CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A: Stakeholder Engagement Plan

June 2024 | CEC-500-2024-060-AP

APPENDIX A:
Stakeholder Engagement Plan

Deliverable dated July 2019

CAL-ADAPT 3.0 STAKEHOLDER ENGAGEMENT PLAN

Under EPIC (EPC-17-033) and PIER (PIR-17-012) funding, the Geospatial Innovation Facility (GIF) is collaborating closely with the Energy Commission and energy stakeholders, including investor-owned utilities (IOUs), to build a next-generation Cal-Adapt that will provide enhanced tools, data services, and visualizations to improve usability and decision support capabilities to plan for climate-related risks.

The GIF team produces websites through a user-centered approach that solicits feedback from stakeholders throughout the development process. New data, features, and tools on Cal-Adapt are being designed in close coordination with stakeholders, as each stakeholder organization requires tools specific to their application needs. Development work that has been completed and is currently underway on these grants followed directly from stakeholder input and the direction of the Energy Commission and the Technical Advisory Committee (TAC). Additionally, regular discussion with key stakeholders provided critical feedback during tool development and beta testing. Iterative development of custom tools enables the development team to present initial tools to stakeholders, gather feedback, and then refine tool design.

Under the EPIC and PIER grants the development team will coordinate closely with IOUs to provide focused on-site workshops to develop data services, visualizations, and custom tools. The tools will enable IOUs to more effectively identify vulnerable assets and develop actionable resilience plans to minimize future risk. In addition, the development team will reach out more broadly to engage a range of California energy stakeholders, climate adaptation practitioners, planners, resource managers, educators, and ratepayers through a series of public workshops, webinars, and presentations.

This document presents an overview of the scope of work (SoW) for outreach tasks under each grant and outlines the stakeholder engagement work planned within these grants, including:

- Identify key stakeholders
- Engage stakeholders
- Gather feedback
- Build a user community

Anticipated Outcomes

Stakeholder engagement is critical to the successful development of a more powerful and useful next-generation Cal-Adapt. Cal-Adapt is continuously evolving to become a more accessible and powerful support tool that will enable decision makers to use research results

and climate projections to inform effective adaptation decisions and policies. The Cal-Adapt development team requires direction from users to ensure that the tools and visualizations the team builds are actionable and fit within users' current and planned climate data needs and workflows.

The close collaboration with stakeholders described here will help the development team to envision, design, and build custom tools for use by the energy sector to assess climate vulnerabilities and develop resilience plans. An enhanced Cal-Adapt that can directly support climate-resilience planning and decision-making will help the energy sector to meet its important climate, energy, air quality, and other environmental goals while also maintaining safe, reliable, and affordable energy for California.

Outreach Tasks: Scope of Work

EPC-17-033 (Electricity Sector)

The EPIC-funded project included a specific outreach and training task (task 4). The goal of this task was to engage with a range of energy electricity sector stakeholders through targeted workshops, webinars, and presentations. Outreach efforts detailed in the project SoW included:

- Engage key IOU stakeholders by offering on-site workshops designed to introduce new features and elicit feedback on energy sector needs for targeted custom tool development
- Host and facilitate a minimum of two user needs assessment workshops open to the public and focused on the energy and electricity sector. The workshops introduced users to new tools and features and elicit stakeholder comments and insights to help guide web site development. The audience will be invited in consultation with the Energy Commission, the TAC, and other energy sector partners.
    - Provide the workshop presentation materials to the Energy Commission.
- Develop and facilitate a quarterly series of virtual workshops (webinars) that will target practitioners involved in the electricity sector to train potential new users.
    - Develop one general webinar to introduce the many tools and features in Cal-Adapt that enable users to incorporate locally relevant climate considerations into their projects.
    - Develop additional webinars of interest to users, such as a training focused on using the Cal-Adapt application programming interface (API) and the proposed enhanced sea level rise and wildfire tools.
    - Develop webinar presentation visuals and graphics to support training and outreach efforts targeting electricity sector stakeholders.
- Present website development and results at applicable conferences to promote the new Cal-Adapt electricity sector visualizations and tools.

PIR-17-012 (Natural Gas Sector)

The PIR-funded project includes a specific task to engage stakeholders through outreach and collaboration (task 4). The goals of this task are to:

1. Engage with key natural gas sector stakeholders, including IOUs and a range of climate adaptation practitioners, planners, managers, educators, and ratepayers of the state through targeted workshops, webinars, and presentations.
2. Develop training tools and workflows that will generate climate-related parameters needed for resilience planning.

Stakeholder engagement efforts detailed in the project SoW include:

- Hold on-site meetings or webinars with California's natural gas sector IOUs to identify, discuss, and develop useful and customized tools that will inform IOU efforts to plan for and adapt to climate change.
- Host and facilitate a minimum of two user needs assessment workshops that are open to the public and are focused on the natural gas. The workshops will introduce users to new tools and features and elicit stakeholder comments and insights to help guide Cal-Adapt web site development. The audience will be selected in consultation with the CAM, the Technical Advisory Committee, IOUs, and other energy sector partners.
    - Develop and provide all workshop presentation materials to the CAM.
- Provide for outreach and training of potential new users by developing and facilitating a series of virtual workshops (webinars) that will target practitioners involved in the natural gas and energy sectors. These meetings will introduce specific tools still in development to elicit feedback from a range of users early in the design stage.
    - Develop a webinar that introduces users to new Cal-Adapt features that allow for a more tailored user experience, including user-defined thresholds and advanced data download capabilities.
    - Host a webinar in partnership with USGS team members to introduce users to new Fourth Assessment data tools based on population and land cover projections.
    - Host and facilitate additional informal webinars that engage stakeholders early in the design stage (as indicated above) and enhance training support for use of the Cal-Adapt API (as described below).
- Develop expanded training materials focused on the Cal-Adapt API. Cal-Adapt's web service architecture is designed to allow users to have considerable control over aggregating, exporting, and displaying climate variables of interest to allow for advanced analysis beyond what is in the Cal-Adapt web-based tools. However, some familiarity with using a representational state transfer (REST) API and a scripting or programming language such as Python, R, or JavaScript is required to make full use of the API features. Users have noted that it would be helpful to develop more how-to

training guides around making use of the API particularly for geospatial information system (GIS) users.

    - The GIF has authored several examples on using the Cal-Adapt API with Python and Jupyter notebooks. The Jupyter Notebook is an open-source web application that allows a user to create and share documents that contain live code, equations, visualizations and narrative text, making it ideal for rapid prototyping and sharing of data analysis. In addition to these notebooks the GIF team will develop how-to guides for ArcGIS users and (if identified as helpful by users) a guide for R users.
    - Develop presentation visuals and graphics as needed to support training and outreach efforts targeting energy sector stakeholders.

- Present website development and results at relevant conferences to promote the new Cal-Adapt natural gas sector visualizations and tools.
- Provide regular memos and information pertaining to new data, visualizations, and tools to be included within the Cal-Adapt Newsletter.

Subtask 1: Identify Key Stakeholders

The GIF has developed a list of energy sector contacts that will be continuously updated throughout the projects. Soliciting feedback from IOU users of Cal-Adapt is critical to the success of these projects, and the development team's contact list includes staff from IOUs who have previously engaged with Cal-Adapt during the team's on-site meetings or conference calls. To date, much of the team's interaction with IOUs has taken place through the TAC, the Energy Sector User Needs Assessment Workshop held in 2017, an on-site meeting at PG&E, and conference calls with SCE. IOUs under each award are:

- EPIC: California's Electric Investor-Owned Utilities
    - Large IOUs: PG&E; SCE; SDG&E
    - Smaller IOUs: PacificCorp; Liberty Utilities; Bear Valley Electric Service
- PIR: California's Natural Gas Investor-Owned Utilities
    - Large IOUs: PG&E; SCG; SDG&E
    - Smaller IOUs: Southwest Gas

Under the PIR award, the GIF is partnering with the consulting company ICF to help develop the development team's contact list and outreach plan for relevant staff at Sempra Utilities/SDG&E and SCG. Collaborators at ICF are already using and processing Cal-Adapt outputs into insights that support resiliency efforts at SDG&E and other California utilities. Because of such efforts, the team's partners at ICF are well-acquainted with common climate data needs of utility clients and are in a unique position to help design and facilitate planned on-site workshops at IOUs.

Additional contacts at stakeholder organizations including the California Independent System Operator, the California Public Utilities Commission, small IOUs, and other state agencies,

continue to be identified and added to the contact list through suggestions from the Energy Commission, the TAC, and other users. The team also adds contacts from the attendee lists of Cal-Adapt webinars and workshops, newsletter subscribers, and active users who have reached out to the GIF team through support@Cal-Adapt.org.

Particular focus will be directed toward identifying the technical people within each organization who can recognize agency needs for directly accessing data and features on Cal-Adapt. These technical staff can also be asked to beta test particular tools or features that they have requested early in the development stage. Potential beta testers include technical contacts at IOUs, staff at environmental consultants such as Ascent Environmental, and researchers and graduate students working at the Energy Commission and UC Berkeley.

In addition, the development team is actively identifying people who are experts or key stakeholders related to specific climate impacts to take part in focus groups that will meet early in the development phase to identify what features are needed as the design of new tools begins. The research team used this approach to begin to plan the expanded sea level rise tool and will continue with this approach as new tools and datasets, such as wildfire and land use/land cover projections, are added.

Subtask 2: Engage Stakeholders

Frequent communication with stakeholders will be key to successfully developing a more powerful and useful next-generation Cal-Adapt. Outreach to energy sector stakeholders includes on-site meetings at each large IOU, enabling the development of tools targeted towards specific IOU needs. In addition, the GIF team plans for ongoing engagement with IOUs and other energy sector stakeholders through a series of meetings, webinars, and workshops.

On-site Meetings at IOUs

Through previous Cal-Adapt development grants the development team found that the most effective way to get direct feedback on key stakeholder needs was to have targeted in-person or web conferences with individual IOUs. While IOUs participate in the TAC and in publicly offered events such as workshops and webinars, it is the active engagement of key technical staff at each individual organization that has generated the most actionable feedback.

Travel time and expenses have been budgeted for two on-site meetings at IOUs under EPC-17-033 and for one on-site meeting under PIR-17-012. For Fall 2019, the team plans to schedule an on-site meeting for the PIR grant in collaboration with partners at ICF, potentially at SDG&E offices. The team will coordinate with ICF and the Energy Commission to identify relevant staff to invite and to identify a format for these meetings that will help to determine what climate-related parameters would benefit adaptation planning efforts. If successful, the team would then apply a similar meeting structure in subsequent on-site meetings to be planned at other IOUs for early 2020.

User Needs Assessment Workshops

While developing Cal-Adapt 2.0 under the previous EPIC-funded award EPC-15-008, the GIF and the Energy Commission co-hosted a User Needs Assessment Workshop for Energy Sector stakeholders that was open to the public. Participants at that workshop included energy sector stakeholders as well as a wide range of additional Cal-Adapt users. The workshop format included breakout sessions that allowed the development team to hear directly from Cal-Adapt users in a smaller group setting. For each breakout group, facilitators had some planned questions and also allotted sufficient time for general questions and feedback.

This format proved to be extremely effective at eliciting actionable feedback from users, which has been invaluable in helping to shape ongoing and future developments in Cal-Adapt. For example, one suggestion for allowing batch processing of multiple point locations uploaded by users in a simple spreadsheet file such as .csv has recently been implemented as part of the new Data Download tool. The workshop materials including detailed notes from each breakout session can be found at https://cal-adapt.org/blog/2017/gif-opr-energy-sector-workshops/.

Because this format was so successful at generating discussion, several similar workshops are planned under the current awards. These user needs assessment workshops will be focused on the energy sector and open to the public to introduce users to new tools and features and elicit stakeholder comments and insights to help guide web site development. The invitation list and targeted advertising will be developed in consultation with the Energy Commission, the Technical Advisory Committee, and other energy sector partners.

The first of these workshops is being planned for Fall 2019 to be held at the Energy Commission in Sacramento on a yet-to-be-determined date.

Webinars

Quarterly webinars are designed to engage stakeholders early in the design stage as the development team builds new tools and also to enhance outreach and training of potential new and returning users. Webinars hosted thus far include:

- "Cal-Adapt – Linking Climate Science with Practitioner Need," held on 12/6/18. This webinar introduced participants to the features, tools, and data available in Cal-Adapt 2.0; gathered feedback regarding what updates or additional features would be most valuable; and elicited discussion around what new tools, visualizations, or features would help support adaptation and resilience planning. (50 attendees)
- "Introducing the New Extreme Precipitation Tool on Cal-Adapt," held on 3/28/19. This webinar introduced participants to the new extreme precipitation tool, including the underlying methodology used for extreme value analysis. The development team also invited feedback on what additional features would be most valuable for users. (45 attendees)

The next Webinar is planned for June 27, 2019, and is titled "Accessing Climate Data through Cal-Adapt." The development team will introduce the new Data Download tool as well as review other methods of extracting data, including through individual climate tools and through the API.

Web Conferencing

While the quarterly webinars have thus far proven to effectively communicate new developments on Cal-Adapt to users, the webinar format is not ideal for soliciting feedback from attendees. While time is provided for questions and follow the online chat, the webinar format is best for showcasing new tools or providing instruction and training, rather than generating substantial feedback from participants.

