University of Colorado-Boulder Hosted Year 2 Annual Report

August 2020

Submitted by:
Jennifer Balch (University Director)

North Central
Climate Adaptation
Science Center

1. TERM SHEET
The Term Sheet of key elements of the USGS-University of Colorado Boulder Cooperative Agreement for the hosting of the North Central Climate Adaptation Science Center (NC CASC) is located in **APPENDIX I**.

2. ADMINISTRATIVE:
Award Recipient: Dr. Jennifer Balch
Issued to: The Regents of the University of Colorado
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Institution of the Award Recipient: University of Colorado-Boulder
Award Agreement Number: G18AC00325
Data of the Report: 02 August 2020
Period of time covered by the report: Oct. 1, 2019 to Sep. 30, 2020

2. PURPOSE AND OBJECTIVES:
The overarching objective of the North Central Climate Adaptation Science Center (NC CASC) and its consortium partners is to accelerate actionable science through co-production, data-intensive discovery and open science. In Year 2, we made significant progress on our core goals: partnerships; science; capacity building; and communications/outreach. The efforts described below arose from key partnerships with stakeholders, including the U.S. Fish and Wildlife Service, National Park Service's Climate Change Response Program, and Tribal Colleges and Tribal students.

Year 2 science activities included continued efforts of the Climate Science Support Platform (CSSP), a "go-to" resource for climate science expertise and services. A new R package: Climate Futures Toolbox (CFT) was released in April 2020 (see RESULTS). The CFT was developed to support the user needs of our stakeholders. Initial development and design of the CFT was funded jointly by the USGS Community for Data Integration and the CU hosting agreement; continued development and maintenance is supported by the efforts of the university team. Research on ecological drought in Year 2 included the selection and development of drought indices, including a new index of snow drought, and continuing operations of the Evaporative Demand Dryness Index (EDDI) and Landscape Evaporative Response Index (LERI) tools.

Important progress was made in regard to our capacity building activities. In Year 2, we launched the NC CASC Tribal Climate Leaders Program (TCLP) that will support five Native American students from Tribal Nations pursuing a graduate degree at the University of Colorado Boulder in the area of climate adaptation science (a significant in-kind contribution from CU departments supports this program).

We continued to develop our communications/outreach capacity in Year 2. In October 2019, we initiated the distribution of a bi-monthly newsletter within the NC CASC network. In July 2020, we launched the NC CASC Webinar Series to highlight ongoing research, and feature relevant topics of interest to natural resource managers and stakeholders in the region. We continue to develop and share events and successes on our website as well.

A key administrative activity in Year 2 was the coordination of a change request to the Cooperative Agreement to add in directed funding via subawards for consortium partner activities. This effort required significant programmatic support (implemented, in part, via in-kind administrative support and

indirect finance support from the CIRES finance team). Additional efforts were conducted on the part of the leadership team to assist with realignment of activities and goals. It greatly impacted NC CASC's progress made towards the objectives as agreed upon in the award Term Sheet. Although work with our consortium partners was slowed as a result, the approved contract modification (July 2020) for subawards to our consortium partners will now increase momentum on these proposed collaborative efforts in Year 3. Despite being unfunded, our consortium partners have participated regularly in monthly meetings and helped to lay the groundwork for future collaboration.

Additional unplanned efforts in Year 2 arose in response to COVID-19 and the national discussion around greater inclusion of underrepresented communities in STEM. Beginning in early March 2020 there were substantial delays and disruptions to work activities related to COVID-19 and transitions to fully remote work. Additionally, the NC CASC is reflecting on ways in which the CASC-network can be more inclusive, and identify key activities that already support underrepresented communities and that we can collectively do in the future (e.g., development of an NC CASC statement on diversity, equity, and inclusion and a responsive action plan that includes current and future efforts).

3. ORGANIZATION AND APPROACH:

Table 1. Funded University of Colorado (CU) personnel; GPTWA=Great Plains Tribal Water Alliance; NCASC=National CASC.

Person	Role	Responsibility	Level of effort re-budgeted in 2020 grant modification
Jennifer Balch	University Director	Responsible for coordinating all elements of the cooperative agreement, including overseeing the leadership team and consortium partners.	***Content Removed from this Version***
Brian Johnson	University Deputy Director	Oversee the operations of the NC CASC. He managed the climate science support platform team, directly supervising Rangwala, Joseph and Yocum.	
Jane Wolken	Program Manager	Oversee day-to-day university operations of the NC CASC.	
Lisa Dilling	Adaptation Co-Lead	Guide the co-production platform efforts of the NC CASC, including working with Yocum, the consortium partners and additional resource managers.	
William Travis	Adaptation Co-Lead	Guide the development of adaptation strategies and their implementation through the co-production and consortium process.	
Leah Wasser	Education Lead	Oversee the development of training plan and material for climate data.	
Imtiaz Rangwala	Climate Science Lead	Provide primary climate expertise to the NC CASC-directed projects; work with the boundary organizations to facilitate effective integration of climate research into natural resource management and planning.	

