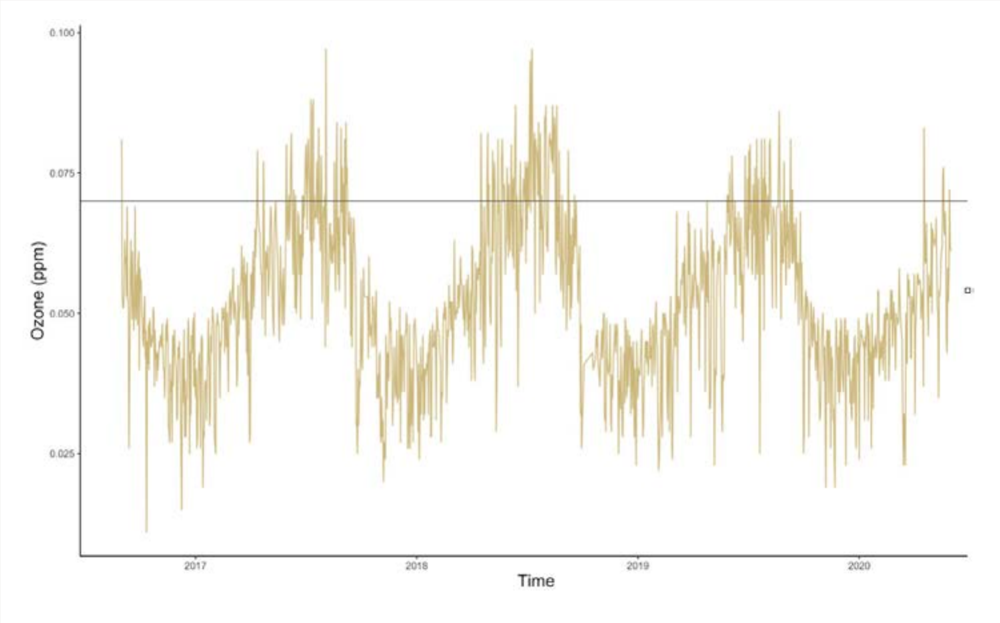


Figure 1: Ozone concentrations at the Boulder Reservoir, measured in parts per million (ppm). The gold lines represent maximum daily ozone concentrations, measured per hour for an eight hour time period each day. Ozone data is collected using a Teledyne UV absorption monitor. The horizontal black line represents the EPA national air quality standard of 0.07 ppm. Notice that there is strong seasonal variation in ground-level ozone concentrations. High ozone concentrations typically peak during the summer months.
Source: Data collection sponsored by Boulder County Public Health. Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE).

Maximum ozone levels, according to day of the year

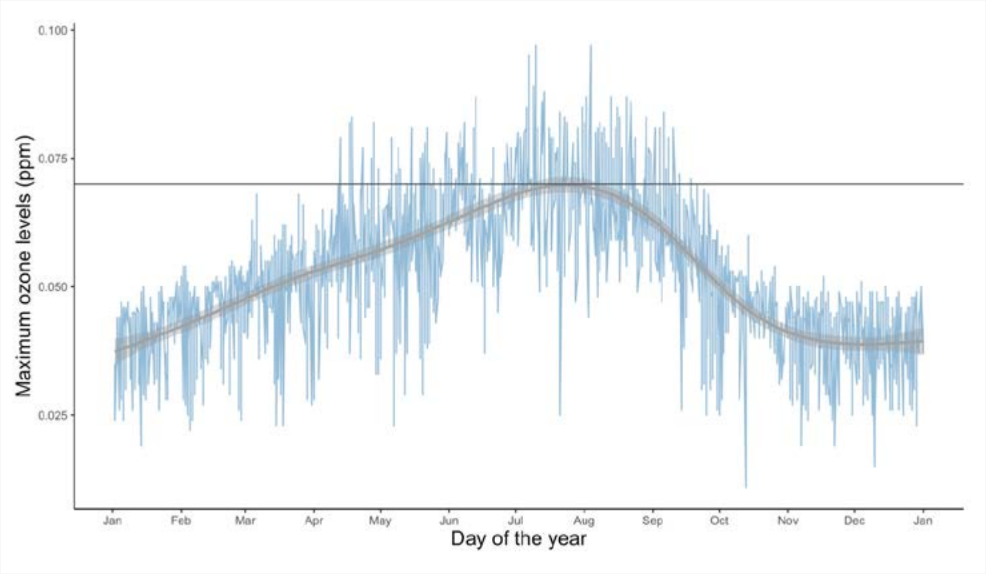


Figure 2. Maximum ozone levels (ppm) at Boulder Reservoir by day of the year. Blue lines represent ozone concentrations, the gray curve represents the smoothed conditional mean of the data, and the horizontal black line represents the EPA national ambient air quality standard of 0.07 ppm. Maximum levels above the threshold occur during the months of April through September. Notice that high ozone concentrations occur seasonally, during summer months. Ozone data is collected using a Teledyne UV absorption monitor.
Source: Data collection sponsored by Boulder County Public Health. Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE).

Table 1. Number of days above the EPA ozone threshold and peak vulnerability at Boulder Reservoir for years 2017, 2018, and 2019. Notice that high ozone concentrations occur seasonally, during summer months. *Source: Data collection sponsored by Boulder County Public Health. Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE).*

Year	# of days where levels surpassed the EPA threshold	Peak vulnerability
2017	40	April 13 - Sept 8
2018	65	April 17 - Sept 18
2019	26	May 28 - Sept 13

RECOMMENDATIONS

Continuing to monitor the main emissions that contribute to the formation of ozone

Ozone cannot be monitored as a direct emission product from any of the major manufacturing, urban, and energy production sectors, so it is harder to monitor outputs that contribute to its production in the atmosphere. High concentrations of ozone, especially those that exceed EPA standards, have implications for public health. With this in mind, our recommendation is that Boulder should continue to tackle sources of ozone pollution and focus on improving its standards for vehicle and public transit emissions, creating an action plan to deal with regional haze, and working with industries to reduce VOC and NOx waste byproducts.

AIR QUALITY

Greenhouse gas emissions continue to rise, despite reports of downward trends

Colorado has taken large steps to reduce methane emissions, but NOAA data from Niwot Ridge suggest it's far too soon to celebrate. Data show that both methane and CO2 in the atmosphere, both warming-causing gases, continue to rise.

Atmospheric greenhouse gases, including methane and CO2, can dramatically impact the course of climate change. In 2014, Colorado became the first in the country to crack down on methane, which can escape from oil and gas wells, lines, equipment and tanks, as well as from landfills, cattle operations and natural seeps. The state started requiring oil companies to regularly inspect and repair leaks at their biggest facilities.

While CO2 persists in the atmosphere for centuries, or even millennia, methane warms the planet on steroids for a decade or two before decaying to CO2. Methane's potency has made it a target of policymakers looking for a quick way to slow the effects of climate change.

In 2019, Colorado's lawmakers went further to pass new regulations for the oil and gas industry, including a section to further crack down on methane emissions and the accompanying volatile organic compounds that can escape from wells.

However, data from NOAA's Global Monitoring Laboratory suggest it may be too soon to celebrate.

Atmospheric samples taken weekly at the Niwot Ridge site show that greenhouse gas emissions continue to increase over time, specifically methane and carbon dioxide. The Niwot Ridge site is a regional background site, so data from this site reflect large scale concentrations in the atmosphere.

EXPLORE THE DATA

Comparing methane and carbon dioxide emissions

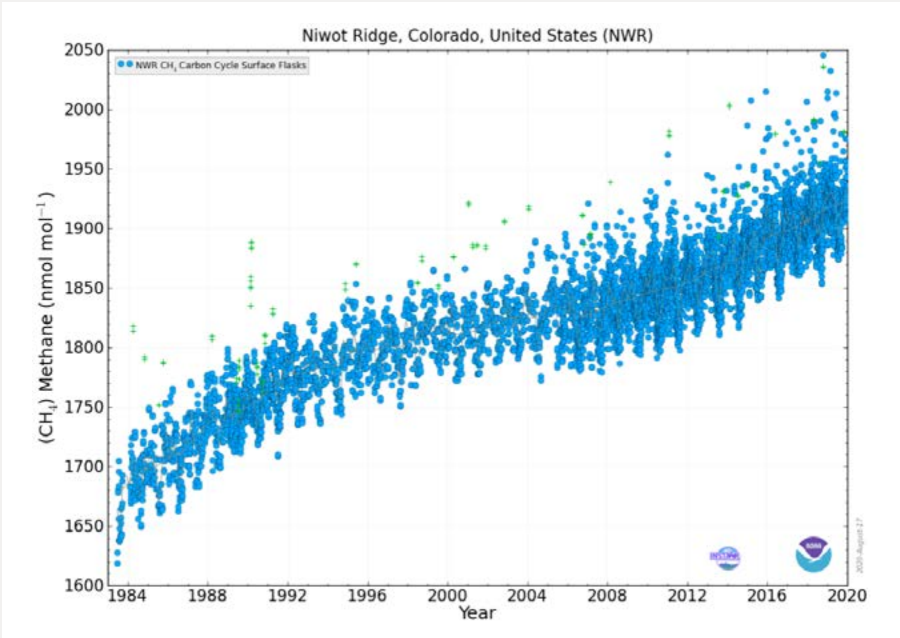


Figure 1. Methane emissions over time, sampled from air collected weekly at the Niwot Ridge site. Blue circle symbols represent samples from a well-mixed troposphere, while green plus symbols represent poorly-mixed air masses that were influenced by local or regional emissions. Note that any local emissions of greenhouse gases will show up in the data as enhancements to the background concentration. The Niwot Ridge site is a regional background site, which often reflects large scale concentrations in the atmosphere. *Source: Data have undergone rigorous quality assurance and are freely available online at the NOAA Global Monitoring Laboratory's Interactive Data Visualization for the Niwot Ridge site.*