The development team found that informal web-based conference calls with targeted groups have been a better way to generate discussion and feedback, particularly from the IOUs. IOU-focused discussions will supplement the on-site meetings planned at each IOU and will help to identify and connect with a list of key people within each organization who are using Cal-Adapt or may use the site in the future.

Since this is a valuable way of generating actionable feedback that has not been explicitly identified in the project SoW, it might be beneficial to intersperse this type of stakeholder engagement with the scheduled quarterly webinars. A proposed schedule of topics for these webinars and web conference calls is included at the end of this document.

Tool Development and Testing

The GIF actively engages stakeholders during the tool development process. Each major tool to be developed is identified through collaboration with the Energy Commission, the TAC, and other users. Initial design for new tools and features is discussed with the Energy Commission and used to build a beta version of envisioned web pages. The resulting beta tool or visualization can then be shared with the Energy Commission and other stakeholders for review. This iterative development of visualizations and tools allows the development team to present initial tools to stakeholders, generate feedback, and then refine tool design.

Under these awards, the team is expanding user outreach during the early tool design stages to broaden user input beyond the Energy Commission and TAC groups. For major new tools under development, such as the expanded Sea Level Rise and Wildfire tools and the planned Land Use/Land Cover projections tool, the team plans to form focus groups of experts and key stakeholders involved in that specific climate impact topic to help define what questions each tool should be able to address and what features are necessary to answer those questions. This focus group can be convened at the beginning of tool development, and that information can be used to build a working beta version of the new tool.

A design review meeting with the Energy Commission and the project's Science Advisor at Eagle Rock Analytics will help ensure that the tool and data visualizations meet state recommendations and follow state guidance. Beta tool testing can be shared with a broad group of interested participants, including the focus group for that tool, technical contacts at IOUs, and partners at consulting agencies such as Ascent Environmental.

Subtask 3: Gather Feedback

Each of the engagement efforts detailed above is intended to both share information on the new tools and features that are continually being added to Cal-Adapt and to gather feedback

on what additional data, features, or tools would be useful to include on Cal-Adapt. The development team is interested in learning from users how they are already using Cal-Adapt tools and what they do or don't like about these existing tools. Questions directed towards stakeholders fall into the following categories.

General User Survey

At the request of the TAC from the Strategic Growth Council award, the team is developing a general user survey that will be shared online with Cal-Adapt users, sent to the newsletter list, and shared with all Cal-Adapt TAC members for dissemination. This survey is designed to gather feedback on who is using Cal-Adapt now, what they are using it for, and what improvements or additions they would like to see on Cal-Adapt. The draft survey can be found at https://forms.gle/yqLpzeExhE67Uaf68

In-Person or Phone Survey Questions

There is a basic set of questions that to which stakeholders can respond throughout outreach efforts. Forums to ask these questions will be both formal (for example, during some of the previously described outreach efforts) and informal (at conferences and other climate adaptation venues). Key questions include:

1. How does your organization currently use climate data?
2. What information do you need to make climate data useful and actionable? In what format is climate data most useful (for example, exportable graphics, reports, csv files, or raster data)?
3. What support might your organization need to use Cal-Adapt tools (training, API, etc.)?
4. What additional data layers or features would be most useful?
5. What suggestions do you have for improvements to Cal-Adapt to better meet your needs?

Tool-Specific Questions

For focus groups and key stakeholders that are convened to help plan and design specific tools, a set of questions geared towards that tool could include:

1. What questions do you need to answer about this climate topic?
2. How do you plan on using this tool (i.e. putting charts into reports or presentations, downloading raster or csv data, etc.)? Can you give examples of use cases?
3. What is the most important information to include in this tool?
4. Are there additional datasets that should be included on this tool?
5. What is the key functionality that is needed in this tool?

Feedback Compilation

A key element of this stakeholder engagement effort is the compilation and categorization of the feedback received during each of these interactions. Notes from each meeting or event will be recorded, including participant information when available. These notes will then be reviewed and compiled into a single Google document with feedback organized into the following categories:

- Actionable and within current scope
- Potentially actionable but will need to determine how this request falls within Energy Commission priority task list
- Potential area for future research (not actionable with currently available data)
- Not actionable or within scope

Subtask 4: Build a User Community

The development team is working to develop a community of Cal-Adapt users who are able to successfully implement Cal-Adapt tools to help evaluate climate-related risks and vulnerabilities.

The Cal-Adapt Newsletter and Blog

One method of direct communication with Cal-Adapt users is through the Cal-Adapt newsletter, which currently has 395 subscribers. With Cal-Adapt 2.0, the Cal-Adapt newsletter has been migrated to MailerLite, a hosted newsletter service. MailerLite provides several powerful and easy-to-use features including user subscription management, tools and examples for designing newsletters and subscription forms, and tools for tracking statistics on how users are interacting with the newsletter content. The newsletter is used to highlight new blog entries, new tutorials on using Cal-Adapt API, new tools and data added to Cal-Adapt, and upcoming events such as workshops and webinars.

Support@cal-adapt.org

Another valuable method of direct communication with users is the support email address. Users are able to reach out directly to the GIF web development team with questions or comments about Cal-Adapt data and tools. The developers provide technical assistance to inquiries when possible or refer users to documents or other guidance as needed. Many of these requests and suggestions have been implemented or are planned in future improvements.

Expanded Training Materials

Cal-Adapt's web service architecture is designed to allow users to have considerable control over aggregating, exporting, and displaying climate variables of interest to allow for advanced analysis beyond what is in the Cal-Adapt web-based tools. Detailed instructions on using the Cal-Adapt API can be found at https://berkeley-gif.github.io/caladapt-docs/index.html.

However, some familiarity with using a REST API and a scripting or programming language such as Python, R, or JavaScript is required to make full use of the API features. Users have noted that it would be helpful to develop more how-to training guides around making use of the API, particularly for geospatial information system (GIS) users.

Under this grant funding, the development team is working on developing expanded training materials focused on the Cal-Adapt API. The GIF has authored several examples on using the Cal-Adapt API with Python and Jupyter notebooks. The Jupyter Notebook is an open-source web application that allows a user to create and share documents that contain live code, equations, visualizations, and narrative text, which makes it ideal for rapid prototyping and sharing of data analysis. In addition to these notebooks the team plans to develop a how-to guide for ArcGIS users.

New training materials will be the focus of one of the planned quarterly webinar series when completed. Web applications developed by third-party users can also be shared with the user community and highlighted either through the Cal-Adapt website or the newsletter.

Presentations at Relevant Conferences

Additional outreach efforts under this funding include reaching out to broader audiences through conference presentations and live demonstrations. Potential opportunities include the American Geophysical Union Fall Meeting under a session proposed by Owen Doherty (Eagle Rock Analytics) and events such as the California Adaptation Forum, among others.

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Appendix B: Web Application Transfer Brief

June 2024 | CEC-500-2024-060-AP

APPENDIX B:
Web Application Transfer Brief

Deliverable dated January 2020

Cal-Adapt Web Application Transfer Brief

Geospatial Innovation Facility
January 23, 2020

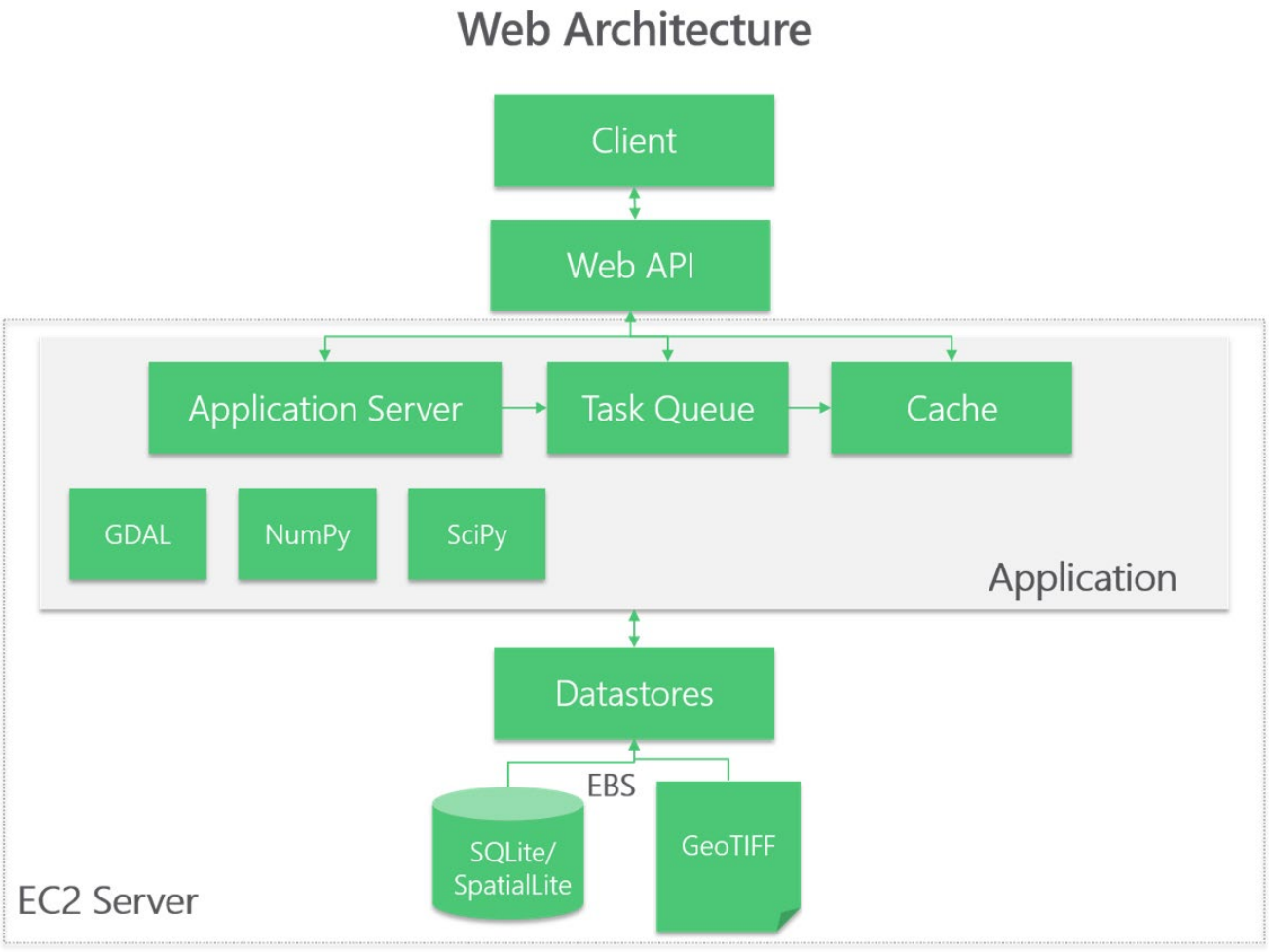
The Cal-Adapt web application is cloud-based and runs on Amazon Web Services (AWS). This application environment allows for a transfer of ownership if required under future Cal-Adapt funding. To transfer site ownership, an image of the production server as an Amazon machine image (AMI) could be created within the standard AWS management console. The self-contained AMI includes the database, web server, services, and all static assets necessary to run the entire site. This AMI would be shared with the Amazon account tasked with taking over hosting and management of Cal-Adapt. The AMI could be copied and then launched as a new Amazon Elastic Compute Cloud (EC2) instance. At that point, the Geospatial Innovation Facility (GIF) hosted instance would be deregistered and the Cal-Adapt.org domain transferred to the new owner. The latest source code release developed for generating front-end tools and visualizations could also be packaged or cloned from GitHub and provided for future development.

The hosting, management, and ongoing development of the web application upon transfer would require expertise in Python, JavaScript and some familiarity with Amazon Web Services. Cal-Adapt is built on top of the Python-based Django web framework along with supporting libraries such as the Geospatial Data Abstraction Library, NumPy, and SciPy. The application stack also includes SQLite with SpatialLite as a database, Nginx as the web server, and Redis as a job queue for asynchronous task handling. Additional capabilities for spatial querying and manipulating geo-formats are provided by the Django-Spillway package, an open source library developed at the GIF. The combined web framework provides fast and dynamic temporal aggregation of time series data and spatial aggregation by different vector boundaries.

The front-end tools and visualizations featured on Cal-Adapt have been designed to allow users to easily interact with and explore climate change data. The user interface is built using popular JavaScript libraries including Bootstrap, MapBox, and D3. MapBox is an open source mapping platform for custom designed maps. Cal-Adapt uses MapBox basemaps and API for mapping components in climate tools. Upon transfer, the ownership of the Cal-Adapt MapBox account could also be transferred to the new owner. While this is currently within the free service tier, this may change in the future as the popularity and complexity of the climate tools increase.

The front-end code is built and packaged using Babel and Webpack.