Heather Yocum	Stakeholder & Communication Lead	Facilitate research-to-operations processes, convening and structuring stakeholder engagement between scientists and information users, expanding the stakeholder base and soliciting user feedback to refine information content and delivery platforms. She will also be responsible for developing the communications strategy. Primary contact for Tribal Climate Leaders Program.	
Max Joseph	Open Science Architect	Develop open source, reproducible software, workflows and accompanying trainings to increase access and usability of various data sources.	
Jenny Palomino	Education Trainer	Assist with the development of course materials for the Climate Science Workshops.	
Lauren Herwehe	Education Trainer	Assist with the development of course materials for the Climate Science Workshops.	
James Rattling Leaf	GPTWA consultant/ Research Associate	Work with the GPTWA and other Tribal organizations in the NC CASC region to form Tribal engagement plans, identify key climate science training needs, bring awareness of adaptation and planning needs to resource managers in tribal communities, and encourage and recruit students into educational programs; Rattling Leaf will also be part of the Grasslands Project.	
Dawn Umpleby	Executive Assistant	Provide project support in areas of web site development, maintenance, content design, social media platforms, newsletter creation/distribution, logistics planning for events, reporting and budget planning and tracking, including sub-awards to consortium members, support Tribal Climate Leaders Program, Director support.	
Katherine Halama	Undergraduate/ temp aide communications assistant (hourly)	Assist Executive Assistant with website and social media content and maintenance, newsletter content and creation.	
Max Cook	Graduate research assistant	Mapping current aspen cover using remote sensing imagery.	
Kylen Solvik	Graduate research assistant	Developing a deep learning model to accurately predict playa lake inundation.	
TBN	Postdoctoral Researcher	Understanding and Managing Changing Wildfire Risk to lead an effort on generating the fire science needed for resource management decisions in the ecosystems of the North Central region. Will connect to NCASC efforts on the Future of Fire.	

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TBN	Postdoctoral Researcher	Work to synthesize scientific information in partnership with the working groups and through the Climate Solutions Summits.	

Institutions receiving sub-awards: Conservation Science Partners (CSP): Co-PI Shelley Crausbay; South Dakota State University (SDSU) Extension: Co-PI Laura Edwards; University of Montana (UM): Co-PI Phil Higuera; and Wildlife Conservation Society (WCS): Co-PI Molly Cross. James Rattling Leaf (co-PI) is now conducting activities for the Great Plains Tribal Water Alliance (GPTWA) under the CU hosting agreement.

Contributions from unfunded personnel: Dawn Umpleby provided project support in areas of website development and maintenance, logistics planning for events, reporting, and budget planning and tracking, including sub-awards to consortium members in Year 2, as part of the CU cost share. Additionally, Jenny Briggs assisted the NC CASC in collaborative engagement with partners both on and off campus.

Issues hiring or retaining personnel: We had several departures in 2020. Brian Johnson left January 2020 (Aerospace Corps.). His roles and responsibilities are being filled by our new Program Manager, Jane Wolken (started July 2020). Jenny Briggs left June 2020 (Colorado School of Mines), and her support of the TCLP is being transferred to Heather Yocum. Jenny Palomino left July 2020 (Google) and her efforts on the education trainings are being replaced by Lauren Herwehe and additional efforts of co-PI Leah Wasser.

Summary of consortium governance and operations, and interactions. The role of each consortium partner (CP) is to produce actionable science on a dedicated management theme, serve as a connector between researchers and stakeholders in their region, and help to guide the overall efforts of the NC CASC. CPs are updating their statements of work to reflect changes/delays in planned stakeholder engagement activities due to delays in funding from the contract modification process and COVID-19-related meeting restrictions. The majority of these CP activities will take place after October 2020. Supported CP activities include: salary support for 1-year of an early career scientist efforts (graduate students, postdocs, or existing staff) and partial support to accommodate co-PI salary time to mentor and advise or to complete activities; funds to support two co-production scientist-stakeholder workshops during the 5-year award; and funds to support CP-hosted NC CASC meetings (e.g., ideas colliders). In-kind support from CU includes: support and consultation on the best-available climate science from the CU Climate Science Support Platform (CSSP); and access to additional training and skills-building opportunities. Monthly conference calls with Consortium Partner Co-PIs, monthly CSSP calls, and an annual meeting are key touch points for consortium interactions.

4. RESULTS:

A selection of key results from Year 2 are summarized below under the following four core goals: partnerships; science; capacity building; and communications/outreach.

Partnerships: Our ongoing stakeholder tracking efforts illustrate that we are working with stakeholders from 87 different organizations or groups, including: 25 Tribal Nations or inter-Tribal organizations; 10 Tribal Colleges; 11 Federal government agencies; 15 state government agencies; 13 academic or research institutions; 11 nonprofit organizations; and 2 regional boundary organizations (see **APPENDIX**

II-NC CASC Network Map). Part of Heather Yocum's time coordinating the Grasslands Project is supported by the NC CASC, including her efforts to coordinate with and leverage the USDA Northern Plains Climate Hub's efforts to conduct a vulnerability assessment for U.S. Forest Service grasslands.

Science: Our goal is to advance the understanding of the impacts of climate change and variability on fish, wildlife, plants, water, land, and people by providing relevant and usable science, data and analytic tools to support sound resource management and adaptation in the NC CASC region. One of the main science efforts in Year 2 was to provide quantitative summaries of downscaled climate and hydrology projections for U.S. Fish and Wildlife Service Region 6 Species Status Assessments (SSAs) and other stakeholders, including the Wyoming Game and Fish Department. The SSA activities that were supported include: (i) White-tailed ptarmigan (northern and southern CO population)-see **APPENDIX III**; (ii) Skiff milkvetch (southwest CO); (iii) Monkey flower (CO Front Range); (iv) North Park Phacelia (northern CO); (v) Desert tortoise and several other species (Mojave Desert, UT); and (vi) Silverspot butterfly (southern CO). This effort also involved further development of the methodology to generate quantitative information on desired climate and climate extremes metrics. A substantial effort was also made to co-produce this information with stakeholders by identifying several touchpoints where stakeholders are providing relevant input and final decision making in the selection of future climate scenarios, choice of climate metrics and final display of quantitative summaries used for SSA activities.