Maximum ozone levels, according to day of the year

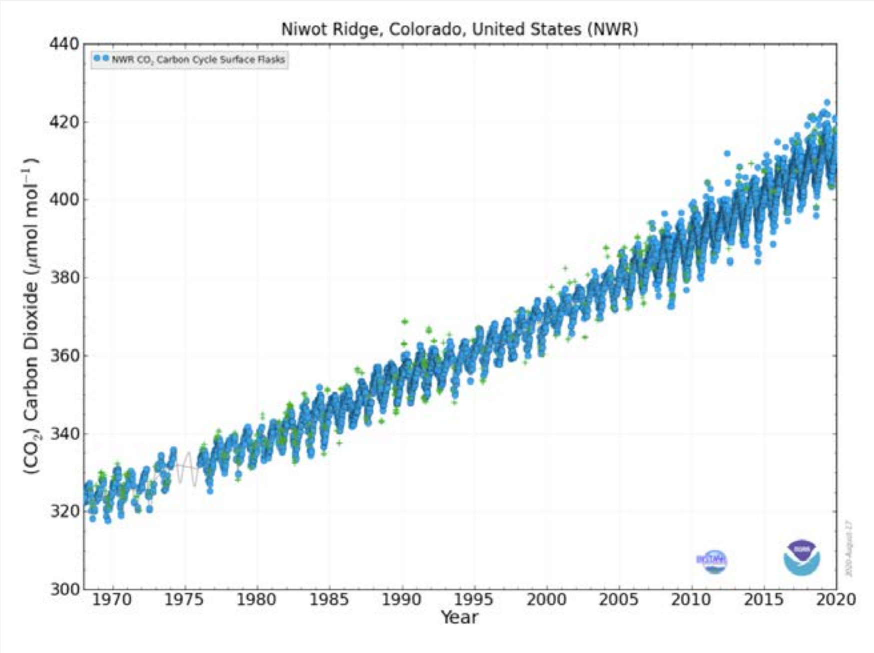


Figure 2. Carbon dioxide emissions over time, sampled from air collected weekly at the Niwot Ridge site. Blue circle symbols represent samples from a well-mixed troposphere, while green plus symbols represent poorly-mixed air masses that were influenced by local or regional emissions. *Source: Data have undergone rigorous quality assurance and are freely available online at the NOAA Global Monitoring Laboratory's Interactive Data Visualization for the Niwot Ridge site.*

RECOMMENDATIONS

Data collection can inform strategies that curb greenhouse gas emissions

The measurement of atmospheric concentrations of greenhouse gases, particularly CO2 and methane, is complicated by the fact that they come from a variety of sources, and they also mix well with other gases in the atmosphere and are easily transported across land and water. Further enforcement of regulations, by **tracking oil and gas wells at the source**, and proper investment of funding to monitoring systems and quality controls will build public confidence in our ability to track greenhouse gases that arise from our local industries. That way, we can get a better sense of how effective our current policies are towards reducing greenhouse gases in Boulder and the surrounding counties. Implementing robust monitoring systems and rigorous testing of field and lab equipment will help ensure that data collected on local and state greenhouse gas emissions are reliable and repeatable.

Individuals in Boulder County can also make a dent in greenhouse gas emissions by making personal choices that reduce emissions of greenhouse gases, including choosing to cycle instead of drive, converting to more fuel-efficient vehicles and appliances, and reducing food waste. To learn more about Boulder's efforts to combat climate change, check out the city of Boulder's Climate Mobilization Action Plan and Boulder County's Climate Action initiatives, both of which provide excellent guidance for actions to reduce emissions, such as reducing fossil fuel use in transportation, increasing energy efficiency, and reducing waste that ends up in landfills.

AIR QUALITY

Presence of VOCs show oil & gas heavily influence nearby air quality

Monitoring systems have been set up at the Boulder Reservoir to measure levels of ethane and propane gases, which are emitted in the process of oil and gas manufacturing and distribution. These two volatile organic compounds (or VOCs) are clear tracers of oil and gas emissions. When we see decreases in these two VOCs, it also represents decreases in other harmful pollutants.

Ethane and propane are emitted in association with industrial oil and gas production and processing, and can provide clear tracers of oil and gas activities. Ethane and propane have atmospheric lifetimes of approximately two months to two weeks, respectively. These gases contribute to the formation of ground-level ozone on a regional and continental scale. Propane can also be released into the atmosphere from the storage and distribution of liquefied petroleum gas.

To better understand how oil and gas industries generate emissions that contribute to rising ozone levels, Boulder County started a monitoring study to record real-time concentrations of different atmospheric gases that are known byproducts of oil and gas industries (with a focus on ethane and propane concentrations). Atmospheric monitoring systems at the Boulder Reservoir are used to monitor air quality and have provided data to Boulder County regarding local increases in atmospheric ethane and propane, signalling emissions from oil and gas activity.

The seasonal cycles of ethane and propane shown in the figures below are driven by two factors:

1. During the winter, the mixing of the lower atmosphere is weaker, which causes emissions from nearby sources to accumulate longer and to build up in higher concentrations.

2. The breakdown/oxidation of these compounds is slower during the winter, which gives them longer lifetimes and results in a build up to higher levels.

Oil and gas production has definitive impacts on the levels of propane and ethane. For example, there is a significant distinction between VOC concentrations closer to oil and gas facilities versus farther away. As you can see in Figure 1, concentrations are much higher in Longmont, which is closer to oil and gas facilities, compared to at Boulder Reservoir. Both figures show that each year during the winter months, ethane and propane concentrations spike. This suggests that oil and gas activity in and around Boulder County has been influencing local air quality.

EXPLORE THE DATA

Taking a closer look at ethane and propane levels in Boulder's air.

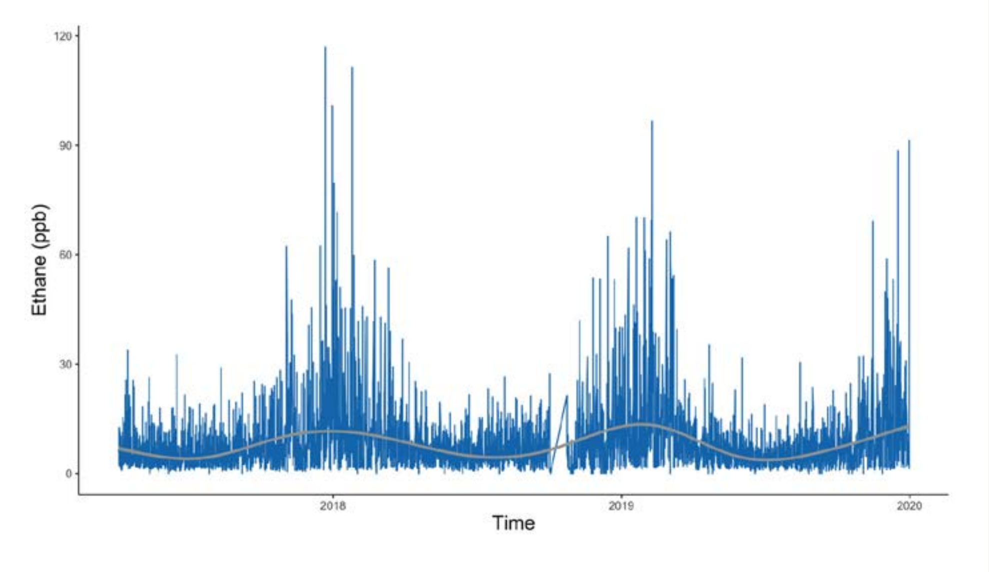


Figure 1: Ethane concentrations measured at Boulder Reservoir from 4/04/17 to 9/03/2020. The blue lines represent the raw data and the gray line represents the smoothed conditional mean of the data. Notice that peak concentrations occur in winter months.
Source: Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE) and sponsored by Boulder County Public Health.

Maximum ozone levels, according to day of the year

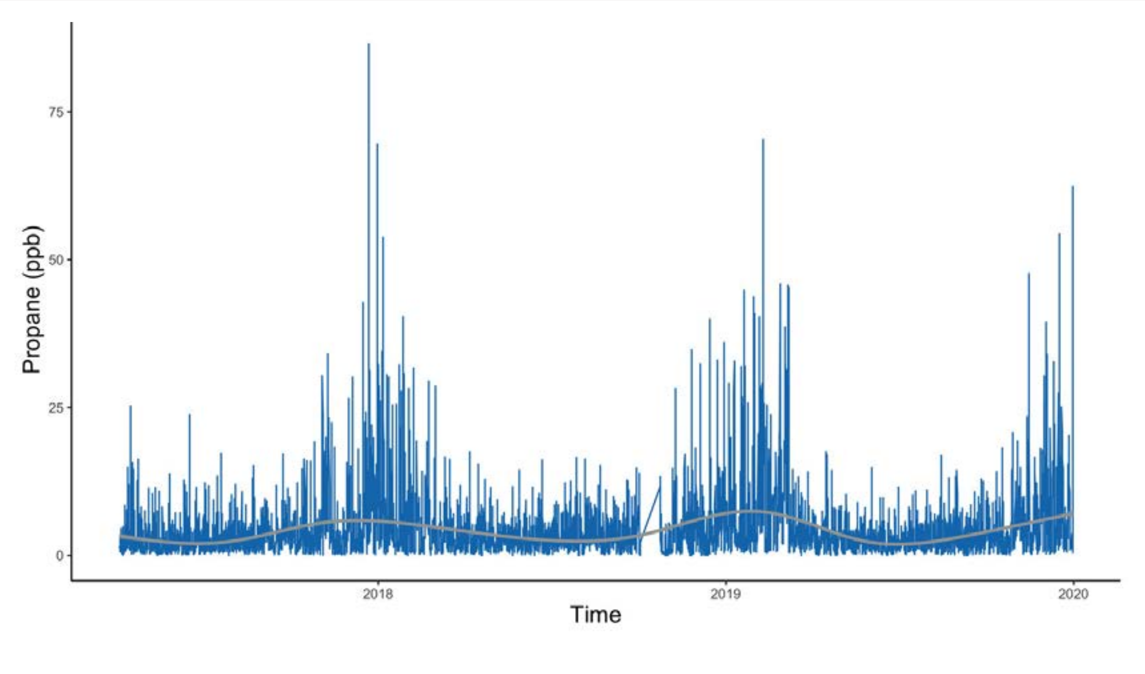


Figure 2: Propane concentrations measured at Boulder Reservoir from 4/04/17 to 9/03/2020. The blue lines represent the raw data and the gray line represents the smoothed conditional mean of the data. Notice that peak concentrations occur in winter months.
Source: Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE) and sponsored by Boulder County Public Health.

