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U.S. Senate Committee on Agriculture, Subcommittee on Climate, Conservation, Forestry, and Natural Resources

Hearing on: The Western Water Crisis: Confronting persistent drought and building resilience on our forests and farmland

June 7, 2022

Chairman Bennet, Ranking Member Marshall, and Members of the Subcommittee:

Thank you for the opportunity to speak to you today about maintaining resilient forests and farmland in this era of climate change and increased drought, heat, and fire. I am a professor in the Department of Forest and Rangeland Stewardship at Colorado State University (CSU), specializing in national forest policy and governance. I direct the Public Lands Policy Group,[1] a research group studying policy developments that affect US public lands, and I also lead the university's new Climate Adaptation Partnership,[2] which serves to accelerate innovative research and promote communication with policy makers to support effective and equitable approaches to climate adaptation.

Over the last decade, I have led national-level analyses of many of the primary forest restoration policies, including the Collaborative Forest Landscape Restoration Program and the Joint Chiefs Landscape Restoration Partnership. With funding from the Joint Fire Science Program, in partnership with researchers at the University of Oregon, I completed a four-year study of the policy barriers and opportunities for prescribed fire application. I am part of a team investigating the interactive effects of climate and management across all US forests with funding from the National Science Foundation. In close partnership with the USDA Forest Service, I have also led research on national forest planning, National Environmental Policy Act implementation, climate change vulnerability assessment, and science-based tools for improving fire response. In addition, I work closely with the Colorado Forest Restoration Institute and with a network of thought leaders working on forest management issues from rural and community-based forestry organizations. Through my research and outreach, I have developed a strong understanding of the challenges and opportunities surrounding forest and community resilience in light of climate change, and I have written about the critical importance of collaboration and capacity-building to support effective forest and fire management.[3]

Colorado is facing dramatic impacts from climate change that are expected to increase in frequency and severity. I will discuss some of those impacts and CSU's existing and extensive work addressing climate impacts and transitions. I also will speak to some areas where I see potential for CSU to support activities to promote climate adaptation and comment on progress related to Congress' investments in forest and fire management based on my own scholarly expertise.

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[1] https://sites.warnercnr.colostate.edu/courtneyschultz/
[2] https://www.research.colostate.edu/cip/cap/
[3] Schultz, C.A. and Moseley, C. 2019. Collaborations and capacities to transform US fire management. *Science* 366 (6461), 38-40; doi: 10.1126/science.aay3727

Climate Change Impacts in Colorado

Climate change is affecting Colorado through increased fire, smoke, flooding, and, perhaps most importantly, drought. While I do not aim here to provide an overview of all climate-related impacts to our Colorado ecosystems, communities, and economy, I offer an overview of some of the impacts of drought, heat, and fire for farms and forests.

In late April of this year, the USDA designated the entire state of Colorado as a "primary natural disaster area" due to severe drought conditions.[4] As of May 24, 2022, drought conditions across sixty percent of Colorado were classified as severe, extreme, or exceptional.[5] Scientists anticipate that there is a 94% chance of the drought continuing through 2023 and a 75% chance of it continuing until 2030; the current multi-decadal drought impacting the American Southwest would likely not be of record proportion without anthropogenic climate change.[6]

In the last twenty years, streamflows in the Colorado River Basin have declined as a result of this persistent "hot drought".[7] Major reservoirs including Lakes Powell and Mead are now at record lows. As of May 4, 2022, the Colorado Basin River Forecast Center projects that the most likely inflows to Lake Powell will be 38% below average.[8] As of May 31, 2022, snow water equivalent in the Upper Colorado River Headwaters were at 22% below normal. What is perhaps more shocking is that the San Miguel, Dolores, Animas, and San Juan Rivers in southwestern Colorado were at 99% below normal and the Rio Grande watershed at 92% below normal as of May 31. With the exception of the South Platte and Arkansas Rivers, not a single river basin in Colorado has reached average snow water equivalent for this point in the season.[9]

It is also getting hotter in the region. Colorado's west slope has faced some of the largest increases in average temperature in the southwestern states over the last 30 years, with large areas of the region increasing from 2.5 to 3.0 degrees Fahrenheit compared to the average temperature from 1901-1960 (Fig. 1). By the middle of the next decade, climate-model projections indicate that extreme heat (as determined by the number of days in the year when temperatures exceed 90 degrees Fahrenheit) in Colorado will increase as compared to the period of 1976-2005 (Fig. 2). Days of extreme heat in the western half of Colorado are expected to increase by 10 to 20 days; on the eastern plains, they will increase by 30 to 50 days.[10]

The impacts of drought and heat are significant for Colorado. Agriculture is one of Colorado's major industries, contributing $47 billion annually and supporting nearly 200,000 jobs; drought is projected

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4 https://www.fsa.usda.gov/news-room/emergency-designations/2022/ed_2022_0426_rel_0020

5 U.S. Drought Monitor - Colorado, May 24, 2022. (https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?CO)

6 Williams, A.P., Cook, B.I., and Smerdon, J.E. 2022. Rapid intensification of the emerging southwestern North American megadrought in 2020–2021. *Nature Climate Change* 12, 232-234; doi: 10.1038/s41558-022-01290-z