Cal-Adapt currently runs on a single AWS m4.large EC2 instance type that bills at $0.117/hour per on-demand instance and uses an 857GB Amazon Elastic Block Storage volume at a cost of $0.12/GB for a general purpose SSD. Current monthly costs for the application average around $220.00, subject to change with varying data volume and usage. In addition, the GIF manages the Cal-Adapt Data Server, which is a 15-terabyte Ubuntu Linux Dell PowerEdge R730 server hosting primary climate research data, commonly stored in NetCDF format. The machine could be taken offline and shipped to a new location, and the networking, DNS entry, and links on the Cal-Adapt website would have to be modified for ongoing accessibility to California's climate change research.



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Appendix C: Strategic Growth Council Final Project Report

June 2024 | CEC-500-2024-060-AP

APPENDIX C:
Strategic Growth Council Final Project Report

Dated 2021

INCREASING DATA ACCESSIBILITY AND CLIMATE RESILIENCE PLANNING SUPPORT THROUGH CAL-ADAPT

The California Climate Change Investments Programs Climate Change Research Program

Nancy Thomas

nethomas@berkeley.edu

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1. RESEARCH SUMMARY

Introduction

Cal-Adapt is a statewide resource for climate change data and visualizations. Our mission is to make data portraying climate change in California more accessible and actionable for a broad audience. This Strategic Growth Council funded research project has allowed Cal-Adapt to expand beyond our primary energy sector users to a more diverse user community, especially users working in municipal governments, natural resource management agencies, and community-based organizations.

A fundamental goal of this research has been to share climate change information across state agencies and California Climate Investments programs to advance the State's climate goals. The project team strives to support interagency coordination that can help leverage resources across multiple projects and State Agencies, and to ensure that new data and tools developed in Cal-Adapt will provide multiple benefits to stakeholders. The climate data visualizations and guidance materials developed through this research will help businesses, public agencies, nonprofit, and other community institutions understand the risks of climate change and therefore enable efforts to plan for and adapt to future conditions.

Research Approach

Our research approach was user-oriented and began with needs assessment outreach efforts to a diverse range of user groups including state agencies, local and regional planners, natural resource and water managers, community-based organizations, and the interested public. The project team facilitated user-needs assessment workshops and webinars to identify new datasets to incorporate onto Cal-Adapt and new features and targeted tools that could be developed to better meet the needs of user groups beyond the energy sector.

These stakeholder comments and insights informed the major projects tasks, including:

- Increase data accessibility through Cal-Adapt
- Develop merged/compound climate products
- Develop new data visualizations, features, and tools in Cal-Adapt

Stakeholder Engagement

To explore the evolving needs of Cal-Adapt past, current, and potential user bases, the Cal-Adapt team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and over 40 hours of focused interviews.

One of the main takeaways from these listening sessions was that users are looking for more guidance and an easier entry point to climate data. Historically, using Cal-Adapt has required a minimum level of climate science literacy that includes an understanding of climate models, emissions scenarios, environmental variability, and scientific (un)certainty. We've heard that

Cal-Adapt is considered "too technical" for some users who are tasked with local adaptation and resilience planning.

Research Findings

In recognition of these needs, the Cal-Adapt team has redesigned Cal-Adapt to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect to other state resources available for climate adaptation and resiliency planning. An example of these improvements can be found in our revamped Help content. We identified three main goals to address in our new Help content in response to requests we heard from engagement efforts:

- Create a "onboarding" ramp for new or less technical users who are not familiar with climate science and best practices for using climate data (Get Started)
- Provide comprehensive answers to frequently asked questions we receive from users (FAQs)
- Define and explain technical terms used on Cal-Adapt (Glossary)

Our new Get Started guide helps build climate science literacy for users who may be new to climate science. We have updated our list of FAQs and developed more comprehensive answers to queries sent by users over the years. A newly developed Glossary defines terms frequently used throughout Cal-Adapt. These Glossary definitions are also being integrated into all our climate tools. Users can search and filter FAQs and Glossary by topic. In addition, we are redesigning Cal-Adapt tools to streamline and standardize the user experience of exploring and accessing climate data.

Another key outcome of this research was the design and development of the new Local Climate Change Snapshot (LCCS) tool in Cal-Adapt, designed to support climate change adaptation practitioners in addressing the threats posed by rising temperatures, changing precipitation patterns, and climate change-influenced wildfire patterns. The LCCS tool was developed to serve two purposes:

- Provide a simple, beginner-friendly interface for accessing basic climate change projections
- Support users in accessing climate change projections by location, rather than by climate variable of interest

Our target audience for these enhancements is a broad audience of local climate planners, community organizations, technical users, educators, and anyone with an interest in exploring climate change projections in California.

In addition to these key outcomes, project highlights include:

- Research on compound climate events, including development of drought and wildfire weather data visualized on the LCCS tool

- Improved integration with state adaptation resources, in particular the ICARP Adaptation Clearinghouse
- Expanding access to climate data with newly developed ArcGIS and R Cal-Adapt packages, supported by webinars and hands-on workshops to train users

Advancing the State's Climate Goals

California is a global leader in addressing climate change and in developing energy policies that strive to conserve resources, protect the environment, and protect public health and safety. Senate Bill 32 sets targets for the state to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030. Cal-Adapt has been recognized by California's legislature as a key resource to support local hazard mitigation efforts and has helped California move forward on climate policy by providing easy access and exploration of high-resolution, regionally downscaled climate projections that are sanctioned by the state to be used in climate adaptation resiliency and planning.

This research helps achieve the state's statutory energy goals by providing needed actionable information on climate change consequences to California's populations and infrastructure by being able to identify locations that may be at risk from climate-related impacts such as increased wildfire risk and extreme heat events. With this information state agencies, local planners, resource managers, and communities will be better prepared to safeguard vulnerable populations and important assets.

Future Projects

Cal-Adapt development continues under two California Energy Commission awards. Ongoing work includes a new comparative Sea Level Rise tool which is currently being designed. The project team will continue to focus on developing guidance and training to support our growing user base and inform adaptation planning with quantitative and spatial information.

Additionally, the California Energy Commission is funding the development of an Analytics Engine, which will expand the Cal-Adapt enterprise to provide unprecedented computational and technical resources to directly support energy resilience. Cal-Adapt continues to evolve to present the latest scientific data and to further support stakeholders in understanding climate-related impacts relevant to local decision making.

2. Overview of the Research Project

Cal-Adapt is a statewide resource that provides free and open access to climate data, visualizations, and tools developed to aid in adaptation and resiliency planning across California. This Strategic Growth Council-funded research project has allowed Cal-Adapt to expand beyond its primary energy sector users to a more diverse user community, especially users working in municipal governments, natural resource management agencies, and

community-based organizations. This research has made data portraying climate change in California more accessible and actionable for a broad audience.

An additional objective of this research was to share climate change information across state agencies and California Climate Investments programs to advance the state's climate goals. The project team has supported interagency coordination to help leverage resources across multiple projects and state agencies, and to ensure that new data and tools developed in Cal-Adapt provide multiple benefits to stakeholders. The climate data visualizations and guidance materials developed through this research help businesses, public agencies, nonprofits, and other community institutions understand the risks of climate change and therefore enable efforts to plan for and adapt to future conditions.

The project goals were achieved through a user-centered approach that began with needs assessment outreach efforts to a diverse range of user groups including state agencies, local and regional planners, natural resource and water managers, community-based organizations, and the interested public. To explore the evolving needs of Cal-Adapt past, current, and potential user bases, the Cal-Adapt team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and more than 36 hours of focused interviews. These efforts helped us identify new datasets to incorporate onto Cal-Adapt and new features and targeted tools that could be developed to better meet the needs of user groups beyond the energy sector.

One of the main takeaways from these listening sessions was that users are looking for more guidance and an easier entry point to climate data. Historically, using Cal-Adapt has required a minimum level of climate science literacy that includes an understanding of climate models, emissions scenarios, environmental variability, and scientific (un)certainty. We've heard that Cal-Adapt is considered "too technical" for some users who are tasked with local adaptation and resilience planning.

These stakeholder comments and insights informed the major projects tasks as detailed in this report, including:

- Increase data accessibility through Cal-Adapt.
- Develop merged/compound climate products.
- Develop new data visualizations, features, and tools in Cal-Adapt.

This project has been completed within the proposed budget and scope, and project funds were spent in accordance with the proposed budget. This research took place during the global COVID-19 pandemic, and some alterations were made to the timeline and fund categories, in consultation with the Strategic Growth Council (SGC). Key impacts of the COVID-19 pandemic involved the cancellation of several user needs outreach events that were in the process of being scheduled for Spring 2020 and in the planning stages for Summer and Fall 2020. In response to the inability to host and facilitate in-person user needs events, workshops and other stakeholder engagement events were all transitioned to a remote format. This change triggered a minor change to the budget to redistribute funds originally earmarked for travel.

Despite the many challenges inherent in developing a research project during a global pandemic, we are fortunate that the Cal-Adapt development team was able to seamlessly transition to remote work throughout this project. One unexpected benefit to holding virtual stakeholder engagement activities remotely was that a greater number of participants were able to attend who might not ordinarily have funding for travel.

3. ACCOMPLISHMENTS

3.1 STAKEHOLDER ENGAGEMENT AND OUTREACH

To explore the evolving needs of Cal-Adapt past, current, and potential user bases, the Cal-Adapt team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and more than 40 hours of focused interviews. This effort began with the development of a comprehensive Stakeholder Engagement Plan that detailed the planned approach and outlined the stakeholder engagement process. This document outlined the planned approach for engagement, including:

- Analyze existing user data.
- Review literature on climate data applications.
- Survey Cal-Adapt users for broad feedback.
- Conduct focus interviews with key current and potential users.
- Construct end-user profiles.
- Conduct usability tests of tools in development, as useful.

3.1.1 Institution Review Board Process

Stakeholder engagement began with submitting required documents and receiving approval from the UC Berkeley's Institutional Review Board (IRB), which is required for being able to publish research related to the user outreach interviews, surveys, and workshops planned under this project. The project team created several guiding documents required under the IRB protocol, including: an interview guide for one-on-one phone or in-person interviews; a workshop guide for facilitators involved in user needs assessment outreach efforts; research participation consent forms; and anonymity protocols.

3.1.2 Cal-Adapt User Survey

As suggested by the TAC, the Cal-Adapt team developed an online user survey designed to gather feedback on who is using Cal-Adapt now, what they are using it for, and what

improvements or additions they would like to see on Cal-Adapt. To publicize the survey, the Cal-Adapt team included the survey link in:

- A targeted email sent to Cal-Adapt newsletter subscribers
- A quarterly Cal-Adapt newsletter
- A banner on the Cal-Adapt website
- Partner email newsletters
- Emails with the Cal-Adapt Technical Advisory Councils

The Cal-Adapt user survey contained 16 questions in varying formats. Most selection questions allowed respondents to write in a response if the list of available choices did not capture their response. Questions requesting one or more selections from a list of possible answers were mandatory for response submission. All other questions were optional to maximize the response rate from survey respondents who did not have strong feelings about or considered responses to all questions. To date there have been more than 80 respondents to this survey.

3.1.3 Focused Interviews

The project team conducted more than 36 hours of focused interviews to guide Cal-Adapt development. This effort was designed to expand the user base and learn more about the climate data needs of local planners, state agency representatives, natural resource managers, and local communities. The team strove to include a wide range of community organizations and geographic locations in the focused interviews. In the 36 organizations interviewed, 12 participants were from local municipalities, 7 were from CBOs, and 8 participants were natural resource managers. Other interviewees were from state agencies, non-profits, and utilities. In particular, the Cal-Adapt team worked closely with the project TAC, SGC, and other agencies to identify CBOs and other community groups to which to reach out and extend invitations for the interview process.

These interviews were semi-structured allowing for open-ended conversation. Key questions discussed within every interview included:

- How does your organization currently use climate data?
- What information do you need to make climate data useful and actionable? In what format is climate data most useful (for example, exportable graphics, reports, csv files, or raster data)?
- What support might your organization need to use Cal-Adapt tools (training, API, etc.)?
- What additional data layers or features would be most useful?
- What suggestions do you have for improvements to Cal-Adapt to better meet your needs?

3.1.4 Workshops and Webinars

The Cal-Adapt team facilitated and participated in a number of stakeholder outreach events to better understand user needs and to help users learn more about climate science and apply the wealth of data and tools available. Because Cal-Adapt is a statewide resource and is funded through multiple state agency grants, attendees at events often represented many sectors including utility managers and decision makers, state agencies partners, local and regional planners, natural resource and water managers, community-based organizations, and the interested public. As such these public events represent an area of overlap among the various Cal-Adapt funding streams in that several of the workshops and webinars were focused on energy sector topics, with considerable application to this award.

Outreach and training workshops and webinars have all been open to the public and are listed below.

3.1.4.1 Workshops and Presentations

The Cal-Adapt team outreach efforts have included both hosting Cal-Adapt focused user-needs assessment workshops and participation in events hosted by other state and regional entities. The specific funding agency is noted below.