To support the above activities and others desired by our stakeholders (e.g., National Park Service's Climate Change Response Program's scenario planning work) we developed open workflows to extract and derive downscaled climate metrics for a specific region. These include the Climate Futures Toolbox (CFT), which can quickly acquire downscaled climate data (MACAv2-METDATA) subsets for a spatial region of interest, with first class support for U.S. National Parks. The new tool is downloaded by approximately 60 unique users each month, and we expect this user base to grow. New utilities are continuously being added to CFT to compute new derived quantities, and to summarize and visualize data. Another open workflow is related to future projections of the Forest Drought Stress Index (FDSI), also using the MACAv2-METDATA as input to this workflow. FDSI projections help to quantify changes in the frequency and intensity of extreme droughts in forests of the western United States. A large portion of the open workflows (e.g., FDSI projections) that are (or will be) developed arose directly out of our stakeholder engagement and science support efforts. And several of these workflows will have a future projections component as a primary focus. Another open workflow that we created as part of a student mentoring project allows for accessing and standardizing in-situ soil moisture observations at multiple depths from the National Soil Moisture Network.

In collaboration with our research affiliates - the Western Water Assessment (WWA) and Earth Lab - we developed and released the Drought Index Portal (DrIP). Limited online resources are available to quickly compare different drought indices across time and space. The DrIP has gone through multiple stages of development to meet this need, and now provides a singular portal on which to perform quick visual comparisons of drought indices across time and space, and extract regional time series data. Initial development was funded by a WWA/National Integrated Drought Information System (NIDIS) grant to support a ranching decision model. Subsequent development to promote it as a more widely accessible research tool was done in collaboration with NC CASC and Earth Lab scientists. DrIP was released in Spring 2020, and we have been doing quality control checks since then. We intend to make NIDIS aware of DrIP's utility. Several other analytical features are also made available in the DrIP, including the ability to quantify and visualize any index's time series, such as the Drought Severity Coverage Index, a metric developed by the U.S. Drought Monitor to assess the severity of drought and its extent. In addition to the development of these tools, we continue to manage the effective

functioning and outreach of these tools including those developed earlier by our team which include the Landscape Evaporative Response Index (LERI). LERI was developed as part of an earlier funded proposal (2017-2018) through the USGS. We have been doing outreach with it and also presented it to the NIDIS team. We are currently working with NIDIS to put LERI on Drought.gov.

Additional Year 2 science efforts include: (i) research into understanding future drought risks in the Northern Great Plains region. A manuscript was submitted for peer-reviewed publication in February 2020 and is currently under revision; and (ii) developing a working paper (by two university host and two USGS scientists) to integrate Structured Decision Making and Scenario Planning approaches to climate adaptation. This working paper is part of our scoping effort on adaptation science in theory and as practiced in resource management.

Capacity building: A primary goal of the NC CASC is to build a community of researchers and managers and foster their leadership in science-based resource management. To support this goal, in spring and fall 2019 we conducted a training needs assessment to identify management priorities and associated technical data challenges. The fall assessment consisted of two separate surveys---data skills and resource management priorities, receiving 74 and 43 responses respectively. The majority of respondents for both surveys were from federal agencies and tribal organizations. Their management priority areas were identified as: water quality; integrated management of land and water resources; emergency management, planning, and response; climate, habitat, vulnerability assessment; and capacity building and action planning. Their primary data challenges include finding data at the right spatial and temporal scale, working with data of different formats, creating appropriate visualizations, and identifying patterns in and determining adaptation actions from data. Guided by these results, in fall 2020 we will conduct a data skills training that focuses on working with climate data, implementing open reproducible workflows, and working with heterogeneous data formats. Climate scenario training events may also be conducted by NC CASC staff, if additional resources support this effort or if USGS partners wish to contribute to this identified training need.

The Tribal Climate Leaders Program (TCLP) provides five fully-funded, 2-year fellowships to Native American students affiliated with the 32 federally-recognized tribes in the North Central region. The NC CASC welcomed the first PhD student (see Shelby Ross below) to the Geography Department in Fall 2019, and four masters degree students were recruited in Year 2 and will be joining the Environmental Studies Program and Department of Civil, Environmental and Architectural Engineering in Fall 2020. Six CU programs provide funding for the TCLP, and we have identified additional social, professional, and scholarly support for the students from a variety of on-campus and community resources. Jenny Briggs served as the Program Coordinator through June 2020; Heather Yocum is the current Program Coordinator.

In Year 2, the NC CASC supported three graduate research assistants: Shelby Ross; Kylen Solvik; and Maxwell Cook, who all pursued projects that support our Strategic Science Agenda and offer potential future opportunities to build out additional efforts.

- Shelby Ross is the first participant in the NC CASC Tribal Climate Leaders Program. Her PhD research is focused on understanding the impacts of climate change on health for the Pine Ridge Indian Reservation in South Dakota through qualitative methods of semi-structured interviews and survey data. The semi-structured interviews will focus on the elderly population of the reservation and will gather their in-depth observations on climate change-related environmental changes, including

ecological and landscape changes. The interview questions will also explore the human health impacts of climate change-inducing severe weather events.

- Kylen Solvik is a PhD student in Geography and is working on the development of a deep learning model to accurately predict playa lake inundation based on weather and playa hydrology attributes. This model can be used to map how inundation will change under future climate and land-use scenarios for every playa in the Playa Lakes Joint Venture's database, maps which can aid in conservation planning.
- Max Cook is a Masters student in Geography. His research is focused on mapping current aspen (*Populus tremuloides*) cover using remote sensing imagery from the Sentinel-2 Multispectral Instrument (MSI). Rocky Mountain National Park, The Nature Conservancy, and Summit County Open Space are interested in the promotion of aspen as a means of creating living fuel breaks for mitigating wildfire risk in the Wildland Urban Interface, but critically need better maps. Using the distinct phenology of aspen trees and dense time-series analysis of Sentinel-2 MSI, our pilot demonstrates that we can detect aspen cover with 90% accuracy.