7 Udall, B. and Overpeck, J. 2017. The twenty-first century Colorado River hot drought and implications for the future. *Water Resources Research* 53 (3), 2404-2418; doi: 10.1002/2016WR019638

8 U.S. Bureau of Reclamation. Upper Colorado Region Water Operations Status as of May 17, 2022. (https://www.usbr.gov/uc/water/crsp/cs/gcd.html)

9 Colorado Climate Center. Colorado SNOTEL Current Snow Water Equivalent Percent of Normal Map. (https://climate.colostate.edu/drought/#gallery-19)

10 Fourth National Climate Assessment (2018) – Southwest Region. (https://nca2018.globalchange.gov/chapter/25/)

to cost the state more than $500 million in annual agricultural damages by 2050.[11] As climate hazards increase in frequency and severity, Colorado's agricultural community is especially vulnerable to temperature and precipitation extremes that can affect crop yields.[12] Possible low-to-no-snow futures later this century and the timing of water availability will have major impacts on critical aspects of the state's economy, including Colorado's renowned, multi-billion dollar ski industry.[13]

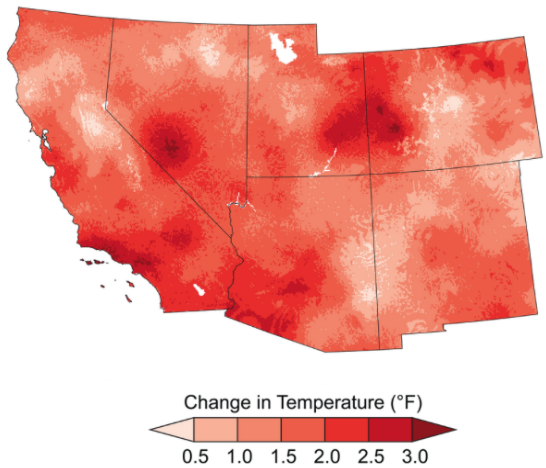

Figure 1: Changes between 1986-2016 and 1901-1960 average temperatures in the southwestern United States (Fourth National Climate Assessment, 2018).

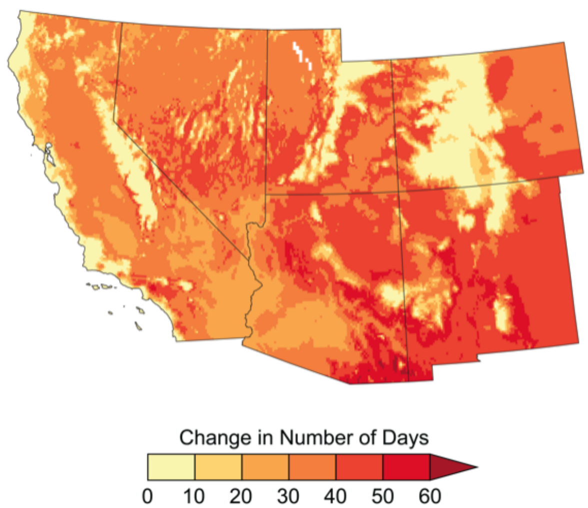

Figure 2: Increase in the number of days with extreme heat (days with high temperatures exceeding 90 degrees) by the mid-2030s as compared to the 1976-2005 average (Fourth National Climate Assessment, 2018).

[11] Kohler, J. 2021. From Western Slope to Eastern Plains, Colorado agriculture under pressure to adapt to warming world. *The Denver Post*, 22 September. https://www.denverpost.com/2021/09/19/colorado-agriculture-grapples-with-climate-change/#:~:text=Agriculture%20is%20one%20of%20Colorado%27s,of%20that%20occurring%20agriculture%20alone

[12] Walsh, M. K., et al. 2020. *Climate Indicators for Agriculture*. USDA Technical Bulletin 1953. Washington, DC. 70 pages. doi: 10.25675/10217/210930.

[13] Siirila-Woodburn, E.R., et al. 2021. A low-to-no snow future and its impacts on water resources in the western United States. *Nature Reviews Earth and Environment* 2, 800-819; doi: 10.1038/s43017-021-00219-y

For Colorado, curtailment on water use to meet Colorado River Compact requirements could have a profound impact on water users, including municipal needs on the Front Range and junior agricultural water right holders on the Western Slope and in the Arkansas River Basin. Colorado also is a headwaters state for vital rivers that supply 18 other US states and Mexico. Drought and its interaction with disturbances like fire have impacts that extend well beyond our state borders.