Now let's compare Boulder's propane concentrations to Longmont, which is closer to areas of oil and gas development.

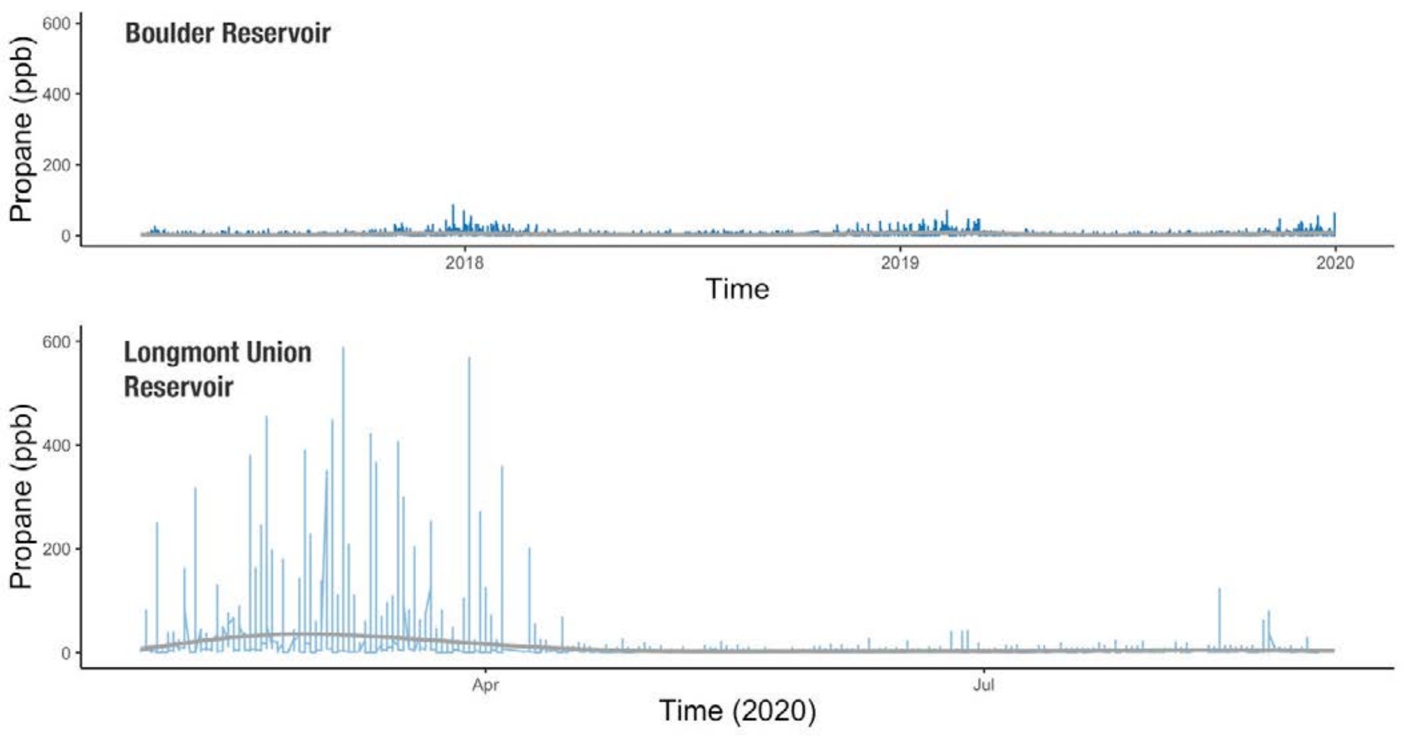


Figure 3. Propane concentrations measured at Boulder Reservoir for 3 years (04/04/17 to 09/03/20) compared to propane concentrations measured at Longmont Union Reservoir for 8 months (01/29/20 to 09/03/20). Note that the scale of the vertical axes in the two figures is the same (ranges from 0-600 ppb). The blue lines represent the raw data and the gray lines represent the smoothed conditional mean of the data. Notice that peak concentrations occur in winter months. This VOC was monitored by preconcentration of 500 ml-samples onto a micro-adsorbent trap, with subsequent thermal desorption, capillary column gas chromatography separation, and flame ionization detection. Samples were collected at 1.5-hour intervals. *Source: Monitoring is conducted by researchers at Boulder A.I.R. LLC, in partnership with the Colorado Department of Public Health and the Environment (CDPHE) and sponsored by Boulder County Public Health*

RECOMMENDATIONS

Monitoring VOC concentrations can contribute to proper air quality regulation.

Monitoring VOCs in Boulder County provides an important step in measuring the impacts of oil and gas activity in the region. These monitoring systems can provide scientific data to help inform regulations to reduce VOCs that contribute to air pollution statewide and throughout Boulder County.

BIODIVERSITY

Boulder County ecosystems support an amazing variety of wild pollinator species

Pollinators are crucial to ecosystem health and human well-being, as they promote the reproduction of flowering plants, most of which are key food plants for both wild animals and humans.

Boulder County is exceptional in its abundance and diversity of pollinators. Bees are the most efficient insect pollinators, and our county has the highest documented bee diversity in Colorado, with 552 species! And although they are less efficient than bees, the more than 200 butterfly species in Boulder County also help to move pollen from flower to flower. This incredible diversity of bees and butterflies is likely due to the rich variety of ecosystems and flowering plants that occur along the sharp elevation gradient from the eastern plains to the western mountain peaks of Boulder County.

Bumblebee pollinator / Unsplash

Recent research led by D**r. Seth Davis at Colorado State University** provides the first description of wild bees in relation to Ponderosa pine forest management in Boulder County, connecting pollinator abundance and diversity to forest thinning treatments and fire disturbances. This study showed that bumblebees were the most common genus captured — in fact, 15 different bumblebee species alone were observed — and were present in high abundance throughout the growing season. Bees occurred similarly in Ponderosa pine forests that had been thinned for wildfire management as well as forests that had not been thinned. In fact, the researchers concluded that a variety of forest types translates into higher diversity of bee species.

> **“ This study showed that if you want to have the greatest number of bee species and the greatest abundance of bees, then you need a mosaic of different habitat types. Where there's a lot of downed wood, like you might find after a fire or a bark beetle outbreak, this is probably creating additional nesting habitat and refugia for bees. ”**
>
> **— Dr. Seth Davis, Colorado State University**
> ***(as quoted in the Longmont Times-Herald, 2019)***

Davis' study showed that Ponderosa pine forest stands on Boulder county public lands provide habitat for an incredibly rich native bee community and represent an important conservation resource. Managing the forests to promote a variety of forest types appears to be a great strategy for providing habitat for a high diversity of bee species.

But bees don't just live in forests. Boulder County's grasslands provide an abundance of plants that produce nectar and pollen that bees love. To add to these critical native grassland plant resources for bees, the city of Boulder has created the Boulder Pollinator Garden Project, which is designed to support and encourage Boulder residents to create their own high-quality pollinator habitat.

By planting a variety of flowering species in their yards and gardens, Boulder residents can create a sustained level of food resources for native bees throughout the growing season. Additionally, these pollinator-friendly gardens can create "pollinator pathways" that connect habitats in residential areas to the surrounding open space grasslands and forests. These efforts will help to provide local and regional environmental resources for bees and other pollinators, enhancing our biodiversity and ecosystem functions.

Ponderosa pine forest in western Boulder County, August 2020 / Sharon Collinge

RECOMMENDATIONS

Support pollinator communities through gardening and restoration efforts

Bumblebee pollinator / Unsplash

Plant a pollinator garden

The city of Boulder's Pollinator Garden Project provides resources for choosing appropriate plants for our semi-arid climate that will support a variety of bird, butterfly, and bee species that serve as pollinators. These flowering plants offer critical food resources for these pollinators. After you plant your pollinator garden, you can map it to add to the city's list of gardens.

If you don't have space to plant a pollinator garden, you can support pollinators in other ways!

Support organizations that focus on pollinator conservation, such as the Xerces' Society's Pollinator Conservation Program and the local Colorado Pollinator Network, which hosts an annual pollinator symposium. Purchase or build a nest structure for your residence that provides nesting habitat for native bees. And support forest management that enhances woody debris for cavity nesting bees.

RESOURCES:

Scott, V.A., J.S. Ascher, T. Griswold, and C.R. Nufio. 2011. The Bees of Colorado. Natural History Inventory of Colorado, University of Colorado Museum of Natural History, Boulder, CO.

Davis, T.S., R. Gelles, B. Kondratieff, and C. Stevens-Rumann. 2019. Effects of fire and thinning disturbances on biodiversity of wild bee communities in the Front Range of Colorado. Final Report to Boulder County Parks and Open Space and City of Boulder Open Spaces and Mountain Parks.

BIODIVERSITY

Black bears in Boulder are expanding eastward

In 2014, a Bear Protection Ordinance in the city of Boulder required residents in the western part of the city to bear-proof their trash and compost at all times. Data on bear sightings show that bears in Boulder are expanding eastward and trash remains a huge attractant.

The **American black bear** (*Ursus americanus*) is North America's smallest and most widely distributed bear species. American black bears are omnivores, with their diets varying greatly depending on season and location. Black bears typically live in forested areas but will leave forests in search of food. They are often attracted to human communities because of the immediate availability of food (*Armstrong et al., 2010*).