- California Public Utility Commission (CPUC) Workshop, August 6, 2018: presented on Cal-Adapt at workshop on adaptation to climate change OIR (EPIC)
- National Academy of Sciences, August 14–15 2018: Thomas (author of EPC-17-033) was an invited speaker as part of a workshop on "Making Climate Assessments Work: Learning from California and other Subnational Assessment Efforts" (EPIC)
- California Adaptation Forum, August 27–29, 2018: Thomas was an invited speaker on a panel on "Sea- Level Rise Adaptation: Understanding the Science, Regulatory Frameworks and Resources" (EPIC)
- Fourth Assessment LA Regional workshop, November 2, 2018: presented on Cal-Adapt and held user needs assessment break-out groups to identify user needs around local adaptation planning (SGC)
- Fourth Assessment Climate Science Symposium for the North Coast Region, December 13–14, 2018. Presented on Cal-Adapt and held interactive user needs assessment (SGC)
- California Climate Action Team Public Health Workgroup workshop, February 4, 2019: invited to demonstrate Cal-Adapt's Extended Drought tool as part of a session on "Drought/Climate and Health Data and Tools" (SGC)
- Fourth Assessment Sacramento Valley Regional Climate Symposium, February 6, 2019: presented on Cal-Adapt during the "Adaptation Tools and Resources" session (SGC)
- ICARP Technical Advisory Council meeting, February 22, 2019 took part in a workshop entitled "Linking Vulnerability Assessment Frameworks and Climate tools with Practitioner Needs" (SGC)

- Strategic Growth Council Climate Change Research Symposium, November 5–6, 2019: Presented a poster on Cal-Adapt and took part in a panel discussion on climate tools and models (SGC)
- American Geophysical Union (AGU) Fall Meeting, December 2019: Presented on "Cal-Adapt: A Cloud Optimized Web Application for Linking Climate Science to Practitioner Needs" (EPIC & PIER)
- Sacramento Cal-Adapt User Needs Assessment workshop, December 5, 2019 (under SGC funding): Cal- Adapt user needs workshop held on site in Sacramento
- Hourly Temperature Data on Cal-Adapt workshop, December 18, 2019: hosted by the Energy Commission and attended by GIF team (PIER)
- Southern Central Valley Climate Change Adaptation Workshop, May 27, 2020: Cal-Adapt hosted and facilitated this online workshop to discuss data, tools, and support needed for climate change adaptation and resilience in the southern Central Valley (SGC)
- Sierra Region Climate Change Adaptation Workshop, September 29, 2020: Cal-Adapt, OPR, and the Sierra Business Council co-hosted this workshop to introduce participants to Cal-Adapt data and tools and the California Adaptation Planning Guide 2.0 through virtual tours and breakout group discussion (SGC)
- APG 2.0 Phase 2, March 17, 2021: Workshop hosted by OPR that included a presentation on how Cal-Adapt can be used for adaptation planning (SGC)
- SCAG Climate Change Projections for Adaptation Planning, March 18, 2021: SCAG hosted workshop that included an introduction to Cal-Adapt data and tools with a demo of the Local Climate Change Snapshot tool (SGC)
- Partners Advancing Climate Equity (PACE) Tools Demonstration, May 14, 2021: PACE workshop that included an introduction to Cal-Adapt data and tools with a demonstration of the Local Climate Change Snapshot tool (SGC)
- SPUR Climate Vulnerability Assessment Workshop, June 23, 2021: included hands-on exercises using Cal-Adapt tools to help teach key climate science concepts to participants (SGC)
- SCAG Local Climate Change Snapshot tool, July 27, 2021: SCAG-hosted workshop with walk-through of the Local Climate Change Snapshot tool (SGC)

3.1.4.2 Webinars

Webinars were recorded and made available on Cal-Adapt. Attendee numbers have ranged from between 30 and 80 participants, depending on the topic.

- Cal-Adapt – Linking Climate Science with Practitioner Need, December 6, 2018
- Introducing the New Extreme Precipitation Tool on Cal-Adapt, March 28, 2019
- Accessing Climate Data through Cal-Adapt, May 27, 2019

- Introduction to Climate Data, January 23, 2020
- Wildfire Projections under a Changing Climate, October 20, 2020
- Working with Cal-Adapt Data in ArcGIS Pro and R, November 12, 2020
- Local Climate Change Snapshot Tool, March 11, 2021
- Hands-On Workshop for Working with Cal-Adapt Data in R, October 1, 2021
- Introducing Cal-Adapt's New Look and Features, December 9, 2021

3.2 Stakeholder Insights and Recommendations

The stakeholder outreach and engagement efforts described here have provided a rich source of information on the evolving needs of Cal-Adapt's past, current, and potential user bases. Recommendations synthesized from this outreach are outlined in more detail in Appendix A, "Assessment of State and Local User Needs and Capacities." The main takeaway from this extensive stakeholder outreach is that many users and potential users want more guidance and instruction in how to use and understand climate data. Users are looking to the state for direct guidance in how to use climate data within their own vulnerability assessments and adaptation plans.

3.2.1 Common Use Cases

The climate applications that Cal-Adapt's users report are too varied to list exhaustively, but common applications include:

- Identifying, accessing, and downloading raw climate change projections for scientific modeling and research
- Completing municipal plans (for example, local hazard mitigation plans and general plan safety elements) that require a characterization of future climate change, descriptions of climate change-influenced hazards, and proposed climate change adaptation actions
- Informing colleagues, constituents, representatives, and partners about potential climate futures
- Teaching about climate change in high school and university settings
- Generating graphics for reports and presentations that illustrate possible climate change trajectories
- Completing funding applications that require a climate change narrative (for example, the Affordable Housing and Sustainable Communities program)
- Assessing differential risk across planning areas (for example, counties or administrative regions) and identifying highest-priority communities and/or climate change impacts

3.2.2 Best Features of Cal-Adapt

Stakeholder engagement has helped to identify the best features of Cal-Adapt that have made it a useful and actionable tool for adaptation planning:

- Authoritative and trustworthy source of data, sanctioned by the state
- Development team's responsiveness and active support to help assist users in accessing data, tools, and visualizations
- Site's general ease of use and aesthetically appealing user interface
- Depth and quality of linked citations and reference material
- Data access that supports a range of user technical capacity, including scenario and threshold flexibility for advanced users
    - Easy switch and toggle options to quickly explore climate possibilities
    - Frequent updates and new tools
    - Wealth of data download options
- Co-location of historical and projected climate data
- Open source status
- Data visualizations that inform and educate users
- Incorporation of statistically robust approaches in tools
- Summaries of climate change on a municipal and county level

3.2.3 Key Recommendations for Improvements

Users and potential users reported the following gaps and challenges in using Cal-Adapt to support their climate needs. Some of the gaps have been or are in the process of being addressed by Cal-Adapt staff and state agency partners; others are still outstanding or cannot yet be reconciled, given the state of the science. These recommendations are synthesized and presented below as either 1) in project scope and addressed as part of this research, or 2) recommendations for future research or funding. The majority of recommendations fall under requests for additional support and guidance for using climate data.

3.2.4 In Scope and Addressed within This Project

- More guidance and an easier entry point to climate data. Create more robust help materials that translate acronyms, answer common questions, and teach the basic climate science literacy that is required to use most of the tools on Cal-Adapt. This page should be located in a prominent position on the Cal-Adapt landing page.

- In recognition of these needs, the Cal-Adapt team redesigned Cal-Adapt to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect to other state resources available for climate adaptation and resiliency planning.

- State guidance in determining appropriate climate change analysis parameters (for example, time horizons, emissions scenarios, climate change indicators, and model ensembles). Many users report understanding that such choices are specific to location and context, but at the same time, additional (and even prescriptive) guidance would be helpful. Users point to the Ocean Protection Council's guidance on sea level rise planning (for example, 2018 update) to be an example of helpful guidance.
    - New content under the Get Started page includes best practices for using climate data. However, providing prescriptive guidance is outside the scope of this project and would need to be generated at the state level.
- Development of a simple tool that provides an introductory picture of climate change for a location of interest across a suite of climate indicators.
    - This has been accomplished with the design and development of the new Local Climate Change Snapshot (LCCS) tool in Cal-Adapt, designed to support climate change adaptation practitioners in addressing the threats posed by rising temperatures, changing precipitation patterns, and climate change-influenced wildfire patterns.
- The ability to characterize compounding hazards (for example, debris flows after fire and extreme precipitation)
    - Research on compound drought and wildfire weather conducted under this research is included within new LCCS tool.
- A library of short walkthrough and tutorial videos (not to exceed five minutes in length) that show users how each tool works and how climate change data should be interpreted. Many users expressed a preference for learning new information in short videos, rather than longer webinar recordings or written documentation. Additionally, users indicated that it would be useful for short videos to be embedded in Cal-Adapt so that users can mimic the video walkthrough in a browser window while simultaneously watching the video.
    - The Cal-Adapt team has begun to build these videos and integrate them into tools, such as for the LCCS tool.

3.2.5 Recommendations for Future Research

- Connection of physical climate change to spatially explicit representations of socioeconomic conditions and impacts. In many tools, Cal-Adapt has been updated to allow users to evaluate climate change using census tracts that align CalEnviroScreen 3.0. However, state agency partners have determined that a more thorough

representation of socioeconomic climate change (dis)advantage and the factors informing such characterizations merits its own robust process that the Office of Planning and Research is spearheading, so it has not been addressed under this project.

- Economic impacts of climate, particularly resulting from changes in agricultural productivity, excess mortality, and migration and displacement
- Inclusion of additional relevant available data layers such as Federal Emergency Management Agency flood maps
- Investment in story maps and other narrative content to support climate change literacy, climate adaptation advocacy, and scenario planning for adaptation.
- More robust support for climate change adaptation planning through a guide that connects Cal-Adapt to state planning requirements and regulations and common planning frameworks (e.g. decision scaling, stress testing, and scenario planning).
- A full-time staff person to develop and support the user community, provide technical assistance, and perform outreach. This staff member would be responsible for hosting weekly Cal-Adapt office hours, demonstrating Cal-Adapt at conferences and meetings, planning and hosting monthly webinars, conducting continual user engagement to direct future development, generating new web content like story maps and user narratives, and building and delivering a train-the-trainer curriculum for regional climate change collaboratives and professional organizations.

3.3 Stakeholder Informed Enhancements to Cal-Adapt

In recognition of user needs and recommendations, the Cal-Adapt team redesigned Cal-Adapt to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect to other state resources available for climate adaptation and resiliency planning. The following information describes the new content has been developed specifically under the SGC award to support a diverse user community, especially users working in municipal governments, natural resource management agencies, and community-based organizations.

3.3.1 New Help Content

Many new users report being overwhelmed by the volume of information on Cal-Adapt. Interviewees reported that Cal-Adapt is "too wonky" and "too technical" for them and that there is no obvious "learning on-ramp" for them to become more familiar with climate science and the mechanics of Cal-Adapt. Stakeholders recommended that the Cal-Adapt team should create a "New to Cal-Adapt" webpage that teaches basic climate science literacy and the layout of Cal-Adapt. The webpage should be immediately and obviously accessible from the

landing page, perhaps as a link in the navigation bar displayed in the upper right-hand corner of the site.

The Cal-Adapt team identified three main goals to address in a new Help section in response to requests heard from engagement efforts:

- Create an "onboarding" ramp for new or less technical users who are not familiar with climate science and best practices for using climate data (Get Started).
- Provide comprehensive answers to frequently asked questions received from users (FAQs).
- Define and explain technical terms used on Cal-Adapt (Glossary).

The Cal-Adapt team collaborated closely with partners at SGC, OPR, ERA, and CEC on writing and refining this new content, particularly the Get Started pages. The Get Started guide helps build climate science literacy for users who may be new to climate science and identifies best practices developed by climate scientists for using climate data. The Get Started guide is organized into the following five topics:

- **Climate change and climate data in California:** Why climate data is important for adaptation planning and how to use it
- **Climate data and other data on Cal-Adapt:** Information about the types of data available through Cal-Adapt
- **About climate projections and models:** How climate models are generated, validated, and account for greenhouse gas emissions scenarios
- **Accessing data on Cal-Adapt:** Different ways of exploring and downloading the data available on Cal-Adapt
- **Best practices for using climate projections:** Understanding uncertainty, natural variability, and how to use climate projections in your work

3.3.2 Developing the Local Climate Change Snapshot Tool

Stakeholder engagement activities clearly highlighted the need for a simplified entry point for less technical users to access climate information. The design, beta testing, and launch of Cal-Adapt's new LCCS tool was developed to specifically address the feedback and requests from users. This iterative development process allowed the Cal-Adapt team to present an initial design to users, generate feedback, and then refine the tool design. This development process is explained in detail below.

3.3.2.1 Identify User Needs

The Cal-Adapt development team gathered feedback from a variety of sources to envision the new tool, including breakout sessions held during workshops and focused discussions. The

team collaborated closely with partners at Climate Resolve, OPR, and SGC to build a beta version of the tool. Key functionality and features requested by users for this new tool include:

- Simplified language and data: users don't want to have to decide which models or GCMs to use for their analysis
- Location-based: enter tool by location first
- Links to additional resources including the Adaptation Clearinghouse
- Multiple climate variables available in one location
- Easy output options including pdf report

3.3.2.2 A Rigorous and Scientific Approach

The LCCS tool required a new approach to presenting climate data on Cal-Adapt. Lead climate scientist Owen Doherty from Eagle Rock Analytics recommended that the LCCS tool incorporate ensemble data from the full set of 32 GCMs, rather than the reduced set of 10 (or 4) recommended models for California. Other climate tools on Cal-Adapt incorporate the reduced set of 10 models, so in order to meet the requirements for the LCCS tool, the GIF development team processed climate data such that each variable of interest incorporates the full 32-model ensemble. Data processing steps included identifying the model range during the 30-year time periods in addition to processing the ensemble averages for each of the time periods and then making these datasets available through the Cal-Adapt API.