Fire has become a prominent aspect of life in Colorado. This summer, again, temperatures statewide are likely to be above average, and precipitation is projected to trend below average across much of the state (Fig. 3). This combination has led to predictions of an “above normal” potential for significant wildfire across most of the state.[14] Four of the five largest wildfires in Colorado history have occurred since 2018, with three of the five in 2020 alone. The largest fire (Cameron Peak in 2020) covered 209,000 acres and was 51 percent larger than the previous largest fire (Hayman) that occurred in 2002. The 20 largest fires in Colorado history have all occurred since 2001 (the beginning of the ongoing megadrought over the southwestern United States).[15] Increasing populations in the wildland-urban interface in Colorado will only face increased risk to wildfire over the coming decades.[16]

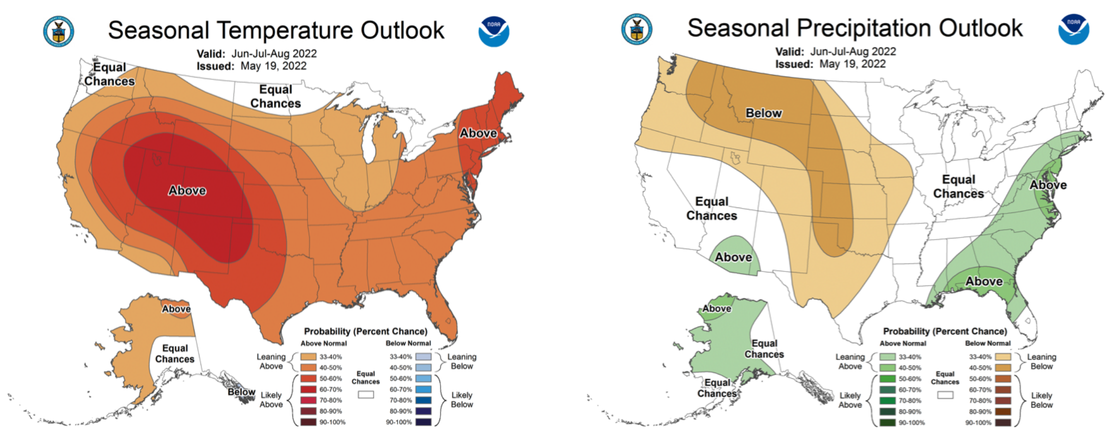

Figure 3: Outlook for seasonal temperature (left) and precipitation (right) effective for June, July, and August 2022 (National Oceanic and Atmospheric Administration).

Wildfire also has become a year-round issue in Colorado. The state witnessed its costliest fire in state history, and the 10th costliest fire in US history, in December of 2021. The Marshall Fire burned 6,000 acres and over 1,000 homes in Boulder County, northwest of Denver. NOAA labeled the fire a “billion

[14] National Interagency Fire Center Predictive Services. Available from the Colorado Climate Center at: https://climate.colostate.edu/drought/#outlook.
[15] Colorado Division of Fire Prevention and Control - Historical Wildfire Information. https://dfpc.colorado.gov/wildfire-information-center/historical-wildfire-information.
[16] Radeloff, V.C., et al. 2018. Rapid growth of the US wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences, USA* 114:2946-2951. doi: 10.1073/pnas.1718850115 https://www.pnas.org/doi/10.1073/pnas.1718850115

dollar disaster."[17] Due to the cost of materials and insurance policy coverage, most estimates have shown that homeowners in Superior and Louisville attempting to rebuild are considerably underinsured.[18]

Such impacts are being felt across the West. Wildfires in the western United States cost the nation over $10 billion in 2021.[19] Increases in heat, aridity, and earlier snowmelt are adding to the risk of wildfires in the western United States, including the Rocky Mountain ecoregion in Colorado. Moreover, fires are increasing in size, severity, extent and frequency[20] with longer wildfire seasons.[21] Wildfires also are increasing in size and extent specifically in high-elevation landscapes,[22] which could further harm threatened water supplies. And these burned landscapes are often not recovering to their pre-fire structure.[23]

Communities and land managers must assess and manage ever-larger post-fire landscapes for future resilience, dealing with the direct damage caused by wildfires, but also post-fire flooding and erosion, water quality issues, and changing ecosystem services. High sediment loads in rivers following wildfires can fill reservoirs and clog water intakes. Both agricultural and municipal water supplies can be affected by poor water quality and infrastructure damage after wildfires. After the 2002 Hayman Fire, for instance, an estimated $26 million of damage to water infrastructure occured around the Denver metropolitan area. That fire and others prompted a series of watershed partnerships among water utilities, partner organizations, and the US Forest Service to fund forest fuel reduction along the Front Range.[24]

Smoke from these wildfires is increasing in the western United States and is counteracting air quality improvements from cleaner electricity, industry, and transportation[25]. In Colorado, we regularly experience smoke from both local, in-state fires as well as fires from other western US states and

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[17] Smith, A. 2022. Beyond the Data - 2021 billion-dollar weather and climate disasters in historical context. National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical

[18] Mullholland, S. 2022. For people who lost homes in the Marshall Fire, insurance might not cover everything. *Colorado Public Radio News*, 12 January. https://www.cpr.org/2022/01/12/boulder-county-marshall-fire-homes-insurance/

[19] Smith, *supra* note 17.