A series of events shook Boulder back in 2013. A sharp rise in bear encounters in the area led to four incidences where bears were ultimately killed by state wildlife officers. This number was unprecedented for Boulder (where previously, an average of 0.5 bears was lost annually to human-wildlife related conflict). The community set a plan into motion to address the dynamics that factored into the death of these four bears.

BOULDER'S BEAR PROTECTION ORDINANCE

The bear protection ordinance in the city of Boulder (Ordinance 8161) created an obligation for residents to secure trash and curbside compost in bear-resistant containers in certain parts of the city (west of Broadway and south of Sumac). The ordinance was put in place to protect bears, improve human-wildlife co-existence and increase sanitation and cleanliness of the city.

According to Valerie Matheson, *Senior Wildlife Conservation Coordinator* for the city of Boulder, the impetus for the ordinance was the observation that bears that spend time eating human-generated food sources, including trash, get used to being around people, lose their natural fear of people and spend more time in town. These habituated bears have a higher mortality rate than bears that live in natural areas. Though black bears tend to avoid humans, the potential for interaction with community members is a threat to human safety. The most effective way to prevent bears from learning to live off trash is to secure it.

BOULDER BEAR SIGHTINGS

When the bear ordinance was being considered, community and city council members wondered about the possible unintended consequence of pushing the bears east of Broadway because trash is secured and thus harder to get west of Broadway. Bear sighting data for the city of Boulder collected from 2009-2019 by Matheson show that bears appear to expanding eastward (*Figure 1*). While not presented here, other bear observations indicate that bears have been spotted as far east as Longmont, Louisville, and Lafayette.

Although bears do appear to be moving eastward in the city of Boulder, it is not clear that the ordinance is driving this eastward expansion. Observations throughout the Front Range indicate that bears have been sighted further east than usual in recent years, **even in areas without trash ordinances**. So, these observations suggest that this bear ordinance is not the sole driving force for the eastward expansion of black bears.

Instead, the increasing availability of food (a consequence of a rapidly growing population) may be driving the eastward expansion and the increase in bear sightings throughout Boulder. Data show that trash and compost are still the primary attractants of black bears, along with bird feeders, domestic animals, and planted items, such as fruit trees (*Figure 2*). When Matheson conducted a survey with residents east of Broadway, she found residents were often surprised to learn that bears could be on their property.

EXPLORE THE DATA

Number and location of bear sightings, from 2009-2019.

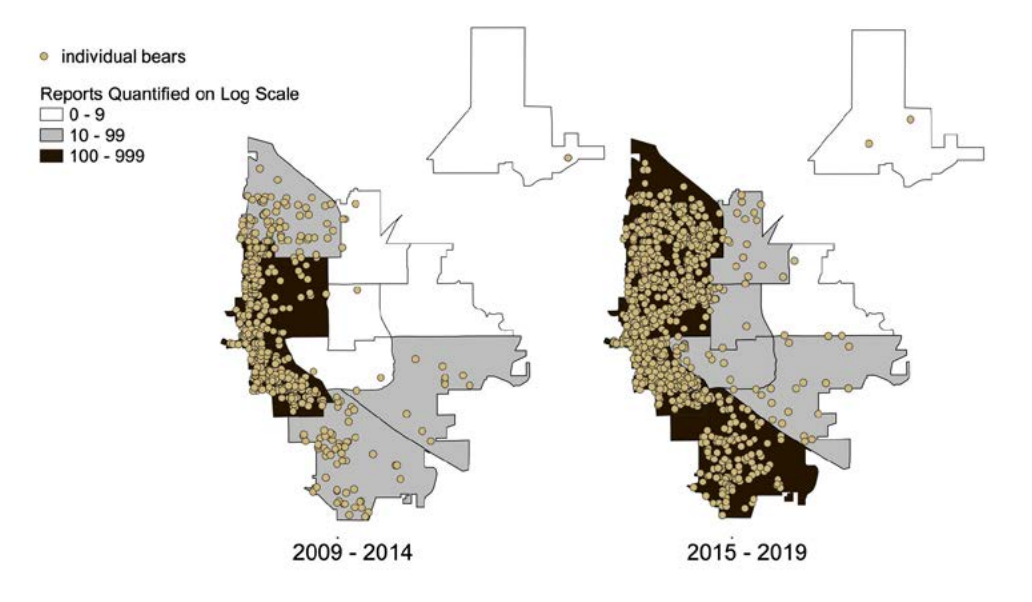
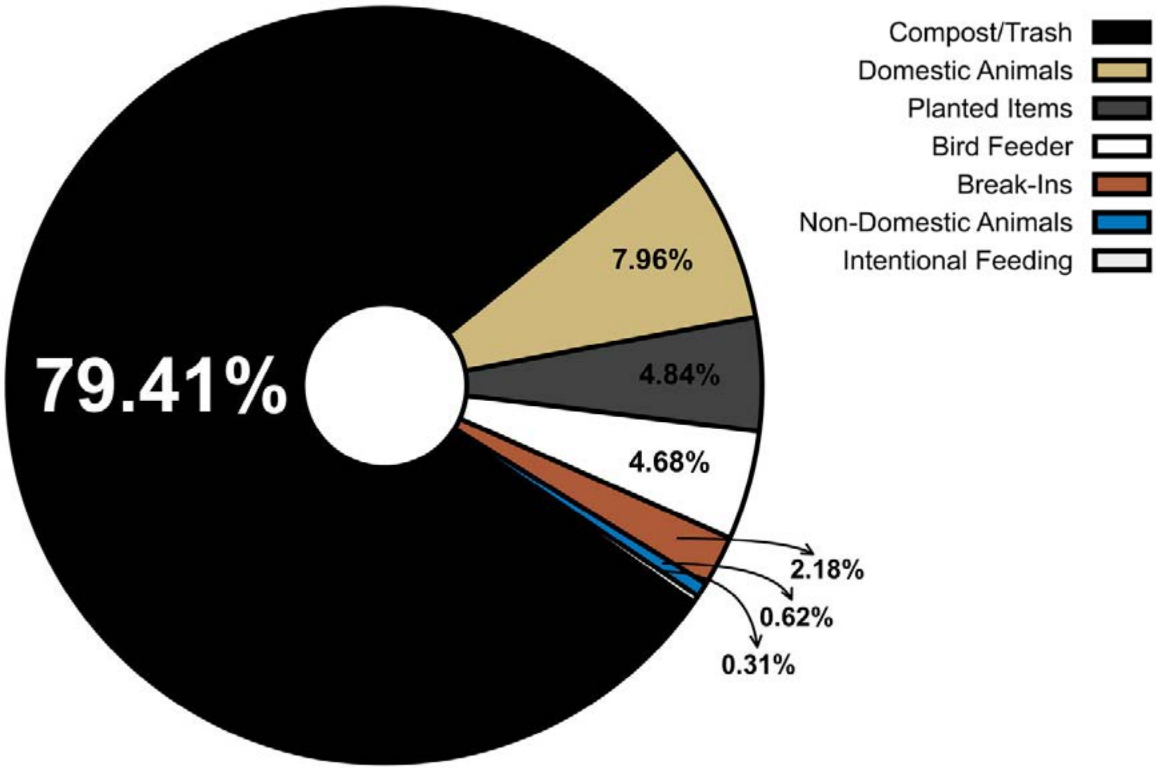


Figure 1. These maps of the city of Boulder show bear sightings reported from 2009-2019. Police report data on bear sightings were added to this data set starting in 2015. The left-most border of the maps is the western city boundary, where city streets meet the foothills. The polygon in the upper right corner of the maps is Gunbarrel. The maps show an overall increase in individual bear sightings (gold circles) since the 2014 Bear Protection ordinance, and an increase in bear sightings in the eastern part of the city from 2015-2019. There are likely more bear sightings than reported to the city. *Data provided by Valerie Matheson, Senior Wildlife Conservation Coordinator, City of Boulder Planning and Development Services Department.*

Bear attractants in Boulder

Figure 2. The chart below shows the items that bears were attracted to when they were sighted in the city of Boulder from 2009 - 2019. We can see that trash and compost (a combined category in black) are the items most frequently associated with black bear sightings - **nearly 80% of all sightings involved trash or compost.** *Data provided by Valerie Matheson, Senior Wildlife Conservation Coordinator, City of Boulder Planning and Development Services Department.*



Individual attractants include:

DOMESTIC ANIMALS

- BEEHIVES
- CHICKENS
- GOATS
- PETS
- FISH

PLANTED ITEMS

- FRUIT
- FRUIT TREES
- FLOWERS
- PEPPERS
- GARDENS

BREAK INS

- SHEDS
- CARS
- HOUSES
- OUTSIDE FREEZERS
- GARAGES

RECOMMENDATIONS

Reduce attractants in your yard, report all bear sightings, and learn more about bears in Boulder.

To reduce attractants at your home, keep your trash and compost secured, keep domestic animals (including chickens and goats!) protected, and collect the fruit in your yard, especially in good fruit years. Alternatively, find fruit gatherers that will come collect the fruit for you, such as the Community Fruit Rescue. Registering your pets will also help the city identify pet-bear interactions more accurately.

Several local organizations provide excellent resources for learning more about bears, as well as specific guidance for improving human-wildlife coexistence:

The Boulder Bear Coalition hosts meetings and events and provides resources for understanding bear-human interactions. Wild Boulder engages in outreach and education campaigns, community science engagement, and collaborations with diverse stakeholders to promote wildlife protection. The Bears and People project by Melanie Hill provides “a visual case story of Boulder’s efforts to coexist with urban black bears.”

Call to report a bear sighting:

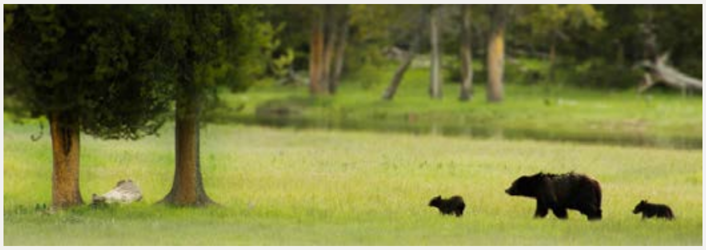
City of Boulder:
303-441-3004

Animal Protection, non-emergency:
303-441-1874

City Dispatch, non-emergency:
303-441-3333

If you want to share information about a bear sighting, you can file a report on the city of Boulder website.