3.3.2.3 Usability Testing

An additional focus of stakeholder engagement was to get early and frequent input into the beta version of the LCCS tool, including discussions with potential users at Climate Resolve as well as meetings with SGC and OPR. The project team shared a beta version of the tool with Climate Resolve so they could test it and share their feedback. After that initial review from Climate Resolve the Cal-Adapt team made several refinements to the tool and then conducted a more rigorous beta testing to better understand how local planners navigate the information and what improvements can be made to make climate information actionable for users.

Beta testers were recruited from Cal-Adapt workshop attendees, a newsletter announcement, and interview follow-ups. Beta testers included representatives from municipalities, consultants, academics, state agencies, nonprofits, and utilities. The project team invited 12 people to join the beta testing group, and 7 people accepted. Research suggests that 5 to 10 beta testers are ideal.

The testing included two phases: 1) a live observed tool interaction with prompts to answer questions that require users to explore the tool, and 2) a follow-up survey form. Goals of the live observation phase were to:

- See how people navigate the tool, particularly where they get stuck, miss important cues, or take a long time to find what they're looking for

- Explore the potential gap between the information users think they are getting and the information they are actually getting
- Capture wide-ranging large and small feedback (easier than a form, as it requires less time investment from beta testers)

In addition, the survey included a standardized "system usability" test. The initial version of the Local Climate Snapshot tool received an average score of 79, which falls into the "acceptable" and "good" categories. Key insights from the first round of beta testing included:

- Some beta testers had difficulty navigating the location selection map. Simplified approach might be helpful
- Ability to toggle between units or default to imperial (rather than metric)
- Suggestion to eliminate the CDD/HDD from the snapshot tool. Many folks interested in this information are more advanced users and would benefit from the main tool on Cal-Adapt. Confusing concept to include in the Local Climate Snapshot tool and would require extensive explanatory text
- Name update would be a good idea: Local Climate Change Snapshot tool
- Confusion over model uncertainty. Some testers like the strip chart approach but most were unclear about what information was portrayed. Need to rethink the best way of showing the uncertainty of climate projections.

3.3.2.4 Iterative Design

The Cal-Adapt development team compiled the information learned in beta testing and created a prioritized list of the suggested refinements, bugs, and feature requests. The team worked with Owen Doherty (Eagle Rock Analytics) and SGC on explanatory text around wildfire projections and model uncertainty. These changes were then implemented in the tool code and a second round of beta testing was performed with several key stakeholders. Major revisions included:

- Worked on revisions to the location selection map to simplify the approach for users.
- Began revising presentation of uncertainty information by include the model range from the full set of 32 models for each climate variable.
- Revised text as requested by SGC for wildfire.
- Added watershed as a boundary layer option.
- Revised links to other resources as shown in LCCS tool.
- Added links to Adaptation Clearinghouse and other Cal-Adapt tools that have the location and/or topic "pre-selected" to improve ease-of-use.

- Identified and processed additional climate indicators as suggested by beta-testers including new indicators:
    - Maximum 1-day precipitation
    - Maximum length of dry spells
    - Historical observed data for wettest day of year
    - April SWE (snowpack)

3.3.2.5 Outreach and Education

The LCCS tool workflow and interface is particularly applicable for adaptation practitioners who are in charge of adaptation planning for a place, rather than for a specific anticipated impact. To support potential users of the tool, the Cal-Adapt team developed supplementary materials including a detailed blog post, a recorded webinar, and a video walkthrough that guides users through how to use the tool.

3.4 Improved Integration with State Adaptation Resources

Another goal of this research program was to strengthen the linkages between Cal-Adapt and related state-funded efforts to give users information on how to take practical climate actions. Many stakeholders noted that integration with resources such as the ICARP Adaptation Clearinghouse would improve Cal-Adapt's usability. The Adaptation Clearinghouse hosts hundreds of documents ranging from adaptation planning case studies to state-endorsed manuals to datasets and scientific studies. The Clearinghouse is easily searchable, and results can be filtered by sector, planning phase, climate impact addressed, geography, and document type.

The Cal-Adapt team collaborated closely with SGC and OPR to plan and build easy to use connections between Cal-Adapt and other relevant resources. Links to the Adaptation Clearinghouse and California's Fourth Climate Change Assessment have been included within the majority of Cal-Adapt's climate tools. The LCCS tool includes links to a variety of Statewide Resources related to each climate change variable. For example, when viewing the Temperature variable, users can find links to the California Heat Assessment Tool (CHAT), California's Fourth Climate Change Assessment Regional Reports, and the Adaptation Clearinghouse Temperature Impacts. Links to the Adaptation Clearinghouse present climate impacts pre-selected on the search page for easy exploration. For the Wildfire impact, users can easily link to the Cal Fire Data Hub in addition to the Adaptation Clearinghouse and Fourth Assessment Reports.

In addition to direct links within tools, the Cal-Adapt team partnered with OPR to develop content relevant to adaptation planning within the new Get Started page. In particular, a section on Using Climate Data in Adaptation Planning points users towards the 2020 Adaptation Planning Guide, which provides guidance to local governments on adaptation and resiliency planning, including details on how to use Cal-Adapt within vulnerability assessment

planning. Direct connections to many guidance materials produced by the state of California were include in this section:

- 2020 Adaptation Planning Guide
- State of California Sea Level Rise Guidance, 2018 Update
- Planning and Investing for a Resilient California: A Guidebook for State Agencies
- General Plan Guidelines and Technical Advisories (See Chapter 4, Safety Element, and Chapter 8 for specific guidance on addressing climate change).
- Defining Vulnerable Communities in the Context of Climate Change
- Various state agency-produced regional, topical, and impact-specific guidance documents and technical resources that are compiled and highlighted on the State Adaptation Clearinghouse as Featured Resources, organized under Topic Areas.

As a related outreach and engagement activity, the Cal-Adapt team collaborated with OPR on a webinar for Phase II of the Adaptation Planning Guide, showcasing the LCCS as an adaptation resource. OPR plans to update the Adaptation Clearinghouse with explicit linkages to the new LCCS tool. One option for this would be to embed the tool directly within the Adaptation Clearinghouse so users can directly explore climate information for a location of interest.

3.5 Research on Compound Climate Events

Stakeholders have identified the need to better understand the risks and threats that emerge from the concurrence of multiple extreme climate events. Multivariate or compound climate impacts may lead to more actionable ways to understand potential climate impacts than "raw" climate variables. Cal-Adapt lead scientist Owen Doherty of Eagle Rock Analytics led research to determine what compound events could be presented within Cal-Adapt and to develop methods for including these results on the website (Appendix B).

Compound climate events occur when two or more weather events occur at the same time, leading to a disproportionately larger societal impact. For example, wildfire and drought result from a combination of sustained dry periods, often with high temperature, atmospheric moisture deficits and stronger than average winds enhancing evapotranspiration and reducing soil and vegetative moisture content. Wildfire and drought manifest over different timescales, wildfire being immediate, discrete events and drought building over long periods of time. It is more challenging to assess the risk from compound events, rather than single factor events like a heat wave. These challenges include:

- Simple easy to understand metrics like mean and standard deviation do not provide much insight into compound events, making it harder to represent and understand these events.

- Compound events are difficult to characterize in risk-assessments and vulnerability studies and in turn are often under appreciated by decision makers.
- Compound events often impact multiple sectors of society and the economy, necessitating coordinated responses from multiple entities that may not have historically worked together.
- People often struggle to assess risk, particularly that of very rare events that have outsized societal impacts. Resilience planning for these high-risk, low-frequency events requires a new way of thinking.
- Compound and cascading events require climate models to make an accurate prediction of future weather events and get the timing and location of weather events right, too. Lots of work has gone into showing that the mean values of climate models are very good, but models' ability to predict the right timing and place of weather events is less certain.
- Compound events are, by definition, dependent on multiple variables, which breaks the rules of one of the most common statistical tests and methods: a requirement of independence. As such traditional, well understood statistics are not the appropriate tool, increasing the complexity of analysis while reducing comprehension and accessibility of the work.

Projecting future climate is hard; predicting how people will respond to climate is harder. Not considered here, but of high importance, is how societal disruptions from climate change will cascade — discrete disruptions and vulnerabilities, followed by additional climate stress can be a cascading event. (An example of this might be drought and extreme heat leading to fires, damaging or destroying a community, causing residents in temporary housing to be exposed to subsequent climate-induced events like smoke, landslides, intense precipitation or extreme heat). Individual climate or weather events can have outsized impacts following earlier, unrelated high-impact events. Collectively this is referred to as cascading disasters — a very important topic, but not the focus of the research conducted under this project.

Collaborators at ERA developed methods to visualize two types of compound events that are increasingly common in California: drought and wildfire. To address the time component, both of the indices include a lag component, where the index is informed by the weather of the days preceding it. This is a new advance for Cal-Adapt, which allows for full consideration of the evolution of a compound event.

3.5.1 Drought

Defining drought is a challenge, as drought means different things to different people, depending on their concerns. An ecologist, farmer, water resources planner, well driller, suburban homeowner, and city resident each have different ways of looking at drought.

Drought in California can build and persist for varying lengths of time, each with different societal impacts. Meteorological droughts occur on short timescales (a couple of months)

occurring in response to transient factors: low humidity, high temperatures, high wind, low cloud cover during periods of reduced precipitation. Agricultural droughts occur over a few seasons, resulting in persistent soil water deficiencies, manifesting in plant stress, reduced crop yield and biomass and impacts to ecosystems. Hydrological droughts take many months to years build, resulting in reduced streamflow, lower reservoir/lake levels with major impacts to wetlands (California's delta and coastal sloughs), and reduction in groundwater table level. Multi-decadal droughts, sometimes referred to as "mega-droughts" can occur over many years, leading to ecological regime shifts; reduction in groundwater; and major changes in lake and stream function and structure. California is currently in a multi-decadal drought, with climate change making such events more likely.

Characterizing drought in a simple way that Cal-Adapt users find accessible is a challenge given the many dimensions of drought. One approach is to use a drought metric, a simplified index that combines information from many individual climate variables. After researching drought indices, the Cal-Adapt team settled on the Standardized Precipitation-Evapotranspiration Index (SPEI) as a good compromise. The SPEI depicts the combined impacts of precipitation deficits and potential evapotranspiration on soil moisture. SPEI does not include impacts from effects like wind speed, relative humidity, or solar radiation impacts (typically short-term forcing), making it more reflective of long-term hydrological and ecological drought conditions. Cal-Adapt presents SPEI calculated for a nine-month period, attempting to reflect a length slightly longer than California's typical wet period.

What does SPEI mean? SPEI is standardized, meaning the average value of the index at any location is very close to zero, and values typically range between -2 and 2, with values outside of this range being very rare and suggestive of extreme events (approximately 5 percent of all times). Negative values suggest drought conditions, and positive values suggest wet conditions.

What should one look for in SPEI? A value less than -1 implies the drought is at least moderate in intensity, with more negative values representing more severe droughts. On Cal-Adapt's LCCS tool drought is defined as any nine-month period for which the SPEI is -1 or lower. It is not uncommon for multiyear droughts to have short periods of rainfall, which could show up as a brief period of positive values, but do not erase drought conditions on the ground.

What doesn't SPEI tell us? California's annual and long-term water supplies are dependent on snowpack. Rapid onset droughts, or a very hot spring can cause rapid snowmelt — decreasing water availability for a year. This is not reflected in SPEI. Cal-Adapt's selection of a nine-month lag of SPEI, means short term "flash" droughts are not reflected in the index. A late fall/early winter flash drought could extend fire weather season and stress ecosystems but could be missed by this version of SPEI.

3.5.2 Wildfire

Work done for California's Fourth Climate Assessment included rigorous and detailed simulations of wildfire conditions, but were so numerous and large that including them in Cal-

Adapt was impractical. Summaries in the form of decadal probabilities of wildfire and hectares burned per year were produced and used for tools on Cal-Adapt. However, for decision-making and planning purposes, additional information on wildfire weather has also been produced and included within the LCCS tool. The Cal-Adapt team provided estimates of fire weather risk through calculation of the Keetch-Byram Drought Index (KBDI), from which users are able to estimate the number of days per year of extreme fire risk across California.

The KBDI provides an estimate for how dry soil and vegetative detritus is. KBDI is cumulative: drought values increase on dry and warm days and decrease during rainy periods, meaning in California one would expect KBDI to increase from the end of the wet season (spring) into the dry season (summer and fall). Fire danger is complex (impacted by human activity, vegetation, wind, temperature, relative humidity, atmospheric stability, and more) and KBDI represents a simplified proxy for favorability of occurrence and spread of wildfire but is not itself a predictor of fire. The following list explains what values of KBDI represent.