Communications/Outreach: Communications/outreach are embedded in all aspects of the NC CASC's activities, and integrate our co-produced science, partnerships, and capacity building efforts. In support of the capacity building and communications/outreach goals of the NC CASC, Katherine Halama was hired in October 2019 as a student hourly employee to assist with communication/outreach efforts. Following her graduation from CU in May 2020, she was reclassified as a temp aide and currently works 20 hours per week on the communications activities described below.

We utilize the following strategies to broadly communicate our activities within the NC CASC network: NC CASC Website/Newsletter/Social Media: In Year 2, the NC CASC continued to develop its website and YouTube content. In October 2019, we began issuing a newsletter, currently on a bi-monthly basis. The newsletter is distributed via the website, Facebook (232 followers), Twitter (635 followers), and a Mailchimp email distribution list (435 subscribers). Our YouTube channel contains 7 videos to date, including 3 Tribal Climate Webinars; the number of total views to date for the combined webinars is 374. NC CASC news is also distributed through CIRES and CU communications channels.

NC CASC Webinar Series: In July, we launched the NC CASC Webinar Series to highlight ongoing research from the NC CASC network, as well as feature topics of critical importance to natural resource managers and other stakeholders in the region. The webinars will take place every other month through the end of 2020, and will be monthly thereafter. All webinars are recorded and posted on the NC CASC YouTube Channel. The first webinar had over 50 attendees. Topics for 2020 include post-fire conifer regeneration under a changing climate (July) and the findings from the NC CASC funded project on developing Social, Ecological and Climate Resiliency (SECR) in southwest Colorado (September).

5. OUTREACH:

NC CASC researchers produced 12 peer-reviewed publications/technical reports (see below) in Year 2. Refer to **APPENDIX IV** for additional Year 2 outreach products, including workshops and stakeholder engagement activities.

Peer reviewed journals and non-peer reviewed technical reports

For the following publications, NC CASC researchers/consortium partners appear either in **bold** text, or are noted as a contributing author in ( ):

- Adhikari A., Mainali, K.P., **Rangwala, I.**, and Hansen, A.J. 2019. Various measures of potential evapotranspiration have species-specific impacts on species distribution models. *Ecological Modelling*, 414: 108836, https://doi.org/10.1016/j.ecolmodel.2019.108836.
- **Balch, J.K.**, Iglesias, V., Braswell, A.E., Rossi, M.W., **Joseph, M.B.**, Mahood, A.L., Shrum, T.R., White, C.T., Scholl, V.M., McGuire, B., Karban, C., Buckland, M., and **Travis, W.R.** 2020. Social-environmental extremes: Rethinking extraordinary events as outcomes of interacting biophysical and social systems. *Earth's Future*, https://doi.org/10.1029/2019EF001319.
- Bradford, J.B., Weltzin, J.F., McCormick, M., Baron, J., Bowen, Z., Bristol, S., Carlisle, D., Crimmins, T., Cross, P., DeVivo, J., Dietze, M., Freeman, M., Goldberg, J., Hooten, M., Hsu, L., Jenni, K., Keisman, J., Kennen, J., Lee, K., Lesmes, D., Loftin, K., Miller, B.W., Murdoch, P., Newman, J., Prentice, K.L., **Rangwala, I.**, Read, J., Sieracki, J., Sofaer, H., Thur, S., Toevs, G., Werner, F., White, C.L., White, T., and Wiltermuth, M., 2020. Ecological forecasting—21st century science for 21st century management: U.S. Geological Survey Open-File Report 2020–1073, 54 p., https://doi.org/10.3133/ofr20201073.
- Clifford, K.R., Yung, L., **Travis, W.R.**, Rondeau R., Neely B., **Rangwala I.**, Burkardt N., & and Wyborn C. 2020. Navigating Climate Adaptation on Public Lands: How Views on Ecosystem Change and Scale Interact with Management Approaches. *Environmental Management,* https://doi.org/10.1007/s00267-020-01336-y
- Coop, J.D. et al., 2020. Wildfire-driven forest conversion in Western North American landscapes. *BioScience*, biaa061, https://doi.org/10.1093/biosci/biaa061 (Contributing Consortium Partner Authors: Shelley Crausbay and Phil Higuera).
- Gude, J., DeCesare, N., Proffitt, K., Sells, S., Garrott, R., **Rangwala, I.**, Kujala, Q., Biel, M., Coltrane, J., Cunningham, J., Fletcher, T., Golla, J., Loveless, K., Mowry, R., Newby, J., O'Reilly, M, Rauscher, R., Rose, K., Thompson, M., and Vore, J. 2020. Recommendations for managing mountain goats in Montana: A Decision Analysis Approach. Technical Report, Wildlife Division, Montana Fish, Wildlife & Parks, Helena, Montana. 68 pp.
- Hanberry, B., Reeves, M.C., Brischke, A., Hannemann, M., Hudson, T., Mayberry, R., Ojima, D., Prendeville, H.R., and **Rangwala, I.** 2019. Management effects of drought in the Great Plains. *In* Effects of drought on forests and rangelands in the US: Translating Science into Management Responses. Edited by J.M. Vose, D.L. Peterson, C.H. Luce. T. Patel-Weynand, Gen. Tech. Rep. WO-98. Washington, DC: U.S. Department of Agriculture Forest Service, Washington Office. 227 p., https://doi.org/10.2737/WO-GTR-98.
- McLauchlan, K.K. et al. 2020. Fire as a Fundamental Ecological Process: Research Advances and Frontiers, *Journal of Ecology*, https://doi.org/10.1111/1365-2745.13403 (Contributing Authors: Phil Higuera and Jennifer Balch/In Collaboration with NC CASC).
- **Rangwala, I.** (Introduced by Ott, J.). 2020. Monitoring and Predicting Drought on Our Grasslands, *Grassland News*, USDA National Grasslands Council's Spring 2020 Newsletter, https://drive.google.com/file/d/1wPSk43nLcHoTrt5I3xLGnNOOURfvOH8U/view.
- Runyon, A.N., Carlson, A.R., Gross, J., Lawrence, D.J., and Schuurman, G.W. 2020. Repeatable approaches to work with scientific uncertainty and advance climate change adaptation in US National Parks, *Parks Stewardship Forum*, 36(1):98-104, https://escholarship.org/uc/item/76p7m8rz (Acknowledges collaboration between National Parks Service and NC CASC, and science support from Rangwala).
- Sanderson, J.S., et al. 2020. Cattle, conservation, and carbon in the western Great Plains. *Journal of Soil and Water Conservation,* 75(1): 5A-12A, https://doi.org/10.2489/jswc.75.1.5A (Contributing Author: Imtiaz Rangwala).
- Williams, A.P., Abatzoglou, J.T., Gershunov, A., Guzman-Morales, J., Bishop, D.A., **Balch, J.K.** and Lettenmaier, D.P. 2019. Observed impacts of anthropogenic climate change on wildfire in California. *Earth's Future*, 7(8): 892-910.