RESOURCES:
Armstrong, D.A., J.P. Fitzgerald, and C.A. Meaney. 2010. Mammals of Colorado, 2nd edition. University Press of Colorado, Boulder, CO.



Black bears in action / Unsplash

BIODIVERSITY

Wintering raptor sightings have declined in Boulder over the past 30 years

Boulder County has seen massive changes over the past century when it comes to human populations and development. This has resulted in habitat loss and fragmentation and, consequently, the loss of local biodiversity. Thirty years of wintering raptor data indicate that sightings of several raptor species in Boulder have declined dramatically, with two notable exceptions.

Boulder County has seen massive changes over the past century when it comes to human populations and development. And recent population growth continues this upward trend: according to the U.S. Census Bureau, since 2010, Boulder County's population has grown by roughly 11%, or 32,000 people, with the surrounding counties growing at equal or even higher rates. This growth results in conversion of open lands to development, and may threaten the species that depend on these open lands, including Boulder's birds of prey.

Steve Jones, *Environmental Consultant* and *Volunteer* at the *Boulder County Nature Association* and *Boulder County Audubon Society*, has led surveys of Boulder's raptors every winter for the last 30 years. As his data show, raptor sightings have declined rapidly over that time period with several species now mostly absent from surveys (*Figure 1*). For example, according to the Boulder County Audubon Society, Ferruginous Hawks (*Buteo regalis*, shown as the orange line in *Figure 1*), were observed regularly in winter in Boulder County during the 1980s and early 1990s, but the number of sightings has sharply declined for this species over the past 30 years.

BUT NOT ALL SPECIES HAVE SUFFERED.

Observations of two raptor species, the American kestrel (*Falco sparverius*) and Red-tailed hawk (*Buteo jamaicensis*, the red line in *Figure 1,* below), have actually increased over time. Experts believe the success of these two species is linked to their generalist lifestyles. Both have varied and opportunistic diets and are relatively tolerant of human structures, so they have adapted to the changing landscape in ways that other species have not.

Birds of prey are predators at the top of the food chain, and their presence serves as a barometer for ecological health. The decline in raptor sightings over the last thirty years underscores the need for Boulder County to continue acquiring large parcels of open land for biodiversity conservation (Figure 2).

Raptor with prey / Unsplash

EXPLORE THE DATA

Wintering raptors: a 30-year study

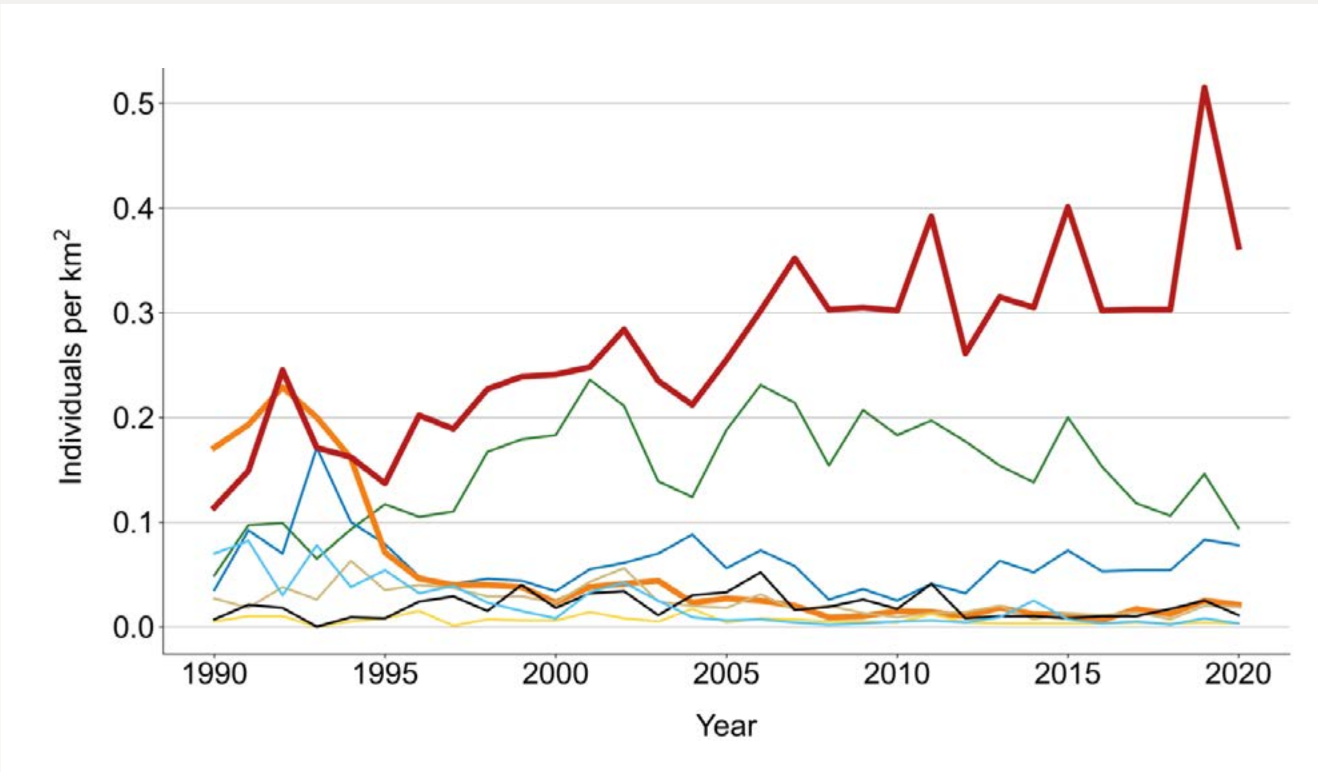


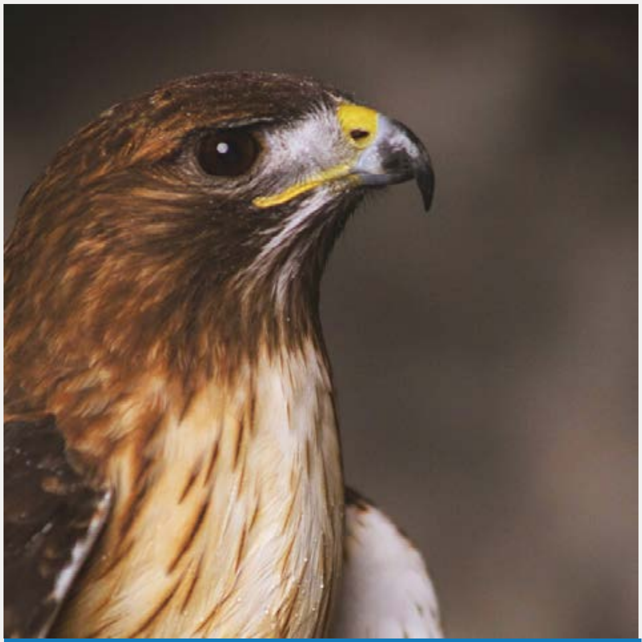
Figure 1. Bird detection data from six Boulder County survey routes, conducted each winter (October – March), from 1990 to 2020.
Data are presented as the number of individuals per square kilometer, which represents the average number of each species of wintering raptor sighted across the six survey routes each year. Generally, raptor observations in Boulder County have declined over the thirty-year period. These declines are likely the result of habitat loss, specifically the loss of large open lands that support their mammal prey. Two species are exceptions to this trend: the American Kestrel (*Falco sparverius*) and red-tailed hawk (*Buteo jamaicensis*), whose sightings have increased over time. *Data provided by Steve Jones, Environmental Consultant and Volunteer at the Boulder County Nature Association and Boulder County Audubon Society.*

Meet the exceptions:

American Kestrel (*Falco sparverius*)

The American kestrel (*Falco sparverius*), also called a sparrow hawk, is the smallest and most common falcon in North America. Their diet typically consists of grasshoppers and other insects, lizards, mice, and small birds (e.g. sparrows). This broad diet has contributed to their wide success as a species, and is likely responsible for why the kestrel has persisted in Boulder, while most other raptors are declining.

Source: Audubon Society Guide to North American Birds.



Red-tailed hawk (*Buteo jamaicensis*)

The Red-tailed hawk (*Buteo jamaicensis*) is one of the most common hawks worldwide. Their diet includes large birds, reptiles, and an array of small mammals, as well as amphibians, fish, and insects. Their diet is highly variable and reflects their status as opportunistic generalists. These generalist tendencies are considered the primary reason the red-tail is expanding in Boulder, while most other raptors are declining.

Source: Audubon Society Guide to North American Birds.

RECOMMENDATIONS

Accelerate the acquisition and restoration of open lands throughout Boulder County.

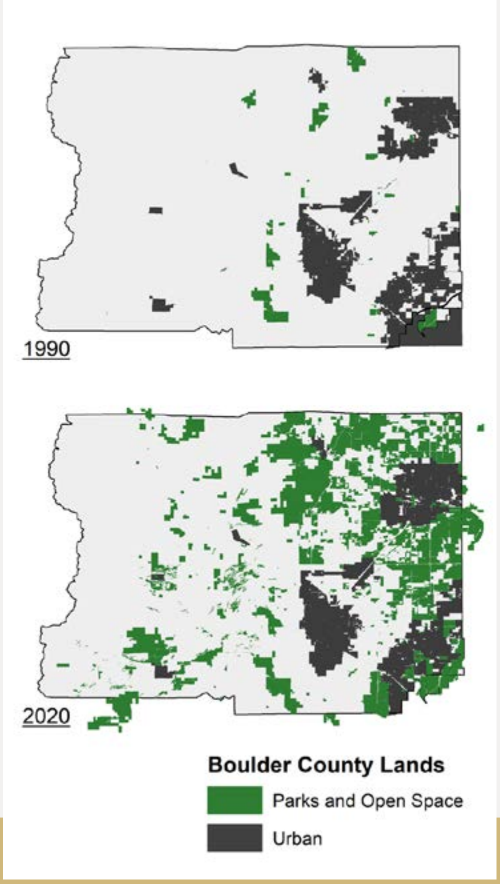
Boulder County Parks and Open Space, as well as the city of Boulder Open Space and Mountain Parks, have acquired and continue to acquire large parcels of land for conservation, agriculture, and recreation (*Figure 2*).