- 0 – 200: Soil moisture and fuel moistures are high, low wildfire risk
- 200 – 400: Soil and fuels start to dry, average wildfire risk
- 400 – 600: Onset of drought with moderate to serious wildfire risk
- 600 – 800: Severe drought, extreme wildfire risk and increased wildfire occurrence

What does KBDI mean? Practically speaking it tells us nothing about wildfire predictions; it just notes the degree to which the environment is susceptible to fire growth and propagation if a fire were initiated. Wildfire behavior is too complex to model with a simple index, as it depends both on human and natural factors.

However, examining, at a given location or region, the degree to which burning is possible is helpful for understanding changes in risk and exposure to wildfire.

What should one look for in KBDI? Bigger values indicate larger soil moisture deficiencies and a greater potential for wildfires to persist and spread. Many locations will see an increase in the number of days with dry conditions, but perhaps more critically these dry days may occur earlier in the spring and later into the fall. Both are critical for decision makers to understand in thinking about a community's vulnerability to fire and resilience capacity.

What doesn't KBDI tell us? It is not a prediction of wildfire occurrence or spread. KBDI knows nothing about the vegetation on the ground or fuels for a fire. It might, for example, suggest that the Mojave Desert is ripe to burn. It doesn't know, per-se, if a Diablo wind is present, or if it is a calm day. Again, treat KBDI as a rough estimate and look at the aggregate — across seasons, months or years — rather than at individual days.

3.5.3 The Future of Conveying Risk from Compound Events

The research and detailed information provided by partners at ERA allowed the Cal-Adapt team to process and present these new compound events indices within the LCCS tool. In addition, the full datasets are available for download through Cal-Adapt's Data Download tool

for additional research. Depending on stakeholder interest, future development could include building stand-alone tools on Cal-Adapt to include spatial representations of SPEI and KBDI and additional thresholds for more sophisticated analysis.

3.6 Expanding Access to Climate Data

3.6.1 Near-Real Time Climate Data Availability on Cal-Adapt

Partners at Eagle Rock Analytics led the effort to identify a scientifically rigorous near-term dataset to include on Cal-Adapt. The Livneh data that is used to generate observed historical baseline information for California's Fourth Climate Assessment and showcased on Cal-Adapt is a gridded dataset produced for the years 1950–2013 and has not been updated since then. It is expected that a new historical observed and modeled dataset will be generated in preparation for California's Fifth Climate Changed assessment. However, Cal-Adapt users have expressed interest in having access to a "bridge" product available on Cal-Adapt that would cover more recent major policy-relevant events (that is, Camp Fire, ongoing drought, near electric grid collapsing heat event of 2020) occurring after the "current" record ends on Cal-Adapt to provide temporal coverage until the Fifth Assessment data products are available.

Dr. Doherty at ERA researched other peer-reviewed, vetted auxiliary gridded data that are continually being updated that might be suitable for inclusion in Cal-Adapt and recommended the gridMET Observed Meteorological Dataset, produced by the Climatology Lab at U.C. Merced (Appendix C). It provides daily representation of all the key variables from the Fourth Assessment at an improved resolution relative to historical products used. GridMET does have some known limitations, which are well described on the gridMET website. For example, gridMET will likely not capture microclimates below 4km in expanse, and gridMET wind fields and solar radiation originate from a 32km grid, and the statistical methods used to generate them cannot characterize local effects. However, this data product is likely to meet Cal-Adapt stakeholder requirements and should be helpful to users who need more up-to-date historical information.

The Cal-Adapt team processed this data and uploaded it into the Cal-Adapt API for easy access through the Data Download tool. This is a modified version (temporally capped at 2020 when it was processed, and spatially clipped to Cal-Adapt area) of gridMET, which is a dataset of daily high-spatial resolution (approximately 4 km, 1/24th degree) surface meteorological data covering the contiguous United States from 1979 through yesterday.

3.6.2 New Tools to Work with Climate Data in R and ArcGIS Pro

Cal-Adapt has a full featured API, which allows users to request data programmatically. This allows users to customize how climate data is analyzed or visualized and allows climate data to be combined with other data or models that predict things like plant or pest growth, health impacts, and so on. However, use of the API requires that users be able to write computer code to access the full set of features. As part of the research, the Cal-Adapt team partnered

with the University of California's Agriculture and Natural Resources Informatics and GIS Program (IGIS) group to develop add-ons for R, Python and ArcGIS, that make it dramatically easier to import climate data into these programming environments.

R is a very mature statistical computing program that is popular with data scientists. To improve usability for R users, IGIS developed CaladaptR, an R-package that streamlines the process of importing Cal-Adapt climate data into R via the Cal-Adapt API. This allows users to retrieve climate values for selected locations, years, and climate models and then combine that information with other data. Users can then analyze and visualize this information using other R packages.

IGIS also developed example applications to showcase the features of CaladaptR. As an example, the team built a calculator to project chill hours for tree crops under different climate futures using Shiny, which allows users to build lightweight, user-friendly decision support web sites that are powered by Cal-Adapt. These lightweight tools can either be run locally or published online so that non-R users can access and interact with the models.

In addition to CaladaptR, collaborators at IGIS also developed new tools to simplify the process of accessing climate data from Cal-Adapt into ArcGIS Pro, the premier desktop GIS program. Caladapt-py is a Python library with functions to find, download, and visualize Cal-Adapt climate data, with an accompanying toolbox that provides a user-friendly GUI within ArcGIS Pro. This library also provides functions to download Cal-Adapt data that users can then analyze in Jupyter Notebooks or similar packages. The ArcGIS Pro Cal-Adapt toolbox provides a simple menu interface so users don't need to know any Python at all to import Cal-Adapt data directly into ArcGIS Pro. Once in Pro, uses can apply a vast suite of spatial analytics, summaries, and visualizations.

3.7 A Collaborative Approach

The collaborative approach taken with this research has led to the wealth of project results and enhancements to Cal-Adapt described in this report. Project partners at SGC, OPR, and Climate Resolve played a large role in designing and developing major new content on the website, including the LCCS tool and the new Help content describe above. Many helpful participants from a range of geographies, sectors, and community organizations were involved in the user-centered design process. This project greatly benefitted from the time and feed-back users and potential users generously gave through responding to the online survey; participating in focused interviews; attending workshops and webinars; and offering detailed feedback in beta testing.

The complex climate data science topics addressed on Cal-Adapt require support from climate scientists and domain experts to develop functional and rigorous tools that can provide actionable information to stakeholders. The partnership with Dr. Owen Doherty of Eagle Rock Analytics as Science Advisor to Cal-Adapt has greatly improved the statistical rigor of climate data and tools, particularly as showcased in the LCCS tool, including the new drought and wildfire weather indices. Working closely with collaborators at IGIS has helped to develop new

tools for users to access the climate data underlying Cal-Adapt and to improve usability of the web API.

4. Challenges and Barriers

The biggest challenge to successful completion of this project has been the COVID-19 pandemic. This initiated a move to fully remote work for much of 2020 and 21. While much of the web development transitioned seamlessly to remote work, revising planned stakeholder engagement activities presented challenges. Stakeholder engagement planned originally detailed in-person user-needs assessment workshops to be held in different geographical regions of the state. While the project team was able to transition these activities to a virtual format, some aspects of communication and feedback are difficult to achieve in a fully remote environment.

One additional impediment to note has been to address the needs of different state agencies in incorporating the latest Fourth Assessment sea level rise data into Cal-Adapt. While SGC would like to have included this as a climate impact within the LCCS tool, the CEC identified challenges to building a simplified data visualization that could adequately capture the various sea level rise models funded under the Fourth Assessment. Incorporating this information in an easy-to-use tool is still an ongoing effort under related CEC funding for Cal-Adapt.

On a broader scale, key challenges identified through this research remain for many users to fully implement the data and tools showcased on Cal-Adapt for their adaptation planning needs. The Cal-Adapt team learned that climate change adaptation work is often understaffed in municipal governments and natural resource management agencies. This is usually attributed to a lack of long-term, reliable funding, even though organizational leadership almost always recognizes the urgency of climate change analysis and adaptation.

Often, staff in charge of climate change adaptation planning also have other pressing responsibilities. Additionally, climate change planning is frequently considered a stand-alone activity that isn't consistently integrated with other day-to-day activities.

As a result, building momentum, continuity, and in-house expertise in climate change adaptation work is difficult. Users consistently report that Cal-Adapt hosts most of the information needed for climate change adaptation planning, but they struggle to make the information presented on Cal-Adapt formatted for and relevant to their planning processes. Many agencies rely on CivicSpark fellows and consultants to address this issue, and while those professionals produce high-quality and essential work, staff report that doing so doesn't necessarily build long-term, internal technical and managerial capacity for climate change analysis and adaptation planning.

The challenges of building deeper analytic and interpretive capacity in a growing user community would be most effectively addressed through a program of targeted technical assistance. To this end, users recommended that Cal-Adapt hire a full-time staff person to build an ecosystem of support and technical assistance that extends Cal-Adapt's reach and

improves Cal-Adapt's usability. This staff member could be responsible for hosting weekly Cal-Adapt office hours, demonstrating Cal-Adapt at conferences and meetings, planning and hosting monthly webinars, conducting continual user engagement to direct future development, generating new web content like story maps and user narratives, and building and delivering a train-the-trainer curriculum for regional climate change collaboratives and professional organizations.

In addition, stakeholders have recommended that Cal-Adapt invest in more narrative content to make the website more accessible to a wider user base while also maintaining the sites' core mission and commitment to scientific rigor. Suggestions included develop story maps to illustrate examples of climate change analysis; provide template narratives for climate change adaptation advocates (often community-based and non-profit organizations); and develop scenario planning capacity in Cal-Adapt's user base. Narrative content could help users walk through an example of a climate change analysis by integrating text and visual context and controlling the pace of information delivery to be more digestible.

In particular, Cal-Adapt could host narrative scenarios that illustrate possible climate futures that cities and economic sectors in California might experience. These narrative scenarios could support adaptation efforts structured through scenario planning, which is a bottom-up adaptation planning method in which participants envision and explore a range of specific plausible futures in order to evaluate possible outcomes and consequences of adaptation decisions. Scenario planning is particularly useful when high degrees of uncertainty are present or stakeholders represent diverse populations, backgrounds, concerns, and skillsets.

5. Strategies for Action

California is a global leader in addressing climate change and developing policies that strive to conserve resources, protect the environment, and protect public health and safety. Cal-Adapt is an important public-facing website that is helping California achieve its mandated climate goals by providing easy access to climate projections that are sanctioned by the state to be used in climate adaptation resiliency and planning.

Historically, Cal-Adapt's user base has consisted of energy sector employees and academic scientists. This research has allowed Cal-Adapt to expand to meet a more diverse user community, especially users working in municipal governments, natural resource management agencies, and community-based organizations.

Cal-Adapt continues to evolve to become a more accessible and powerful climate adaptation and resilience support tool that will enable decision makers to use research results and climate projections to inform effective adaptation decisions and policies. Because Cal-Adapt has been successful in meeting user needs and expanding the use of climate data within adaptation planning, the Cal-Adapt team is encouraged to learn that the state has developed plans to continue to grow and expand Cal-Adapt. The CEC has developed a vision for building a larger Cal-Adapt Enterprise that can encompass both user-friendly and easy-to-use interactive tools as seen on Cal-Adapt while also designing the new Cal-Adapt Analytics Engine to be optimized

for the more technically savvy users who are comfortable writing their own computer code, which will provide unprecedented computational and technical resources to directly support energy resilience.

Funding and support for Cal-Adapt is planned to continue under a recent CEC solicitation (GFO-21-302), and OPR has expressed the goal of securing funding for maintenance and front-end enhancements to the web application. The stakeholder feedback and recommendations described in this report can serve as important guidelines as the state develops its vision for an expanded Cal-Adapt Enterprise that can further support a growing user base in implementing climate change adaptation and resiliency planning for a safe and secure future for all Californians.

Appendix A:
Assessment of State and Local User Needs and Capacities

California is a global leader in addressing climate change and in developing energy policies that strive to conserve resources, protect the environment, and protect public health and safety. Senate Bill 32 sets targets for the state to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030. Cal-Adapt has been recognized by California's legislature as a key resource to support local hazard mitigation efforts and has helped California move forward on climate policy by providing easy access and exploration of high-resolution, regionally down-scaled climate projections that are sanctioned by the state to be used in climate adaptation resiliency and planning.

One key outcome of this research is a better understanding of how Cal-Adapt can be used to further the state's climate goals and objectives. This report presents a synthesis of findings gathered during stakeholder engagement at both the state and local levels to aid California's climate resilience and adaptation moving forward and offer recommendations for leveraging Cal-Adapt across state agencies as a powerful tool in promoting California's climate adaptation and resilience efforts.

User Needs and Capacities

Historically, Cal-Adapt's user base has consisted of energy sector employees and academic scientists. This project has allowed Cal-Adapt to expand to meet a more diverse user community, especially users working in municipal governments, natural resource management agencies, and community-based organizations.