6. NEXT STEPS:

The key mission of the NC CASC is to generate the science needed for key resource management in our North Central region. Our Strategic Science Agenda and proposed efforts guide these major Year 3 activities. See overview timeline (**APPENDIX V**). There is a clear need to define climate adaptation science more fully, as well as provide information on climate-driven changes to species, ecosystems, and disturbance regimes. Continued tool development and maintenance for applied scientists will be a key product. We will be launching the CP activities, with initial efforts on adaptation and conservation planning, post-fire regeneration, and drought and ecological transformation.

Science: Key science efforts include work to better define climate adaptation science by finalizing the working paper on integrating "Structured Decision Making" and "Scenario Planning" approaches to climate adaptation, with draft guidelines for applications to the RAD (resist, accept or direct change) and other frameworks used by resource managers. We are also actively working with the Playa Lakes Joint Venture to support reproducible workflows around playa hydrology and data integration for predicting wildlife population trajectories under different climate futures. We will be contributing to a USGS Powell Center working group on coupled classification models, which provide statistical methodology to connect ecological models (e.g., of climate effects on species distributions) with error-prone automated classification data. This activity is a collaboration with USGS Patuxent Wildlife Research Center and the Northern Rocky Mountain Science Center, which includes case studies built around the USGS North American Bat Monitoring Program. We will be supporting a new postdoc to better understand the Future of Fire, with application to resource management decisions. This effort will also align with the National CASC efforts at integrating fire efforts across CASCs. The Grasslands Synthesis Project will also be hiring a postdoc and convening two working groups and an advisory committee. Additionally, we plan to continue science support for specific stakeholder driven projects, including: (a) Wyoming Game and Fish Statewide Habitat Plan (SHP) update; (b) scenario planning for DINO National Monument grazing management plan; and (c) U.S. Fish and Wildlife Service Ute Ladies's Tresses SSA. The NC CASC is also committed to tool maintenance and development for three R packages: EDDI, LERI, and CFT. The CFT package is under active development, as we are adding support for new datasets (including GridMET and MACAv2) in anticipation of an rOpenSci submission. Maintenance and development will also be carried out for the LERI and DrIP websites. We also plan to develop new workflows to derive projections of metrics related to climate extremes based on the need described by our stakeholders.

Consortium Partner Activities (see **APPENDIX VI**): Key CP activities for Year 3 are the WCS stakeholder workshops on adaptation and conservation planning, especially with Wyoming Game and Fish; UM work on post-fire regeneration and related stakeholder workshops; CSP's work on drought and ecological transformation, informed by stakeholder workshops; and SDSU outreach to land managers. The contract modification to fund the CP's proposed work was approved mid-July. Heather Yocum is working with the CP's to update their Statements of Work based on (1) contracted timeline due to delays in contract modification approval, and (2) COVID-19-based changes to planned, in-person stakeholder meetings.

Education & Trainings: Planned for Year 3 are two additional trainings, related to our Climate Data 101 curriculum that will be derived from the first training in Fall 2020. We will determine at a later date whether these activities will take place in-person, or whether they will be fully remote. The TCLP will shift focus from recruitment to cohort building and mentoring activities to build a strong program and support students in the first years of their graduate program.

Outreach & Communications: Targeted stakeholder engagement will take place under COVID-19 constraints on in-person meetings and travel, focused on existing relationships or new efforts around

fire, ecological transformation, grasslands, invasive species, playa lakes, and climate futures. We will continue to expand on our communications efforts with the website, newsletters, and webinar series. Collectively, across the USGS and CU teams, we have submitted items to the National CASC for communications dissemination. We will streamline the process for submitting these communications products to NCASC in the future and increase the frequency of submissions from the university side. Further, we will begin planning for the Climate Solutions Summit. We believe we may still be able to host the meeting remotely, with the purpose of bringing together students, scientists, educators, and stakeholders engaged in NC CASC efforts, but it may be postponed to Year 4.