The decline in sightings of nearly all raptor species indicates that these efforts may not be enough — that land is not being acquired fast enough to offset the habitat being lost. Moreover, these species may be in decline due to land use changes throughout the front range region of Colorado, not just in Boulder County.

Several important native grassland species have already disappeared from Boulder County, such as the mountain plover (*Charadrius montanus*, a ground-nesting bird that is threatened throughout much of its range) and pronghorn antelope (*Antilocapra americana*, a species that has been in North America for over a million years!).

To reverse the observed declines in raptor sightings, we recommend continuing local efforts to conserve native habitats, as well as continuing to form partnerships with organizations to enhance habitat quantity and quality for these key species. For example, the Colorado Open Space Alliance (COSA) is *"a statewide organization of publicly funded local and regional open space programs, working cooperatively to share information, create public awareness and foster partnerships needed to protect and preserve the special places of Colorado"* and is actively engaged in collaborations around shared values of protecting open lands and biological diversity.

Become an eco-steward! The raptor observations displayed here are the result of a robust, local volunteer program designed to monitor and protect natural areas. Join them for a future survey!



Boulder County land trend: Parks and open space and urban areas 1990-2020

Figure 2. These maps showcase the efforts of Boulder County Parks and Open Space to acquire land for parks and open space from 1990 to 2020. The dark gray spaces represent developed (urban) areas of the county and the green spaces represent open lands owned or managed by the Boulder County Parks and Open Space (BCPOS) department. The urban area in the lower-middle part of the maps is Boulder, and in the upper right corner of the maps is Longmont. Louisville, Lafayette, and Superior are in the lower right portion of the maps. BCPOS is working to acquire more land, with the goal of protecting native plants and animals, including birds of prey. Note that this map does not include open space lands surrounding the city of Boulder that are owned or managed by the city of Boulder Open Space and Mountain Parks department. Source: *Data provided by Boulder County Geospatial Open Data. Symbology was modified to clearly identify Boulder County Parks and Open Space properties.*

URBAN LAND COVER

The city of Boulder has more trees than most, but tree planting efforts could benefit three key neighborhoods

Researchers have well established the benefits of trees in urban neighborhoods. But trees and their benefits are often unevenly distributed in cities, raising environmental justice concerns. Urban tree inventories can help prioritize neighborhoods for tree planting efforts. Here we zoom into three Boulder neighborhoods with low urban tree cover to identify possible areas for tree planting efforts.

Researchers have well established the benefits of trees in urban neighborhoods. Trees remove air pollutants, moderate high air temperatures, lower energy bills, raise property values, and correlate with better health outcomes. But trees and their benefits are often unevenly distributed across neighborhoods, raising environmental justice issues.

A 2015 study in PLOS ONE found that in cities across the United States, urban neighborhoods with higher socioeconomic status had greater tree canopy cover. As the authors of the study wrote, “Money may not grow on trees, but in a way, trees grow on money.”

Research has also shown that African Americans, Hispanics, and Latinos are more likely than whites to live in neighborhoods highly vulnerable to the urban heat-island effect—which is related to urban tree cover, since shady trees can mitigate it.

Recently, Denver has received praise for its efforts to correct disparities in urban tree cover. Part of the plan is to purchase land for new parks and plant trees in areas where shade is sparse. The city has set a goal to reach 20% urban forest cover by 2050.

Boulder conducts tree inventories that give the city a better understanding of which neighborhoods are deficient in tree canopy cover. Although tree cover is high throughout Boulder County, there are several neighborhoods under the 20% threshold, with three neighborhoods below even 10% tree canopy cover: Gunbarrel, East Boulder, and Crossroads.

Here we zoom into these three neighborhoods to identify possible areas for tree planting. The figures below compare tree cover with the percentage of land covered by impervious surfaces (e.g. concrete).

> **“Trees are a lifesaving device in cities, especially in a warming climate. It’s a moral imperative that every neighborhood has them.”**
>
> **— Jad Daley, President Of American Forests**
> ***Quoted In The New York Times***

EXPLORE THE DATA

Tree cover in the city of Boulder and neighborhoods where restoration would make an impact

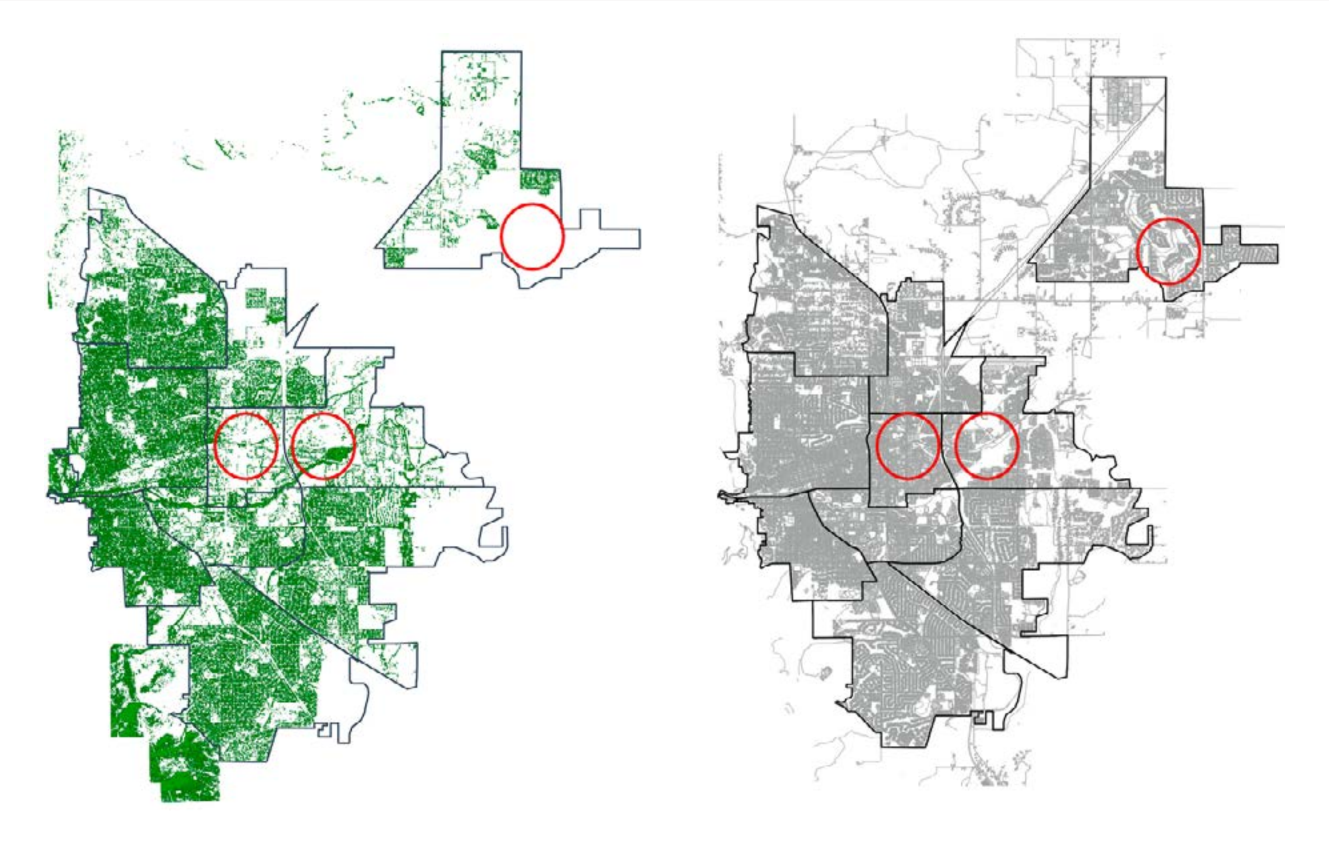


Figure 1. Tree canopy cover and impervious surfaces across the city of Boulder. The map on the left shows all tree cover in the city of Boulder. Image was collected through LiDAR and aerial images in 2013 by GIS Analysts at the city of Boulder Parks and Recreation Department. The map on the right shows impervious surfaces in the city of Boulder, including buildings, structures, concrete, or paved surfaces. Red circles represent target areas for reforestation for the three neighborhoods below the 10% forest cover threshold. *Source: Data provided by the City of Boulder Open Data Catalog. Impervious Areas data available at: https://bouldercolorado.gov/open-data/impervious-areas/*.

Three neighborhoods in the city of Boulder fall below the threshold of 10% forest cover

Neighborhoods	% Forest	% Impervious
Gunbarrel	2.73	33.61
East Boulder	6.67	40.25
Crossroads	8.22	69.78
Palo Park	10.17	40.35
Southeast Boulder	12.30	31.99
Colorado University	15.72	47.07
South Boulder	16.65	33.95
North Boulder	18.35	35.19
Central Boulder	26.60	46.87
Central Boulder - University Hill	30.01	39.26

Table 1. Percent forest cover and percent of area covered by impervious surfaces across neighborhoods. Light gray boxes represent neighborhoods below a 10% forest cover threshold. Forest cover data is sourced from LiDAR and aerial images collected in 2013 by GIS Analysts at the city of Boulder Parks and Recreation Department. *Data provided by the City of Boulder Open Data Catalog. Impervious Areas data available at: https://bouldercolorado.gov/open-data/impervious-areas/.*

RECOMMENDATIONS

Looking beyond tree restoration, other restoration projects for urban areas

One example of a successful program that could be modeled for Boulder is an urban restoration project for Chicago's alleyways called the Green Alley Program. Because it is difficult to plant trees near impervious surfaces due to more limited growth conditions (such as ambient heat and limited light), it is important to rethink the types of restoration projects that could work for these areas.