[20] Parks, S.A. and Abatzoglou, J.T. 2020. Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. *Geophysical Research Letters* 47 (22); doi: 10.1029/2020GL089858

[21] Brey, S.J., et al. 2020. Past variance and future projections of the environmental conditions driving western US summertime wildfire burn area. *Earth's Future* 9 (2); doi: 10.1029/2020EF001645

[22] Higuera, P.E., Shuman, B.N., and Wolf, K.D. 2021. Rocky Mountain subalpine forests now burning more than any time in recent millennia. *Proceedings of the National Academy of Sciences* 118 (25), 1-5; doi: 10.1073/pnas.2103135118 https://www.pnas.org/doi/10.1073/pnas.2103135118

[23] Stevens-Rumann, C., et al. 2018. Evidence for declining forest resilience to wildfires under climate change. *Ecology Letters* 21, 243-252; doi: 10.1111/ele.12889

[24] Huber-Stearns, H.R., Schultz, C.A., and Cheng, A.S. 2019. A multiple streams analysis of institutional innovation in forest watershed governance. *Review of Policy Research* 36 (6), 781-804; doi: 10.1111/ropr.12359

[25] O'Dell, K., Ford, B., Fischer, E.V., and Pierce, J.R. 2019. Contribution of wildland-fire smoke to US PM2.5 and its influence on recent trends. *Environmental Science and Technology* 53 (4), 1797-1804; doi: 10.1021/acs.est.8b05430

Canada[26]. As exposure to smoke is associated with increased respiratory hospitalizations and death rates[27], it is imperative to create smoke-ready communities in Colorado with effective air quality communication and clean-air spaces. These and other effects of fire and other climate-driven disturbances and disasters fall disproportionately on low-income and marginalized populations, who are often left behind in both fire preparedness and recovery efforts.[28] It is essential going forward to ensure the investments in forest and fire management are done in a way that increases social equity and builds collaborative capacity where it is needed.

We also will continue to see compounding effects of various climate-driven disturbances. For example, the increase in area burned by wildfire in recent years has increased the risk of flash floods when heavy rain falls on burn scars. This was highlighted by the debris flows that closed I-70 in summer 2021, and the deadly flash flood in the Poudre Canyon in July 2021. Research indicates this will become more common in the future: thus, not only will extreme fires become more likely, but many more of those will also be followed by extreme rainfall events.[29]

Wind and airborne dust are also likely to increase. Winter and early spring are typically the windiest times of year in Colorado. Although the ground can be snow covered during these seasons, lack of snow and drought will enhance the tendency of exposed soils to be mobilized by wind. This can lead to erosion of arable soils and health-threatening dust storms. Mobilization of dust that is then deposited onto snowpack lowers the reflective capacity (albedo) of snow, causing it to warm more rapidly, leading to earlier snowmelt that affects annual streamflows and water supply for downstream needs. While it is not clear that climate change will lead to stronger winds, land use change and drier conditions during Colorado's windy periods will create vulnerability to increased numbers of episodes of blowing dust and snowpack deposition.[30]

In summary, climate change threatens the resilience of ecosystems and communities in Colorado and in many states for which Colorado forests serve as the headwaters. Evidence suggests conversions from forested areas to shrub or other non-forest systems will continue.[31,32] This further impacts the abilities of natural climate solutions to aid in mitigating further climate change, as loss of forest carbon and

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[26] Magzamen, S., et al. 2021. Differential cardiopulmonary health impacts of local and long-range transport of wildfire smoke. *GeoHealth* 5 (3), 1-18; doi: 10.1029/2020GH000330

[27] Gan, R.W., et al. 2020. The association between wildfire smoke exposure and asthma-specific medical care utilization in Oregon during the 2013 wildfire season. *Journal of Exposure Science and Environmental Epidemiology* 30 (4), 618-628; doi: 10.1038/s41370-020-0210-x

[28] Davies, I.P., Haug, R.D., Robertson, J.C., and Levin, P.S. 2018. The unequal vulnerability of communities of color to wildfire. *PLOS ONE* 13 (11), 1-15; doi: 10.1371/journal.pone.0205825; Anderson, S., Plantinga, A., Wibbenmeyer, M. 2020. Inequality in agency responsiveness: evidence from salient wildfire events. Resources for the Future Working Paper 20-22. Available at: https://media.rff.org/documents/WP_20-22.pdf

[29] Touma, D., et al. 2022. Climate change increases risk of extreme rainfall following wildfire in the western United States. *Science Advances* 8 (13), 1-11; doi: 10.1126/sciadv.abm0320

[30] Lambert, A., et al., 2020. Dust impacts of rapid agricultural expansion on the Great Plains. *Geophysical Research Letters* 47 (20); doi: 10.1029/2020GL090347

[31] Stevens-Rumann, C.S., and Morgan, P. 2019. Tree regeneration following wildfires in the western US: a review. *Fire Ecology* 15 (15), 1-17; doi: 10.1186/s42408-019-0032-1

[32] Coop, J.D., et al. 2020. Wildfire-driven forest conversion in western North American landscapes. *BioScience* 70 (8), 659-673; doi: 10.1093/biosci/biaa061

forest carbon sequestration abilities may accelerate certain feedbacks at large spatial scales.[33] The interaction between climatic stressors, biotic and abiotic disturbances and decreasing resilience at both small and large spatial scales suggest the potential lack of persistence of forested ecosystems.[34] Maintaining the resilience and persistence of our forested watersheds is a critical task for Colorado and one that is important for downstream states both east and west of the Continental Divide. I have written elsewhere about the value of fuel reduction and forest restoration activities, including selective tree thinning and the reintroduction of fire through prescribed and natural wildfire, under certain conditions, to promote the resilience of fire-adapted forests and nearby communities. I have also noted that the science indicates for community protection, home hardening and defensible space in the home ignition and community protection zones are our best chance at protecting homes from fire.[35] There also are other potentially promising avenues to pursue, such as the re-establishment of meadows and riparian corridors within traditionally colder and wetter forests, maintaining sites that serve as refugia to cultivate resistance within these ecosystems, and other potential management actions to support forest persistence, such as assisted migration of tree species from lower, drier elevations to higher sites where conditions are changing. All of this points to the need for reducing carbon emissions, alongside ongoing research on how to promote community resilience and support adaptation to climate change.