7. BUDGET:

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APPENDIX I--Term Sheet

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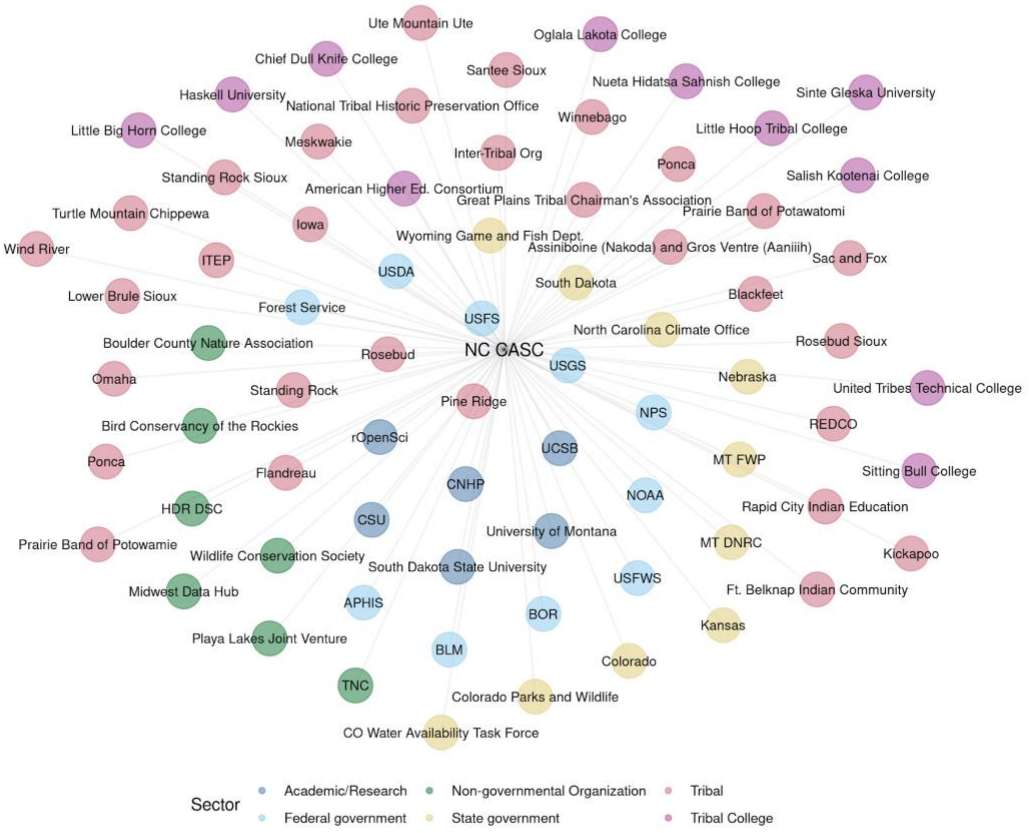
APPENDIX II--NC CASC Network Map



NC CASC Network Map illustrating key stakeholder partnerships by sector. Each node represents a different stakeholder group, and each edge indicates one or more connections. All edges are weighted equally and do not represent the depth or extent of engagement. State abbreviations (e.g., CO) condense engagement with state agencies such as Colorado Parks and Wildlife and Colorado Division of Water Resources. A table containing the underlying data is available here: https://docs.google.com/spreadsheets/d/1ajEOJUU2zRY3y6e4Bg5Wx5N8fZ0awb9XB3PQ-

Climate Scenarios by 2050 for the White-tailed Ptarmigan Range in Northern Colorado

The summary table below describes changes in the future climate by 2050 (2040-2069) relative to the 1971-2000 period under three climate scenarios: **Very Hot and Dry** (IPSL-CM5A-MR.rcp85), **Hot** (CCSM4.rcp45), and **Hot and Very Wet** (MIROC5.rcp45)

Climate Metric	Time Period	Very Hot and Dry	Hot	Hot and Very Wet	*Historical Value*
Mean Temperature (°F)	Annual	8	4	6	*30 °F*
	Winter	6	3	4	*14 °F*
	Spring	6	3	8	*28 °F*
	Summer	8	4	3	*49 °F*
	Fall	8	5	5	*31 °F*
Precipitation (%)	Annual	-8	6	6	*31 inches*
	Winter	6	16	4	*8 inches*
	Spring	-16	11	12	*10 inches*
	Summer	-16	3	16	*7 inches*
	Fall	2	3	0	*6 inches*
Daytime Maximum Temperature (°F)	Annual	7	4	5	*42 °F*
	Winter	6	3	4	*25 °F*
	Spring	7	4	8	*40 °F*
	Summer	8	5	3	*60 °F*
	Fall	8	5	5	*42 °F*
Daytime Minimum Temperature (°F)	Annual	7	4	5	*19 °F*
	Winter	7	4	5	*3 °F*
	Spring	6	3	7	*16 °F*
	Summer	8	4	4	*37 °F*
	Fall	7	4	4	*21 °F*
Snow Water Equivalent (%)	January 1	-19	6	-19	*5 inches*
	April 1	-9	3	-2	*12 inches*
	May 1	-27	1	-29	*15 inches*
Soil Moisture (%)	Spring	0	-2	15	*10 inches*
	Summer	-25	-3	-16	*16 inches*
	Fall	-27	-14	-14	*11 inches*
Potential Evapotranspiration (%)	Summer	22	11	10	*15 inches*
	Fall	61	34	39	*4 inches*