For this program, the city of Chicago breaks up old concrete foundations and plans out greenspaces that include allocated plots for plant beds. The introduction of plants in these areas contribute to ambient cooling in these previously concrete-locked alleyways. The area is repaved with lighter materials to reflect the light, installed with more efficient filtration systems to tackle water runoff, and repopulated with native grasses, bushes, and flowers that reduce the urban heat island effect. This project has been widely successful and has spread to other major cities including Los Angeles, Baltimore, and Detroit.

Planting native and drought-tolerant plants around Boulder's commercial and residential developments can increase the resilience of our urban landscapes in the face of increasing climate variability. Learn more about the city of Boulder's urban forestry program, which involves maintaining urban tree cover and encouraging involvement in community-based improvement projects. With community involvement, these restoration projects can raise neighborhood aesthetics, balance the inequity in local green spaces, support wildlife, and reduce the need for costly replacements come drought season or during extreme temperature shifts. For more information on the 'Revegetation' toolkit issued by Boulder County.

A before and after representation of a Green Alley Program project underway in Detroit. Source: https://www.patronicity.com/project/greenalley#!

URBAN LAND COVER

Weighing the impact of the Emerald Ash Borer on Boulder's ash tree population

Since its arrival in the 1990s, the Emerald Ash Borer (EAB) has spread rapidly throughout the U.S. and Canada, killing more than 100 million ash trees and wreaking havoc on local municipalities in the form of costly mitigation. The EAB spread to Boulder in 2013 and has since killed thousands of Ash trees, with thousands more waiting for it. Here we explore Boulder's tree inventory data to better understand the impact of EAB infestations in Boulder today and into the future.

The Emerald Ash Borer (*Agrilus planipennis*) is an iridescent green beetle, native to Asia, that has made its way to the United States, most likely through the transport of wood-based shipping materials. The Emerald Ash Borer (EAB) was first found in southeast Michigan in 2002, but the USDA estimates that EAB had been here since the 1990s based on the size of the infestation.

The consequences of this insect pest have been devastating. The Emerald Ash Borer (EAB) has killed more than 100 million ash trees from Massachusetts to Colorado and has another 8 billion or so waiting for it. The costs of the EAB hover around $1 billion each year in the U.S. That figure comes from studies by the U.S. Forest Service, and it only takes into account the removal, treatment and replacement of trees in urban areas. Another estimate, from a team of U.S. and Canadian researchers, placed annual damages at $1.6 billion including the loss of residential property values and timber. EAB infestation is almost always fatal to infested ash trees, unless treated, and infested trees will be dead within approximately four years. EAB is the most destructive forest pest in recorded history.

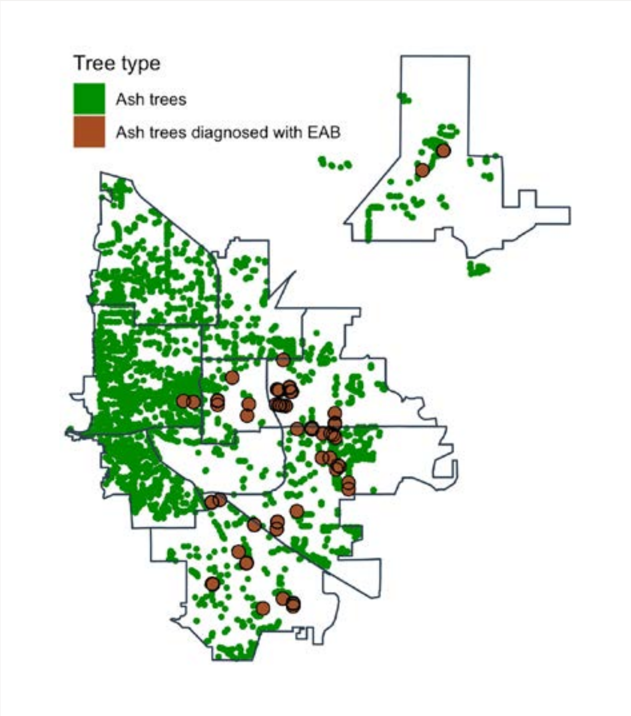
The EAB was first identified in Boulder in September 2013. This incidence marked the western-most extent of the EAB infestation in North America. As of 2018, EAB has only been found in Boulder County, although it has been found in several cities outside the city of Boulder.

According to Boulder's Urban Forest Strategic Plan (2018), tree cover in the city is approximately 16%, as measured in 2013. Ash tree losses due to EAB are expected to reduce that cover by 25% in the coming years. The city is continually working to monitor EAB infestations through visual surveys, traps, and destructive sampling.

The urban tree inventory managed by the city of Boulder provides information on where trees occur on public property throughout the city. It also provides information on where EAB treatments and removals have taken place. Here we explore the tree inventory data to better understand the impact of EAB infestations in Boulder today and into the future.

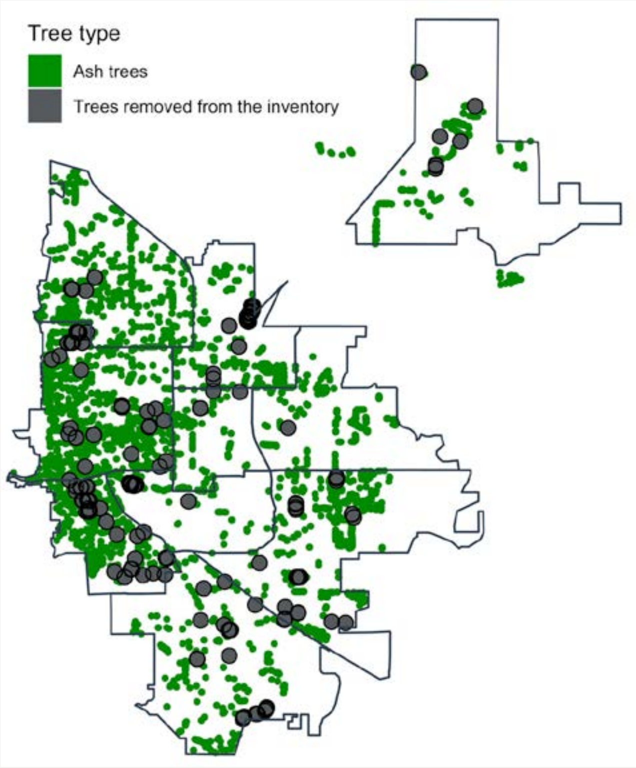
Emerald Ash Borer / City of Grand Prairie

EXPLORE THE DATA



Trees infected with Emerald Ash Borer in the city of Boulder in 2019

Figure 1. Ash trees on public lands in the city of Boulder, including those with EAB.
Green points represent the locations of ash trees managed by the city of Boulder. Brown circles represent ash trees with an EAB infestation.
Source: Data provided by the city of Boulder's urban tree inventory and offers the best available knowledge of tree species located on public lands. The inventory accounts for about 20% of Boulder's tree canopy, although for ash tree species, the inventory includes a much larger percentage. The inventory does not include trees located on private lands.



Ash trees removed from the city of Boulder inventory before 2019

Figure 2. Ash trees in the city of Boulder, 2019.
Green dots represent ash trees in the 2019 urban tree inventory labeled "active" and gray dots represent green dots in the 2019 urban tree inventory labeled "removed". There are 4921 green dots and 204 gray dots. Note: we have no way of knowing why trees were removed from the inventory - only that they were removed, i.e. just because an ash tree was removed does not mean that it had EAB.
Source: Data provided by the city of Boulder's urban tree inventory and offers the best available knowledge of tree species located on public lands. The inventory accounts for about 20% of Boulder's tree canopy, although for ash tree species, the inventory includes a much larger percentage. The inventory does not include trees located on private lands.

Why is the EAB so destructive?

Unfortunately, EAB infestations aren't usually visible until the trees are already half-dead. The borers are smaller. They lay their eggs covertly in cracks and crevasses in the bark of ash trees. Their larvae feed exclusively on the phloem, the part of a tree that carries nutrients from the leaves, killing their hosts with uncommon speed. And they spread fast, unpredictably.

Lab tests show they're capable of flying as much as three miles in a day, although most adults fly less than ½-mile from their emergence tree. Larvae carried along in firewood can go much farther, which is probably how the EAB reached Boulder, which is hundreds of miles from any previously discovered infestation.

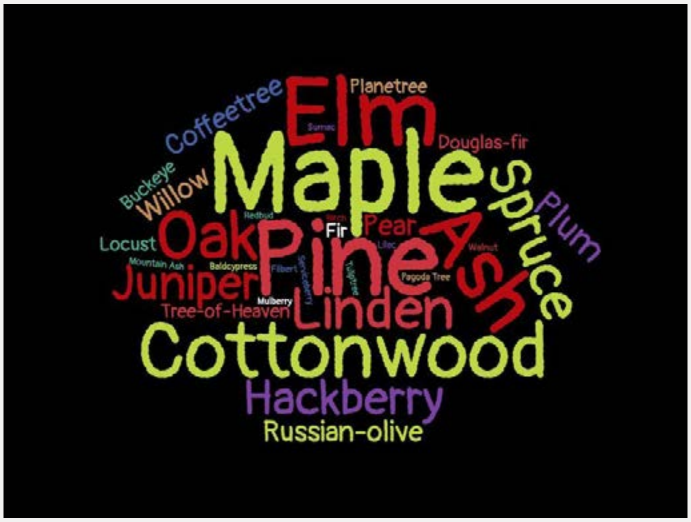
Management strategies and preventing transmission

The city of Boulder's Forestry division and partner agencies have continually worked on detection methods through visual surveys, traps and destructive sampling to determine and monitor the extent of the EAB infestation. The interagency Colorado Emerald Ash Borer Response Team, comprised of nine agencies and organizations, is working with communities to help manage the spread and impacts of EAB. Starting in 2013, the EAB Response Team and partners worked to complete an initial survey to determine the extent of spread of EAB in Colorado, and the team continues working with local governments to determine and map the extent of infestation.