Climate Research, Extension, and Education Activities at CSU

At CSU, we are undertaking extensive work to support both climate change mitigation (i.e., reduction of greenhouse gas emissions) and climate adaptation (i.e., adjusting to living with evolving climatic conditions and climate-driven disturbances). I provide here an overview of some of the work we are doing at CSU to convey the vast expertise and capacity housed at our university, in line with our land grant mission to serve our students and the state with research, extension, and education.

We are in the process of developing a new Master's Certificate program that would be available to post-baccalaureate students and professionals around the country and in Colorado who are interested in learning new skills for climate vulnerability assessment, adaptation planning, and climate-smart land management. We also host a Master's Certificate program in greenhouse gas accounting that is utilized by students across colleges, including natural resource and business students. Colleagues are also offering summer camps for Indigenous K-12 youth in the state with an emphasis on science training.

My own scholarship focuses on understanding policy barriers and opportunities to improve forest and fire management to support greater social and ecological resilience, address the risks associated with fire, and adapt to a changing climate. I have been a partner to the USDA Forest Service for over a decade in conducting research on forest restoration policies, fire planning and response, climate adaptation, and, now, post-fire policy, all in an effort to provide a third-party evaluation of policy needs and activities and to bring to bear my expertise in science-policy studies and public administration.

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[33] Griscom, B.W., et al. 2017. Natural climate solutions. *Proceedings of the National Academy of Sciences* 114 (44), 11645-11650; doi: 10.1073/pnas.1710465114 https://www.pnas.org/doi/10.1073/pnas.1710465114

[34] Anderegg, W.R., et al. 2020. Climate-driven risks to the climate mitigation potential of forests. *Science* 368 (6497); doi: 10.1126/science.aaz700

[35] Schultz, C.A. 2021. Testimony to the US House of Representatives Natural Resources Subcommittee on National Parks, Forests, and Public Lands. Hearing on "Wildfire in a Warming World: Opportunities to Improve Community Collaboration, Climate Resilience, and Workforce Capacity." April 29, 2021. Available at: https://sites.warnercnr.colostate.edu/courtneyschultz/wp-content/uploads/sites/23/2021/04/Schultz.Testimony.4.29.21.HNRC_.NPFPL_.pdf

I also partner with the Colorado Forest Restoration Institute at CSU, one of the Southwest Ecological Restoration Institutes authorized by Congress in 2004.[36] CFRI has been at the forefront of integrating best available science into local forest and wildfire risk mitigation collaboratives to generate zones of agreement about landscape resilience goals and management strategies, and to quantify the outcomes of management so that managers, partners, and policy-makers can assess the return on investments. CFRI's work contributes to pre-fire forest restoration and risk mitigation, during-fire decision making, and identifying cost-effective investments for post-fire forest and watershed recovery and restoration. For example, in collaboration with scientists at the Forest Service's Rocky Mountain Research Station, CFRI has organized collaborative workshops to define Potential Operational Delineations for wildfire mitigation and response on fifteen national forests across the West. Following the Cameron Peak Fire, CFRI scientists integrated a customized wildfire erosion and sediment transport tool to inform managers about the geographic areas where erosion control measures would have the greatest benefit to downstream water users. This same tool is used by local forest and wildfire risk mitigation collaboratives to identify areas to treat before a fire occurs to reduce post-fire impacts to water infrastructure, which is already at risk due to prolonged droughts. As we face these unprecedented challenges to our systems, understanding the needs at all stages of fire planning is critical.

Members of the new CSU Climate Adaptation Partnership, which we started in 2021 with internal funding support, are researching how to improve the resilience of the built environment to natural disasters, how to support tree regeneration post-fire, and strategies for climate adaptation in rangeland ecosystems. Through this partnership we are growing our capacity to address climate adaptation, developing new interdisciplinary proposals and partnerships, training scientists in outreach to policymakers, and exploring a possible climate initiative at CSU to expand upon our current work.

To further address fire and drought, CSU is part of the Transformation Network, a $15 million National Science Foundation transdisciplinary research effort representing diverse communities, sectors, disciplines, and backgrounds aimed at improving resilience to wildfire, drought, and other climate change disturbances in the Intermountain West, including Colorado. The Network focuses on how headwaters and headwater-dependent systems, regional food-energy-water systems, and innovative approaches to governance can be integrated to help direct Colorado along trajectories that result in a sustainable future for humans and the environment. This work includes close collaboration with Colorado Extension offices, the Northern Colorado Fireshed Collaborative, and watershed partnerships.