The project team asked stakeholders to describe how they currently use climate data in their climate resiliency and adaptation work. The climate data applications that Cal-Adapt's users report are too varied to list exhaustively here, but some common applications are:

- Identifying, accessing, and downloading raw climate change projections for scientific modeling and research
- Completing municipal plans (for example, local hazard mitigation plans and general plan safety elements) that require a characterization of future climate change, descriptions of climate change-influenced hazards, and proposed climate change adaptation actions
- Informing colleagues, constituents, representatives, and partners about potential climate futures
- Teaching about climate change in high school and university settings
- Generating graphics for reports and presentations that illustrate possible climate change trajectories
- Completing funding applications that require a climate change narrative (for example, the Affordable Housing and Sustainable Communities program)

- Assessing differential risk across planning areas (for example, counties or administrative regions) and identifying highest-priority communities and/or climate change impacts

Challenges in Climate Change Adaptation Work

Stakeholders reported the following gaps and challenges in their capacity to effectively work on climate adaptation. Some of the gaps have been or are in the process of being addressed by Cal-Adapt staff under this research; others are outside the scope of this project and are recommended as areas of consideration for future research or staff funding.

Staff Capacity

Climate change adaptation work is nearly universally understaffed in municipal governments and natural resource management agencies. This is usually attributed to a lack of long-term, reliable funding, even though organizational leadership almost always recognizes the urgency of climate change analysis and adaptation. Often, the staff member(s) in charge of climate change adaptation planning also has other pressing responsibilities. Additionally, climate change planning is frequently considered a stand-alone activity that is not consistently integrated with other day-to-day activities. As a result, building momentum, continuity, and in-house expertise in climate change adaptation work is difficult. Many agencies rely on CivicSpark fellows and consultants to address this issue, and while those professionals produce high-quality and essential work, staff report that relying on outside expertise does not necessarily build long-term, internal technical and managerial capacity for climate change analysis and adaptation planning.

Understanding Climate Science

The climate science literacy necessary to understand the data on Cal-Adapt is difficult to build given resources available. Historically, using Cal-Adapt has required a minimum level of climate science literacy that includes an understanding of climate models, emissions scenarios, environmental variability, and scientific (un)certainty. We have begun to address this challenge as part of this research by Cal-Adapt's addition of a new Get Started section designed to aid users in understanding basic climate science.

Guidance on How to Use Climate Data

Determining appropriate climate change analysis parameters (for example, time horizons, emissions scenarios, climate change indicators, and model ensembles) is challenging. Many users report understanding that such choices are specific to location and context, but at the same time, additional (and even prescriptive) guidance would be helpful. Users point to the Ocean Protection Council's guidance on sea level rise planning (2018 update) to be an example of helpful guidance. Although it is outside the scope of this project to prescribe how to use climate data, Cal-Adapt's new Get Started pages include a section on Best Practices for Using Climate Data and links to other state resources for adaptation and resiliency planning.

Compound Climate Events

Users wish to be able to characterize compounding hazards (for example, debris flows after fire and extreme precipitation) and socioeconomic impacts (employment or urban heat island effects) of climate change, not just changes in physical climate. Under this research we have developed initial compound climate hazard products that use multiple climate variables to create indicators of long-term drought and wildfire weather as included within the Local Climate Change Snapshot tool. This is a rich area for additional research to improve understanding of complex and cascading climate events.

Recommendations for Supporting Climate Change Adaptation Practitioners

We recommend that future iterations of Cal-Adapt consider pursuing the following actions to support climate change adaptation practitioners in California.

Provide Dedicated Staff to Offer Outreach and Technical Assistance

Users consistently report that Cal-Adapt hosts most of the information they think they need for climate change adaptation planning, but they either did not know that Cal-Adapt exists or do not know how to make the information presented on Cal-Adapt formatted for and relevant to their planning processes. To this end, users recommended that Cal-Adapt hire a full-time staff person to build an ecosystem of support and technical assistance that extends Cal-Adapt's reach and improves Cal-Adapt's usability. This staff member would be responsible for hosting weekly Cal-Adapt office hours, demonstrating Cal-Adapt at conferences and meetings, planning and hosting monthly webinars, conducting continual user engagement to direct future development, generating new web content like story maps and user narratives, and building and delivering a train-the-trainer curriculum for regional climate change collaboratives and professional organizations.

Provide Information on State Climate Change Adaptation Regulations

Many users, particularly municipal planners, struggle to find a reliable and comprehensive source of information on legislation pertaining to climate change adaptation in California. As a result, they also have trouble understanding how Cal-Adapt can fit into their workflow, especially to meet regulatory requirements. Users have suggested building a page on Cal-Adapt that lists California climate change adaptation regulations, briefly explains each regulation, and identifies how Cal-Adapt can be useful in compliance. Listing all legislated requirements for climate change adaptation planning on Cal-Adapt would help users more quickly connect the resources hosted on Cal-Adapt to their own workflows.

Invest in Story Maps and Other Narrative Content

Aligned with the theme of making Cal-Adapt more accessible to a wider user base while also maintaining the site's core mission and commitment to scientific rigor, users suggested that Cal-Adapt host story maps to illustrate examples of climate change

analysis, provide template narratives for climate change adaptation advocates (often community-based and non-profit organizations), and develop scenario planning capacity in Cal-Adapt's user base.

Story maps can walk users through an example of a climate change analysis by integrating text and visual context and controlling the pace of information delivery to be more digestible. Examples of story maps that Cal-Adapt could host include:

- Chill hour analysis
- Social and physical information overlay (for example, identifying priority areas for more thorough analysis by overlaying extreme heat data and CalEnviroScreen metrics)
- Climate change exposure analysis for an example city

Cal-Adapt could also host narrative scenarios that illustrate possible climate futures that cities and economic sectors in California might experience. These narrative scenarios could support adaptation efforts structured through scenario planning. Scenario planning is a bottom-up adaptation planning method in which participants envision and explore a range of specific plausible futures in order to evaluate possible outcomes and consequences of adaptation decisions. Scenario planning is particularly useful when high degrees of uncertainty are present, or stakeholders represent diverse populations, backgrounds, concerns, and skillsets.

Advancing the State's Climate Goals

As the impacts of climate change are being felt across multiple sectors of California's society, an expanding range of increasingly diverse stakeholders need guidance and support to understand complex science in the way of training, education and guidance on best practices. Localization is needed of global climate models to the level of decision making and its impacts. Education and capacity are needed to help users get to the right data and make it available in an approachable way. A focus on actionable data and metrics that can be incorporated directly into stakeholders current planning practices is critical.

Decision makers, policy makers, and members of the public all benefit from distillation of complex climate science data into easy-to-understand information that enhances their understanding and enables smart investment and planning. We offer several recommendations for consideration as CEC and OPR partner on building an expanded Cal-Adapt Enterprise.

Expand Cal-Adapt as a Statewide Climate Data Services Website

We recommend that the state recognize and fund Cal-Adapt as a statewide climate data services website and fund the capacity to include further user support and education. Climate data services can be understood as the broad effort to make climate data widely available, visualize future outcomes, and translate the information to user specified needs. Climate services range from the technical (that is, APIs, advanced

visualizations), to the scientific (that is, applying QA/QC, identifying appropriate data and statistics to employ), to education (that is, teaching users the basics of climate science, helping them to understand what climate scenarios are) and to user training (that is, helping users incorporate data, tools, visualization in their work).

There is an opportunity for Cal-Adapt to include stakeholder engagement experts and climate scientist in addition to web application developers and spatial data scientists. The recent resolutions between CEC and OPR to treat Cal-Adapt as a larger enterprise is a welcome first step, but the focus must continue to grow on supporting the stakeholders who struggle the most to incorporate climate data into their planning and development activities.

Expand the Data Sources on Cal-Adapt Beyond the Fourth Assessment

The majority of data provided on Cal-Adapt is sourced from California's Fourth Climate Change Assessment. All data currently hosted on Cal-Adapt requires authorization from the CEC for inclusion on the site. However, stakeholders at both state and local levels have informed the project team that additional supplemental data (that is, socioeconomic, vulnerability related) would be of use to them. A process is necessary by which data can be added to Cal-Adapt that falls outside of the energy sector, but is still considered authoritative, vetted and ideally peer reviewed. OPR or SGC would likely need to take point on such efforts and respond to stakeholder requests or Cal-Adapt staff recommendations. An important consideration to expanding data on Cal-Adapt is that any new data would need to be hosted on Cal-Adapt's AWS account and would influence overall cost of the data storage.

One approach to expanding access to broader sources of data could be a method of "tagging" data sources on Cal-Adapt as to the degree of validation and level of rigor. For example, one could imagine a tag simply called "source" that could include tags such as "Fourth Climate Assessment, Adaptation Clearing House, User Provided, Scientific – Peer Reviewed." Such tags could originate or refer to legislation or regulations and be included to provide users with key information on data providence.

Cal-Adapt's Role in Disseminating State-Sponsored Climate Data

The emergence of data lakes for environmental data represents a major advance in the information technology and availability of key climate relevant datasets. Ensuring that state sponsored data lakes can share data and assets is important to smart development. Cal-Adapt can play a key role here in disseminating climate data and scenarios in a unified, shared way that makes climate data more approachable for a wide array of users. The state's larger strategy must ensure that data lakes are developed in a way that data may transfer from one to another with no or low costs to users and the state.

Cal-Adapt and Extreme Heat

California is investing significantly in assessments of extreme heat impacts, including efforts like the California Heat Assessment Tool. As the state prepares to invest tens of millions of dollars into extreme heat mitigation work, high level coordination and alignment on climate scenarios and analytics are important. Cal-Adapt could provide data and climate expertise that could help various efforts use the data in scientifically and statistically appropriate ways, or further, could visualize advances made by other researchers.

Community Vulnerability and Resiliency Mapping

A clear need, and opportunity, exists to provide socioeconomic and demographic information layers on top or next to climate data in mapping applications. In many tools, Cal-Adapt already allows users to evaluate climate change using census tracts that align with CalEnviroScreen 3.0. Building an expanded Maps of Projected Climate Change tool to allow users to overlay various socioeconomic data was originally planned under this research effort, but state agency partners have determined that a more thorough representation of socioeconomic climate change (dis)advantage and the factors informing such characterizations merit their own robust process that the Office of Planning and Research is spearheading. We recommend coordination among the Cal-Adapt team and OPR as the Vulnerable Communities Platform is being built to ensure alignment on climate science and user needs among our broad stakeholders, including energy sector and community partners.

Appendix B:
Visualizing Compound Events on Cal-Adapt

Compound Events

What happens when two (or more!) climate hazards occur at the same time? Nothing good. Many of the most impactful extreme climate events occur in a confluence of multiple individual discrete hazards or weather events. These events can emerge suddenly or build slowly over time — with impacts felt differently at different locations and different time points of the event. Such events are referred to commonly as "compound events" or "cascading events," and include occurrences as coastal flooding, wildfire, drought, and landslides. Sometimes compound events have been referred to as "high consequence, low probability events" in reference to the fact that such multiple hazards events occur in concert or sequentially less often than individual extreme climate events, but when they do happen in concert or sequentially, they tend to have major impacts for people and the environment.

Scientists use the terms "compound" and "cascading" somewhat interchangeably when referring to climate events. To make things a bit easier to understand the project team is adopting simplified definitions for each of these terms:

> *Concurrent or Compound Climate Events* — occur when two or more weather events occur at the same time, leading to a disproportionately larger societal impact.
>
> *Successive or Cascading Climate Events* — occur when two or more weather events occur in succession of each other, either building societal impacts over time or potentially leading to a future extreme event.

Both cascading and compound events depend critically on multiple aspects of the climate system but vary in terms of when the effects are felt.

Compound Events in California

Californians are well acquainted with compound events: wildfire, landslides, drought, and coastal flooding. Some compound or cascading events have common underlying hazards associated with them. For example, wildfire and drought result from a combination of sustained dry periods, often with high temperature, atmospheric moisture deficits, and stronger than average winds enhancing evapotranspiration and reducing soil and vegetative moisture content. Wildfire and drought manifest over different timescales, wildfire being an immediate, discrete event and drought building over long periods of time.

Compound events and associated climate hazards include the following.

- Wildfire: More frequent, more intense droughts; damage to ecosystem/forest health; soil and atmospheric moisture deficits; extreme heat; regional wind patterns.
- Drought: More variable precipitation, increased temperature, reduced atmospheric moisture, increased evapotranspiration, changes in snowpack/snowmelt.

- Landslides: Increased wildfire activity leading to burn scars, climate induced disruptions to ecosystems, increased precipitation intensity.
- Coastal Flooding: Sea level rise, increased intensity of coastal storms, more intense precipitation.

Challenges in Representing Compound Events

For a number of reasons, it is harder to assess the risk from compound events, rather than single factor events like a heat wave.

- Simple easy to understand metrics like mean and standard deviation do not provide much insight into compound events — making it harder to represent and understand these events.
- Compound events are difficult to characterize in risk assessments and vulnerability studies and in turn are often under appreciated by decision makers.
- Compound events often impact multiple sectors of society and the economy, necessitating coordinated responses from multiple entities that may not have historically worked together.
- People often struggle to assess risk, particularly that of very rare events that have outsized societal impacts. Resilience planning for these high-risk, low-frequency events requires a new way of thinking.
- Both compound and cascading events require that climate models make an accurate prediction of future weather events as well as get the timing and location of weather events right. Lots of work has gone into showing that the mean values of climate models are very good, but models' ability to predict the right timing and place of weather events is less certain.
- Compound events are, by definition, dependent on multiple variables, which breaks the rules of one of the most common statistical tests and methods: a requirement of independence. As such, traditional, well understood statistics are not appropriately used, increasing the complexity of analysis while reducing comprehension and accessibility of the work.
- Projecting future climate is hard, predicting how people will respond to climate is harder. Not considered here, but of high importance, is how societal disruptions from climate change will cascade — discrete disruptions and vulnerabilities, followed by additional climate stress can be a cascading event. (An example of this might be drought and extreme heat leading to fires, damaging or destroying a community, residents in temporary housing exposed to subsequent climate induced events like smoke, landslides, intense precipitation, or extreme heat). Individual climate or weather events can have outsized impacts following earlier, unrelated high-impact events.