According to Boulder's Urban Forest Strategic Plan (2018), tree cover in the city is approximately 16%, as measured in 2013. Ash tree losses due to EAB are expected to reduce that cover down to 12%, with anticipated losses of hundreds to thousands of ash trees. Because of these expected losses and continued climate change stressors, the city of Boulder's forestry department has set a goal to restore and maintain the the current tree canopy cover around 16 percent.

Figure 3. The common names for the most frequently occurring trees in Boulder, sized by number of occurrences. Larger letters in the word cloud indicate a higher number of that tree species in the tree inventory.

Source: Occurrence is based on data from the city of Boulder's tree inventory and offers the best available knowledge of tree species located on public lands. The inventory accounts for 20% of Boulder's tree canopy, although for ash tree species, the inventory includes a much larger percentage. The inventory does not include trees located on private lands.



RECOMMENDATIONS

Managing the spread of the invasive EAB to protect surrounding cities and counties.

Taking climate change into consideration is important when determining the potential impacts of the Emerald Ash Borer and the spread-risk to nearby counties. When an ash tree dies or is removed, we also need to determine proper replacements. With this essential tree cover shrinking, we will see reductions in the ecosystem services provided by urban tree canopies. By diversifying tree cover in urban areas, we can also provide some immunity to trees farther away from highly infected zones, as these insects aren't as successful at spreading without some form of human-based mode of transport.

By using preemptive strategies to target susceptible trees and strict monitoring programs for the transport of potentially infected wood products, we can prevent the spread to areas that still have healthy ash tree populations.

If your neighborhood is concerned about the impacts of the Emerald Ash Borer on your local trees, talk with an arborist in your area to develop an action plan.

Boulder County's Emerald Ash Borer Management Plan is another great resource to use when considering the management of vulnerable ash trees in your area. Most ash trees are located on privately owned land, so the residents of the city and county of Boulder have the potential to make a huge impact on this initiative to save ash tree populations in Colorado.

Get involved as a Tree Tender! The Tree Trust is a program led by the PLAY Boulder Foundation to work with Boulder residents to plant and care for trees, as well as to support a robust urban canopy and the ecosystem services that trees provide.

URBAN LAND COVER

The City of Boulder succeeds in making trees accessible, regardless of whether you rent or own

Studies conducted in cities throughout the United States have shown, over and over again, that areas with higher socioeconomic status have greater tree canopy cover. Here we investigate the distribution of tree cover in Boulder and ask whether there is a disparity in access to trees for those who rent versus own their home. We found that trees are abundant across the city, with the greatest tree cover actually found in neighborhoods with the highest proportion of renters.

The history of tree plantings in urban areas is fraught with environmental injustice. Studies conducted in cities throughout the United States have shown, over and over again, that areas with higher socioeconomic status have more tree cover. This relationship between income and tree cover is rooted in racially-based discriminatory city planning that started in the 1930's (a practice known today as 'redlining'), with historically Black neighborhoods still feeling the consequences today.

But trees are an increasingly important asset to keep cities liveable in the face of climate change. Tree cover has the ability to mitigate high temperatures in urban environments by providing shade, which in turn lowers energy bills and increases property values. Trees also limit the adverse health effects from ambient pollution and correlate with better health outcomes.

Here we investigate the distribution of tree canopy cover in Boulder and ask whether there is a disparity in access to trees for those who rent versus own their home. We hypothesized that there would be an inverse relationship between the proportion of rental properties and tree canopy cover, such that areas with a high proportion of renters would have lower tree cover. This hypothesis was based on the widespread relationship between socioeconomic status and tree canopy cover in cities.

The data did not support our hypothesis. Instead, the resulting distribution maps show that trees are abundant throughout Boulder, regardless of the proportion of renters (Figures 1 and 2). In fact, the neighborhood with the greatest tree cover also had the highest proportion of renters (*University Hill, Table 1*).

EXPLORE THE DATA

Who has access to trees in Boulder? Answer: almost everybody, regardless of whether you rent or own.

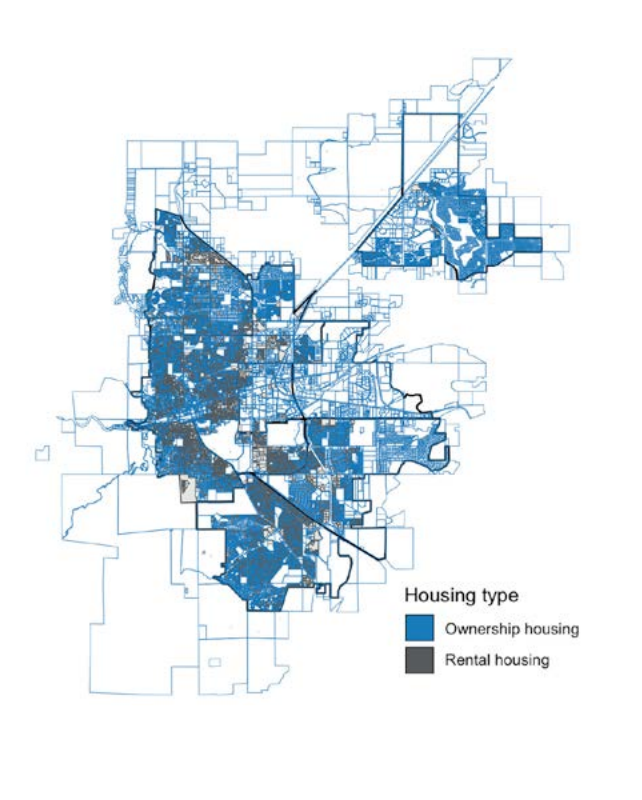


Figure 1. Map of the city of Boulder, showing owner-occupied and rental housing types. Blue properties indicate all owner-occupied housing parcels, and gray properties indicate rental housing parcels that are currently licensed. Notice that Boulder's older, central neighborhoods have more rental properties and tree cover than newer neighborhoods in the eastern parts of the city. *Source: Data provided by the City of Boulder Open Data Catalog. The Rental Property List contains all residential rental properties that are currently licensed.*

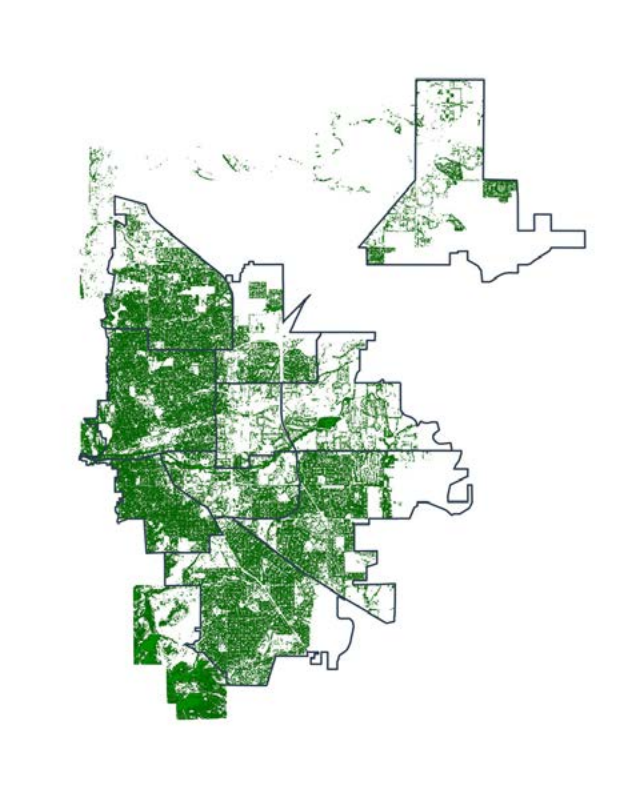


Figure 2. Map of the city of Boulder, showing canopy cover, including trees on both public and private lands. Notice that tree cover is widespread throughout the city of Boulder and not clustered in particular neighborhoods. *Source: Data was collected through LiDAR and aerial images in 2013 by GIS Analysts at the city of Boulder Parks and Recreation department.*

Comparing forest cover and housing across Boulder neighborhoods

Neighborhoods	% Forest	% Rental housing
Gunbarrel	2.73	20
East Boulder	6.67	0
Crossroads	8.22	1.74
Palo Park	10.17	19.72
Southeast Boulder	12.30	49.23
Colorado University	15.72	17.30
South Boulder	16.65	29.15
North Boulder	18.35	24.55
Central Boulder	26.60	24.13
Central Boulder - University Hill	30.01	40.59

Table 1. Percent forest cover and percent rental housing in neighborhoods throughout the City of Boulder. Interestingly, older neighborhoods have more tree cover than newer neighborhoods, which is the opposite of trends in many cities throughout the U.S. Rental housing data is provided by the City of Boulder Open Data Catalog.

The Rental Property List contains all residential rental properties that are currently licensed. Forest cover data was collected through LiDAR and aerial images in 2013 by GIS Analysts at the city of Boulder Parks and Recreation department.

RECOMMENDATIONS

Boulder is doing a great job of keeping trees an equitable resource, so let's continue this trend.

Boulder has been recognized as one of the "Tree Cities of the World", a designation from the Food and Agriculture Organization of the United Nations that identifies cities that have shown a commitment to the responsible planning and management of urban trees and forests. This is a designation that we can all take pride in, and encourages us to continue building urban canopy in equitable ways.

Neighborhoods in the city of Boulder have abundant opportunities to access trees, and this is something to celebrate. Looking forward, we can continue efforts with the city of Boulder urban forestry program to maintain our valued green spaces, seek improvement projects for areas that could use more careful planning and management, and look towards bolstering neighborhoods that would benefit the most from future greening projects. Read our accompanying Urban Land Cover story to learn more about Boulder neighborhoods that could benefit from more trees.

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