Climate Metric	Very Hot and Dry	Hot	Hot and Very Wet	*Historical Value*
Coldest Winter Day (°F) **(warmer relative to historical by °F)**	-12 (7)	-16 (3)	-14 (5)	*-19*
Hottest Summer Day (°F) **(warmer relative to historical by °F)**	77 (8)	74 (5)	73 (4)	*69*
#Days with daytime low above 32°F **(increases in #days)**	143 (44)	123 (24)	135 (36)	*99*
First Fall Freeze **(later relative to historical by #days)**	Sep 21 (49)	Sep 16 (44)	Sep 10 (38)	*Aug 3*
Last Spring Freeze **(earlier relative to historical by #days)**	May 31 (19)	Jun 14 (5)	Jun 14 (5)	*Jun 19*
Growing Season Length (#days) **(higher relative to historical by #days)**	113 (68)	94 (49)	88 (43)	*45*
Growing Degree Days (°F; 32°F base)	3575	2864	3083	*2127*
Frequency of Severe Drought like 2002	Every other year	Every 2-3 years	Every 3 years	-
Duration of Severe Drought like 2002	1-5 years	1-4 years	1-2 years	1 year
"High" Fire Danger Days **(higher relative to historical by #days)**	115 (42)	83 (10)	81 (8)	*73*
"Very High" Fire Danger Days **(higher relative to historical by #days)**	70 (33)	45 (8)	43 (6)	*37*
"Extreme" Fire Danger Days **(higher relative to historical by #days)**	34 (23)	17 (6)	11 (0)	*11*

Very Hot and Dry	• Very large increase in summer and fall temperatures (8°F) with substantial reduction in spring (-15%) and summer (-15%) precipitation • Hottest summer daytime high increases by 8°F; severe drought every other year with extreme drought conditions lasting up to 5 years • Large reduction in spring snowpack (May 1 SWE is 25% lower) • Growing season increases by more than 2 months; "High" fire danger days increase by ~40 days • Summer precipitation decreases significantly, but 20% more intense rainfall events when they occur
Hot	• Moderate increase in annual temperature (4°F) but no change in summer precipitation • Hottest summer daytime high increases by 4°F; severe drought every 2-3 years with extreme drought conditions lasting up to 4 years • No change to slight increase in spring snowpack b/c of increases in winter and spring precipitation • Growing season increases by ~50 days and "High" fire danger days increase by 10 days • 10% more intense rainfall events
Hot and Very Wet	• Least increase in summer daytime high temperature (3°F) but very warm springs (8 °F), and large increase in summer precipitation (+15%) • 40% increase in spring precipitation and a high proportion of that falling as rain • Severe drought every 3 years with extreme drought conditions lasting up to 2 years • Growing season increases by ~40 days and "High" fire danger days increase by 1 week • 10% more intense rainfall events

Values and projected changes described above are for the location at **39.7708°N; 105.9069°W** and a mean elevation of **11,521 ft**. Winter is Dec, Jan, Feb; Spring is Mar, Apr, May; Summer is Jun, Jul, Aug and Fall is Sep, Oct, Nov. Dataset: MACA metdata v2 (4-km downscaled climate projections), VIC (v4.1.2) forced by MACAv2-LIVNEH (6-km hydrology projections) and gridMET (4-km historical).

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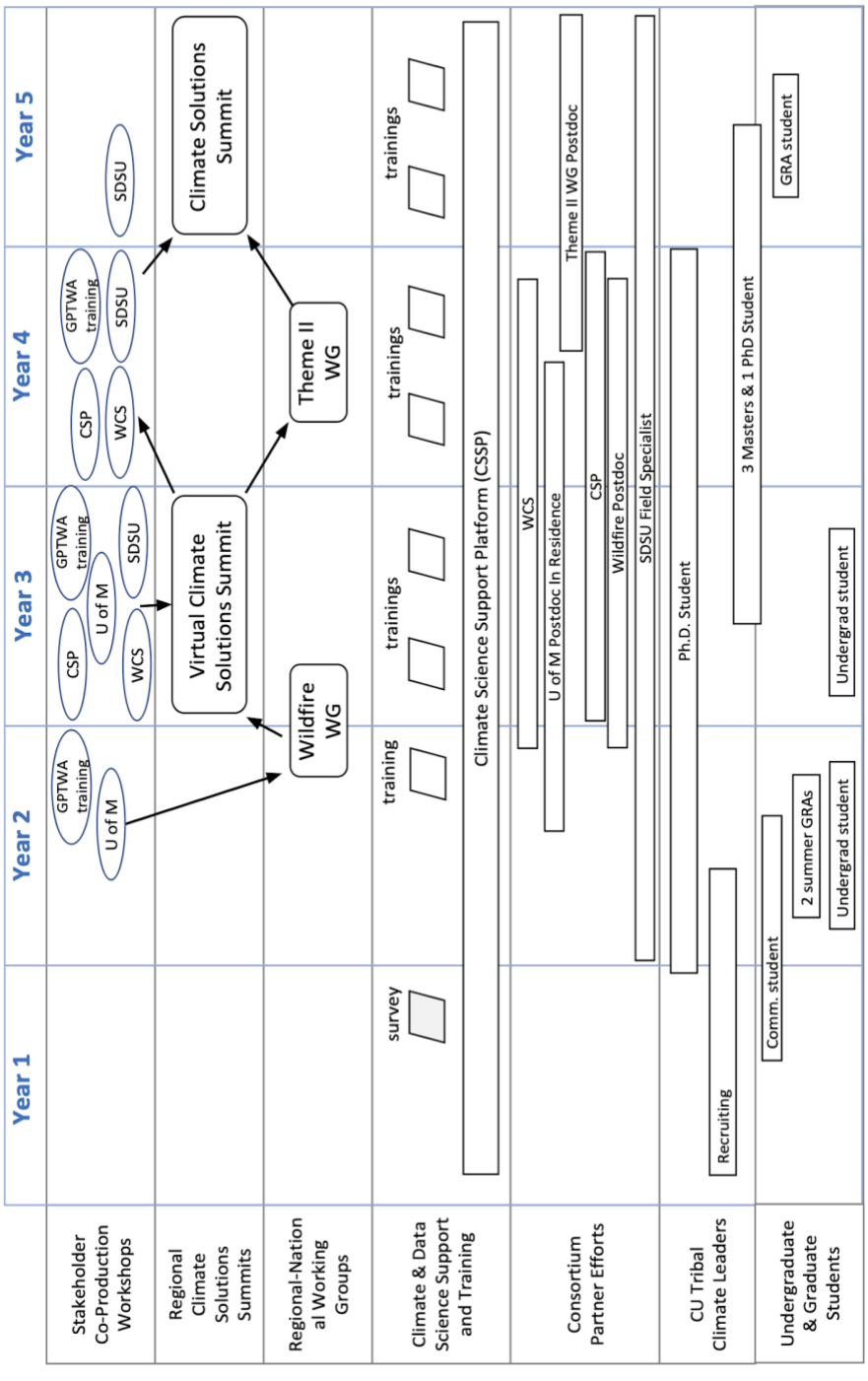
APPENDIX IV--Additional Outreach Products