CSU researchers also are engaged in examining wildfire impacts on forest ecosystems, snowpack, streamflow, and sediment yield. CSU faculty and students collaborate with the USDA Forest Service Rocky Mountain Research Station and the USDA Agricultural Research Service to examine how forest structure, streamflow, and water quality change after fire. They are coordinating with water providers (City of Greeley, Northern Colorado Water Conservancy District) and other organizations (Coalition for the Poudre River Watershed) to evaluate whether post-fire mulch treatments are effective at reducing flash flooding and sediment loads in fire-affected streams. CSU faculty and researchers are examining the role of pre-fire treatments on wildfire behavior and effects as well as natural post-fire recovery and how to optimize post-fire reforestation efforts. This is done in conjunction with the nonprofit Trees, Water & People, the National Forest Foundation, the US Forest Service, and many private landowners. At CSU, we are growing partnerships with the USDA Climate Hubs. CSU partners with the USDA Northern Plains, Northern Forests, and Southwest Climate Hubs to support grassland and forest adaptation through workshops utilizing the Northern Institute of Applied Climate Science's (NIACS) Climate Change

[36] Southwest Forest Health and Wildfire Prevention Act of 2004 (P.L. 317-108).

Response Framework and Adaptation Workbook to provide practical, on-the-ground options to help land managers adapt ecosystems to changing conditions. Members of the Climate Adaptation Partnership are developing additional proposals to USDA National Institute for Food and Agriculture–Agriculture and Food Research Initiative (NIFA-AFRI) with CSU Extension and the Climate Hubs to address drought.

Extension staff members, with support from the state, recently led a five-part Drought Leadership Training[37] in partnership with the Rocky Mountain Farmers Union, the Colorado Ag-Water Alliance, the Natural Resources Conservation Service (NRCS), the USDA Northern Plains Climate Hub, and the National Drought Mitigation Center. This was a virtual and in-person training, accessed by 700 individuals, geared to retail agriculture, agricultural services, extension, and those working for agriculture-focused agencies/organizations. Topics covered the use of forecasts in drought planning, risk management in drought, and drought management strategies for livestock, range, and cropping systems. The same group of collaborating individuals and organizations is now working on a drought planning handbook for Colorado agriculture and have formed a network across the state of extension, NRCS, farmers, and other individuals trained in drought planning.

CSU also is home to the Colorado State Forest Service (CSFS), which is a service and outreach agency that provides staffing to the Division of Forestry for the Colorado Department of Natural Resources. The CSFS partners with federal and state agencies, tribes, water providers, and private landowners through 17 field offices located across the state. The CSFS incorporated climate adaptive goals, strategies, and approaches in the 2020 Colorado Forest Action Plan,[38] a ten-year strategic plan to guide improving forest conditions, living with wildfire, watershed protection, wildlife habitat, urban and community forestry, and forest products across all political, jurisdictional, and ecological boundaries. The unique position of the CSFS within CSU promoted collaboration on this plan with the Forest and Rangeland Stewardship Department at CSU and the Northern Institute of Applied Climate Science. The CSFS also undertakes actions related to fire risk assessment and helping communities and homeowners prepare for wildfire.

In addition to the work of the CSFS and the Colorado Forest Restoration Institute, the Center for Collaborative Conservation at CSU recently launched the Colorado Forest Collaboratives Network, designed to support Colorado's 40+ place-based forest collaborative groups, which together contribute to much of the state's on-the-ground forest health, wildfire risk mitigation, and watershed restoration work. The network supports these collaboratives by connecting them to information, resources, and one another, and by sharing their stories to make their value and needs understood.

CSU's School for Global Environmental Sustainability (SoGES) has contributed to scientific assessments of the impact of climate change on agriculture and global food security and recently worked with a group of USDA climate hubs and other universities to define a set of indicators of climate change impacts on agriculture, published in 2020.[39] SoGES is also conducting research on the intersection of climate change with soil biodiversity and the impacts of climate change on the hydrological cycle and rainfall patterns.

[37] https://drought.extension.colostate.edu/drought-leadership-training/
[38] https://csfs.colostate.edu/forest-action-plan/
[39] *Supra* note 12.

Also housed at CSU is the Soil Carbon Solutions Center,[40] whose mission is to harness the power of soil to restore our climate and support a thriving planet. The Center leverages CSU's world-class scientific expertise to build the tools and approaches needed to accelerate the deployment of credible soil-based climate solutions, measure their impacts, and bring them to scale. The Center serves a diversity of stakeholders, including agricultural producers, policy makers, corporate entities, NGOs advocating for better soil management policy, and the broader land stewardship community that relies on science-based information to guide decision-making.

To address sustainable livestock agriculture, CSU is host to AgNext: Real-World Sustainable Solutions for Animal Agriculture. AgNext leverages a recent university-wide initiative in sustainable livestock systems. One major effort of the group is the quantification of greenhouse gas emissions from ruminant animals, with the goals of exploring scalable solutions to reduce methane emissions, recognizing opportunities for carbon sequestration in animal systems, developing practical solutions to reduce GHG emissions, and measuring progress over time. The effort builds a network of allied partnerships, leverages private investment in equipment and in-kind support, and encourages industry adoption. Our College of Agricultural Sciences is also a leader in agrivoltaics innovation, which promises a high degree of positive spillover for economics development and creation of green jobs. The College also is leading work on regenerative agriculture for climate resiliency, emphasizing the science of regenerative agriculture, defining knowledge gaps, encouraging experimental approaches to cropping systems, and translating this work through on-farm demonstration.

The Colorado Agricultural Experiment Station (CAES) is a center of research and extension excellence and an integral part of CSU's College of Agricultural Sciences. The CAES consists of facilities that span the biogeography of Colorado and its climate systems and is researching and supporting the adoption of climate smart agriculture practices, which are essential for achieving sustainable soil health and productivity by factoring regional variability as one of the main characteristics of CSA. More than 100 CAES supported Faculty are engaged in all aspects of this important topic.

CSU also is home to the Partnership on Air Quality, Climate, and Health, whose members are studying a wide range of topics related to smoke from wildfires, including recent and projected smoke trends,[41] smoke health impacts,[42] and effective smoke-risk communication strategies. Researchers are working to expand monitoring of air quality during fire seasons and collaborating with Colorado cities and health departments on improving community messaging during smoke events to encourage the public to take more protective measures.

Also part of CSU is the Cooperative Institute for Research in the Atmosphere (CIRA, CSU's Cooperative Institute with NOAA), which works with satellite imagery to understand climate change impacts. Such university-federal agency partnerships are critical for generating innovative science, workforce training, and cooperative workshops.

The Colorado Climate Center,[43] our state climate office, is housed at CSU and operates a network of 90 weather stations in Colorado's agricultural areas. Many of these stations have now been operating for

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[40] https://www.research.colostate.edu/cip/scsc/

[41] *Supra* note 25 and Ford, B., et al. 2018. Future fire impacts on smoke concentrations, visibility, and health in the contiguous United States, *GeoHealth* 2 (8), 229-247*;* doi: 10.1029/2018GH000144.

[42] *Supra* note 26.

[43] https://climate.colostate.edu/

over 30 years. This network measures the usual weather variables (temperature, humidity, wind, rain, etc.), and provides critical information about evaporative demand that is used by farmers and water managers for precise irrigation planning. The Center has advanced the science of drought monitoring over the last 15 years through research and real-time analysis of data statewide, monitoring drought conditions and providing recommendations to the weekly US Drought Monitor and the Governor's Water Availability Task Force. The Center is also the headquarters of the Community Collaborative Rain, Hail, and Snow network (CoCoRaHS), with over 20,000 community members who observe precipitation in their backyards. Data from this network of citizen observers is widely used by researchers and drought monitoring experts to track climate conditions across the state.

The Climate Adaptation Program at the Center for Environmental Management of Military Lands (CEMML CAP), housed at CSU, provides interdisciplinary climate change vulnerability assessments for US Air Force installations around the world. In Colorado, CEMML CAP has assessed climate vulnerabilities for integration into the management plans of Peterson Space Force Base, Schriever Space Force Base, Buckley Space Force Base, Cheyenne Mountain Space Force Station, as well as the US Air Force Academy and its associated properties. Each of these assessments highlight issues of extreme heat, drought and wildland fire as primary concerns for military installations in Colorado and impacts to surrounding communities. CEMML CAP staff are responding to Executive Order 14008 by providing climate literacy training to leadership and managers at installations, a key aspect of the Department of Defense Climate Action Plan.

CSU also houses an Energy Institute that has a 30-year history of global impact through developing at-scale energy and climate solutions . Specifically, the Energy Institute: provides support to over 250 faculty within the University's eight Colleges who are developing interdisciplinary energy and climate solutions; manages a portfolio of experiential learning programs for CSU students; organizes and hosts events including the Colorado Climate Transitions Dialogue; delivers programs to support CSU faculty and students commercialize technologies and start companies; and maintains and operates the Powerhouse Energy Campus, the largest freestanding university-based energy research and entrepreneurship facility in the United States. Examples of impactful solutions emerging from the Energy Institute include: a) improvements in the efficiency of large internal combustion engines that has led to emission reductions equivalent to taking tens of millions of automobiles off the road each year; b) through the development of clean cookstoves and small village micro-grids, the Institute and its commercialization partners have improved the lives of millions of people in the developing world; and c) in collaboration with partners across the CSU system, the Institute has successfully launched and/or led more than two dozen cleantech companies over the past two decades with combined annual revenues approaching $100M.

Finally, the One Health Institute[44] takes a transdisciplinary approach to advance health for humans, animals, and the environment and works to solve complex problems at this intersection through research, training, outreach, and advocacy, recognizing the need for multiple disciplines to work together to achieve optimal health outcomes. Their Climate Change and One Health Pilot program awarded funding to research teams working on communication of air quality information, health impacts from temperature extremes under different solar climate interventions, mitigating climate change impacts through virtual livestock fencing, and urban green spaces for pollinators and human health; these teams have gone on to raise substantial external research funding to pursue these topics.

[44] https://onehealth.colostate.edu/

Potential Future Priorities and Investments
To conclude my testimony, I want to highlight a few areas for potential future attention and investment by Congress and potentially this committee. As I have detailed, land grant universities like CSU bring tremendous capacity and expertise related to climate change mitigation and adaptation.