Project-related conference presentations, seminars, webinars, workshops, or other presentations that facilitated some of our major engagements with regional decision-makers, stakeholders, and resource managers. See above section 4. RESULTS (especially "Science" and "Capacity Building") for additional details of stakeholder engagement activities.

- 2019 Fall Water Conference (10-11 October, 2019) -- Presentation by James Rattling Leaf (Great Plains Tribal Water Alliance) and Jennifer Balch (CU NC CASC Director).
- Climate Futures Toolbox (CFT) Webinar (April 16, 2020) -- Webinar by Max Joseph on the recently released version (v 0.1) of the CFT. The webinar provided a tutorial on how to access and install the CFT, and its utility in extracting downscaled climate data for a region of interest, and other resources provided to plot data and derive new metrics. Participants included individuals from the U.S. Fish and Wildlife Service, National Park Service, and U.S. Geological Survey.
- Presentation to MT Fish, Wildlife, and Parks (Sept. 2019) -- Imtiaz Rangwala gave an invited presentation on future climate impacts and planning.
- Society for Range Management (February 2020) -- In collaboration with the USDA Northern Plains Climate Hub, Heather Yocum organized a World Cafe-style session at the Society for Range Management meeting in Denver, CO to engage private and public land managers on *Rangelands & Climate Change: What Can We Learn From Each Other about Impacts & Adaptations?* Heather is co-leading an effort to publish the results in *Rangelands and Society* with the Hub, The Nature Conservancy, and USDA Agricultural Research Service.
- Presentation to U.S. Fish and Wildlife Service Region 6 Biologists Meeting (Sept. 2019) -- Rangwala on development of climate information for resource management.
- Snow Collider Workshop (June 11, 2020) -- The NC CASC, in coordination with CU Boulder EarthLab and CIRES and the U.S. Fish and Wildlife Service convened an interactive virtual workshop to connect with stakeholders in the region to discuss ongoing needs for projections of future snowpack across the Rocky Mountains. This workshop was prompted by input from both federal and state partners (Joint Stakeholder Committee 2019) and from the Northwest CASC that improved snow models and snow projections are of high interest and value for species and ecosystem management across the region.
- NC CASC Webinar Series (July 2020) -- The NC CASC launched its new webinar series that will highlight ongoing research from the NC CASC network and feature topics of importance to natural resource managers and stakeholders in the region. The first webinar *Post-fire conifer regeneration in a changing climate* presented by Kimberley Davis and Philip Higuera (Consortium Partner), University of Montana occurred on July 9, 2020.
- American Indian/Alaska Native Working Group Webinar (July 21, 2020) -- James Rattling Leaf (Great Plains Tribal Water Alliance) and Jenny Briggs (former CU Boulder Community Outreach Program Manager) presented a webinar *UNCI MAKHA TAWOUNSPE WAKITA, Tribal Climate Leaders Program – overview for NASA network*. The webinar was hosted by Daniella Scalise of the American Indian/Alaska Native Working Group Lead, NASA Science Mission Directorate.
- Support for The Nature Conservancy (Boulder) Strategic Plan (Feb. 2020) -- Rangwala presented information on "Climate Change & its Consequences for Colorado."
- Virtual Workshop for 2020 WY Statewide Habitat Plan (April 2020) -- Organized by CO-PI Cross (w/ support from USGS and University NC CASC funds) to support co-production for the WY SHP. Rangwala presented climate change projections to help inform managers.

APPENDIX V--NC CASC Timeline



NC CASC timeline of proposed activities by year.

APPENDIX VI--Timetable of Consortium Partner Activities

Summary of timetable of consortium partner activities; CU=University of Colorado; CSP=Consortium Science Partners; WCS=Wildlife Conservation Society; MT=University of Montana; SDSU=South Dakota State University; and GPWTA=Great Plains Tribal Water Alliance.

Consortium Partner	Year 2 (Oct 2019-Sept 2020)	Year 3 (Oct 2020-Sept 2021)	Year 4 (Oct 2021-Sept 2022)	Year 5 (Oct 2022-Sept 2023)
CU	Virtual CP meeting	Annual CP meeting, w/CSP host	Annual CP meeting, w/SDSU host	Annual CP meeting, w/GPTWA host
CSP		3-day stakeholder meeting; CP meeting	3-day stakeholder meeting	
WCS	Postponed due to CP funding	1-1.5-day workshop -- Adaptation Success (Date TBD)	2-day workshop -- Adaptation Success (timing TBD but probably early in this year)	
MT	Postponed due to CP funding	Workshop (Oct-Nov due to availability of fire stakeholders and to coordinate with NW CASC work)	Follow-up workshop (Jan-Feb; possibly moved to Sept)	
SDSU	Postponed due to COVID-19	Local meetings (beg. Y3; winter for stakeholder availability)	Local meetings; CP meeting	Local meetings
GPTWA	2-day workshop-likely will be postponed		2-day workshop	CP meeting