In addition to the work already occurring through USDA and opportunities through USDA NIFA-AFRI, we see potential for scaling up funding opportunities specific to climate adaptation. CSU plans to work with USDA to help shape such a research agenda in the future. We have submitted a proposal to support a NIFA Climate Change Working Group that will use a systematic Horizon Scanning methodology to develop the NIFA Climate Change RoadMap, including an implementation plan.

We also see potential for augmenting funding for land grant–USDA Climate Hub partnerships, perhaps with multi-year funding in a model similar to the US Geological Survey's Climate Adaptation Science Centers, but in this case with funding to support partnerships for agriculture and forest resilience that leverage the Climate Hubs excellent work with the capacity of land grants to contribute in research, extension, and education. Land grants could partner with minority-serving institutions in the region to serve communities through extension partnerships, and to build educational opportunities across states at different levels and institutions to retrain the existing workforce and train and recruit an inclusive, new generation of land managers, scientists, and community liaisons working in agriculture and forestry. Universities also could augment forecasting capacity related to climate change, provide research on the education and communication techniques to reach different communities and groups of people, and provide added fundraising capacity to augment our collective work in addressing climate change. There are also numerous areas that are in need of additional research to support climate change mitigation and adaptation, and, in particular, to avoid maladaptation. We believe our capacities in research, extension, and education would add value and in turn would benefit from stronger partnerships with the Climate Hubs.

There also may be value in exploring authorizing the Climate Hubs as a separate and important program. The recent five-year review of the Hubs identified that "demand for Hubs programs and products is exceeding current capacity" and that there are multiple areas for growth that would augment their existing and effective work.[45] The implications for USDA and long-term funding, however, are beyond my expertise, and would require further discussion with the Executive Branch.

There are also other funding opportunities we see at CSU. The 2018 farm bill established a novel agricultural research funding program within USDA, the Agriculture Advanced Research and Development Authority (AgARDA). Innovative research funded by AgARDA would not only improve biosecurity, but also advance climate smart technologies and production practices that allow U.S. farmers to address challenges related to climate change. While AgARDA has now received its first appropriation of $1 million, reaching the authorized amount of $50 million would support the full potential of this unique research program.

Wildlife disease, which has significant impacts on human health and agriculture, is also susceptible to the effects of climate change.[46] We see a need for funding to coordinate Federal, State, and university

[45] Steele, R., et al. 2019. *USDA Climate Hubs: Five Year Review.* Report prepared for the USDA Climate Hubs Executive Committee, U.S. Department of Agriculture, Washington D.C.
[46] Hofmeister, E., et al. 2010. Climate change and wildlife health: direct and indirect effects. USGS National Wildlife Health Center. Available at: https://pubs.usgs.gov/fs/2010/3017/pdf/fs2010-3017.pdf

responses and resources to identify risks, integrate surveillance information, develop new diagnostic and surveillance tools, and plan for cost effective mitigation responses for outbreaks posing the highest risk to agriculture and human health and safety. We also are looking for additional investments to scale up the work we are doing in climate-smart and resilience agricultural systems, for instance related to work on agrivoltaics and regenerative agriculture. Likewise, CSU is well-positioned to help facilitate collaboration and learning to engage the global agricultural advisory community through the North American Agricultural Advisory Network (NAAAN), which coalesces existing programs and organizations in the United States, Canada, and Mexico. NAAAN serves as a platform for networking, learning, knowledge sharing, and advocacy for agricultural extension programs and service providers in support of three main thematic areas: biodefense and management of natural disasters; climate change with particular emphasis on water management and soil health; and youth and career empowerment.

Regarding investments in forestry, more funding will be needed on an ongoing basis. Many partners are also seeking greater transparency and engagement around how those funds are allocated. I would recommend ongoing oversight and specific attention to how progress is measured at the national level over the next 5-10 years. For years and across administrations, the US Forest Service and its many partners have acknowledged that traditional performance indicators, such as timber volume sold and acres treated, alone do not convey the quality of work in leading to fire risk reduction. Fire risk reduction and forest restoration require more nuanced approaches to performance measurement and accountability, drawing upon metrics like acres mitigated (i.e., acres on which final treatments to complete fire risk reduction actions have been taken) and considering stakeholder insights on whether treatments occur in priority areas, at large enough scales, and are coupled with work across jurisdictional boundaries. This is a complex challenge, but it is time, given Congress' recent investments, to consider how to design and implement more outcomes-oriented performance assessment.

In addition, despite the challenges associated with implementing prescribed fire and the current moratorium on prescribed fire (in light of the escaped fire in New Mexico that has led to the largest fire in that state's history), prescribed fire, cultural burning by tribes, and generally reintroducing fire under the right conditions will be essential to restoring forest resilience in fire-prone forested ecosystems. The challenges of doing so are significant, but we cannot give up on working to reintroduce fire and must seek ways forward that utilize fire as part of our forest management toolbox if we are to maintain resilient forests and communities into the future.

Considering the impacts of a changing climate, the challenge of managing our connected forests, watersheds, and farmlands is monumental in Colorado and across the American West. We must strive to find ways forward in confronting these predicaments if we are to make these landscapes more resilient to the climate change realities that are already upon us. My colleagues and I are ready to assist in this endeavor and greatly appreciate the opportunity to discuss these issues with the committee.