Collectively this is referred to as cascading disasters — a very important topic, but not the focus of this blogpost.

Representing Compound Events on Cal-Adapt

Having enumerated the long list of challenges to understanding compound events, this section describes the first efforts to visualize compound event risks on Cal-Adapt beginning with two compound or cascading events that are increasingly common in California: drought and wildfire. To address the time component, both indices include a lag component, where the index is informed by the weather of the days preceding it. This is a new advance for Cal-Adapt, which allows for full consideration of the evolution of a compound event.

Drought

Defining drought is a challenge, as drought means different things to different people, depending on their concerns. An ecologist, farmer, water resources planner, well driller, suburban homeowner, and city resident each have different ways of looking at drought.

Drought in California can build and persist for varying lengths of time, each with different societal impacts. Meteorological droughts occur on short timescales (a couple of months), occurring in response to transient factors: low humidity, high temperatures, high wind, low cloud cover during periods of reduced precipitation. Agricultural droughts occur over a few seasons, resulting in persistent soil- water deficiencies and manifesting in plant stress, reduced crop yield and biomass, and impacts to ecosystems. Hydrological droughts take many months to years to build, resulting in reduced streamflow and lower reservoir/lake levels with major impacts to wetlands (that is, California's delta and coastal sloughs), and reduction in groundwater table level. Multi-decadal droughts, sometimes referred to as "mega-droughts" can occur over many years, leading to ecological regime shifts; reduction in groundwater; and major changes in lake and stream function and structure. California is currently in a multi-decadal drought, with climate change making such events more likely (Figure 1).

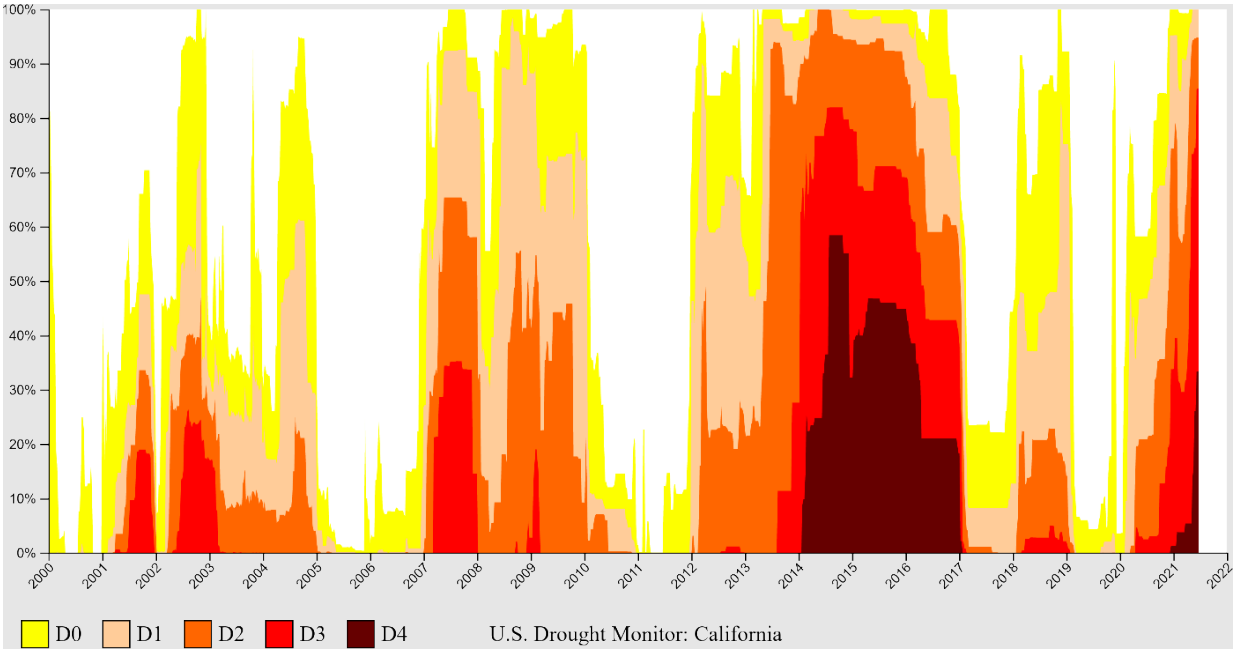

Figure 1. US Drought Monitor showing faction of California under drought conditions from 2000–2021. California has been in a persistent multi-decadal drought since 2012, with only two wet seasons occurring in this period. Some argue that California never recovered from the drought 2007–2010 and consider California as experiencing a "mega-drought."

Drought in California comes in many shapes and sizes. Depending on the societal or environmental impact, people try to quantify drought according to several characteristics. Some common characteristics of drought include duration (how long a drought has been occurring), magnitude (accumulated water deficit), intensity (magnitude relative to duration), severity (how impactful the drought has been), spatial extent (area impacted by drought), or frequency (how often are droughts occurring). How one measures and describes a drought is often a function of what attribute of a drought one is trying to show.

Characterizing drought in a simple way that Cal-Adapt users find accessible is a challenge given the many dimensions of drought. One approach is to use a drought metric, a simplified index that combines information from many individual climate variables. Zargar et al. (2011) found almost 150 indices to describe drought; now 10-plus years later, there are likely more. After a deep dive into drought indices, we settled on the Standardized Precipitation-Evapotranspiration Index (SPEI) as a good compromise. It includes the impacts of increasing temperature on soil moisture loss, a critically important mechanism for driving future droughts in California due to warming. Given this project's California focus, we lean into California's Mediterranean climate, calculating drought on the timescale of nine months to fully encapsulate any given rainy season. A time span of nine months falls in between agricultural and hydrological drought, on the sliding scale of drought timescales.

Standardized Precipitation-Evaporation Index

The standardized precipitation-evaporation index (SPEI) depicts the combined impacts of precipitation deficits and potential evapotranspiration on soil moisture. SPEI does not include

impacts from effects like wind speed, relative humidity. or solar radiation impacts (typically short-term forcing), making it more reflective of long-term hydrological and ecological drought conditions. Here we present SPEI calculated for a nine-month period, attempting to reflect a span slightly longer than California's typical wet period.

What does SPEI mean? SPEI is standardized, meaning the average value of the index at any location is very close to zero, and values typically range between -2 and 2, with values outside of this range being very rare and suggestive of extreme events (approximately 5 percent of all times). Negative values suggest drought conditions, and positive values suggest wet conditions.

What should one look for in SPEI? A value less than -1 implies the drought is at least moderate in intensity, with more negative values representing more severe droughts. Cal-Adapt defines drought as any nine-month period for which the SPEI is -1 or lower. It is not uncommon for multiyear droughts to have short periods of rainfall, which could show up as a brief period of positive values, but do not erase drought conditions on the ground. In terms of longer-term droughts, brief wet episodes should not be considered ends to drought conditions.

What does SPEI not tell us? California's annual and long-term water supplies are dependent on snowpack. Rapid onset droughts, or a very hot spring can cause rapid snowmelt, decreasing water availability for a year. This is not reflected in SPEI. Cal-Adapt's selection of a nine-month lag of SPEI, means short term "flash" droughts are not reflected in the index. A late fall/early winter flash drought could extend fire weather season and stress ecosystems but could be missed by this version of SPEI.

If the version of SPEI on Cal-Adapt doesn't meet your needs, or you prefer a different drought index, please let us know.

Wildfire

Cal-Adapt has lots of great information on wildfire, so why create a new index? Work done for California's Fourth Climate Assessment included rigorous and detailed simulations of wildfire conditions, but were so numerous and large that including them in Cal-Adapt was impractical. Summaries in the form of decadal probabilities of wildfire and hectares burned per year were produced and used for tools on Cal-Adapt. However, for decision-making and planning purposes, these summaries were found to be non-actionable. Here we provide estimates of fire weather risk through calculation of the Keetch-Byram Drought Index (KBDI), from which we are able to estimate the number of days per year of extreme fire risk across California.

Keetch-Byram Drought Index

The Keetch-Byram Drought Index (KBDI) provides an estimate for how dry soil and vegetative detritus is. KBDI is cumulative — drought values increase on dry and warm days and decrease during rainy periods — meaning in California we would expect KBDI to increase from the end of the wet season (spring) into the dry season (summer and fall). Fire danger is complex (impacted by human activity, vegetation, wind, temperature, relative humidity, atmospheric

stability, and more) and KBDI represents a simplified proxy for favorability of occurrence and spread of wildfire but is not itself a predictor of fire. The following list explains the values KBDI represents.

- 0 – 200: Soil moisture and fuel moistures are high, low wildfire risk
- 200 – 400: Soil and fuels start to dry, average wildfire risk
- 400 – 600: Onset of drought with moderate to serious wildfire risk
- 600 – 800: Severe drought, extreme wildfire risk and increased wildfire occurrence

What does KBDI mean? Practically speaking it tells nothing about wildfire predictions; it just notes the degree to which the environment is susceptible to fire growth and propagation if a fire were initiated. Wildfire behavior is too complex to model with a simple index, as it depends both on human and natural factors. However, examining at a given location or region, the degree to which burning is possible is helpful for understanding changes in risk and exposure to wildfire.

KBDI attempts to estimate how much precipitation is needed to bring soil back to its maximum capacity to hold water. But, since this capacity is a function of soil type, among other factors, it is location specific and not calibrated to California's highly varied soil. A simpler way to consider KDBI is to think of it as a rough measure of water deficits in the ground and vegetation on the ground.

What should one look for in KBDI? Bigger values indicate larger soil moisture deficiencies and a greater potential for wildfires to persist and spread. Consider both the number of days above a given threshold (600, for example), and when in the year those days occur. Many locations will see an increase in the number of days with dry conditions; but perhaps more critically these dry days may occur earlier in the spring and later into the fall. Both are critical for decision makers to understand when thinking about a community's vulnerability to fire and resilience capacity.

What does KBDI not tell us? It is not a prediction of wildfire occurrence or spread. KBDI knows nothing about the vegetation on the ground, or fuels for a fire. It might, for example, suggest that the Mojave Desert is ripe to burn. However, it does not know, for example, if a Diablo wind is present, or if it is a calm day. Consider KBDI as a rough estimate and look at the aggregate across seasons, months, or years, rather than at individual days.

The Future of Conveying Risk from Compound Events

We're excited about the progress we've made by making these indices available via the Cal-Adapt API and through the Local Climate Change Snapshot tool. Future efforts, depending on funding, could include, additional metrics and indices, spatial representation of concurrent or cascading climate events, or employing approaches from the social science discipline referred to as decision making under deep uncertainty.

Appendix C:
Towards Near-Real Time Observed Data Products

1. Statement of Problem

Cal-Adapt hosts, primarily, environmental data that originated from California's climate assessments. By law these assessments occur once every five years, meaning that the climate data visualized and distributed by/through Cal-Adapt is updated approximately every five years.

We refer to datasets that are not being updated as "dead data," and their use is deeply problematic for use in climate resilience and adaptation work.

Stakeholders have indicated that dead data is a major hindrance of using Cal-Adapt tools and products. Extreme or high impact climate events in California have increased in frequency and intensity in recent years, with major policy-relevant events (Camp Fire, ongoing drought, near electric grid collapsing heat event of 2020) occurring after the current record ends on Cal-Adapt. Compounding the dead data issue is the fact that the observational product (Livneh) underpinning the current data product (Fourth Assessment) has major systemic issues that preclude its use after 2005, meaning the last 16-plus year record of climate change is not available for view on Cal-Adapt.

Two primary approaches should be considered to address the dead data problem: (1) requiring that assessment-affiliated efforts be constructed in a way that allows for low-maintenance continual updating or (2) supplementing assessment efforts with peer- reviewed, vetted auxiliary data that are continually updated. the following discussion outlines challenges associated with and a potential approach to supplement existing data on Cal-Adapt with externally produced, use-appropriate climate data.

2. Methodological Considerations

a. Challenges Associated with the Current Record

The current Livneh data product has multiple issues that reduce its utility on Cal-Adapt for making climate resilience decisions. (1) The temperature data within Livneh falls outside of range of climate model projections, likely due to biases or systematic errors in temperature estimates as identified in Walton et al., 2017 (Figure 1 for maximum daily temperature and Figure 2, minimum daily temperature). These statewide systematic biases in temperature give the mistaken appearance to casual viewers of Cal-Adapt visualizations that the climate models are wrong relative to historical temperature observations. (2) The 2005 cut-off to Livneh data is problematic, necessitating a bridge product to provide temporal coverage until Fifth Assessment data products are available in 2022 or 2023.

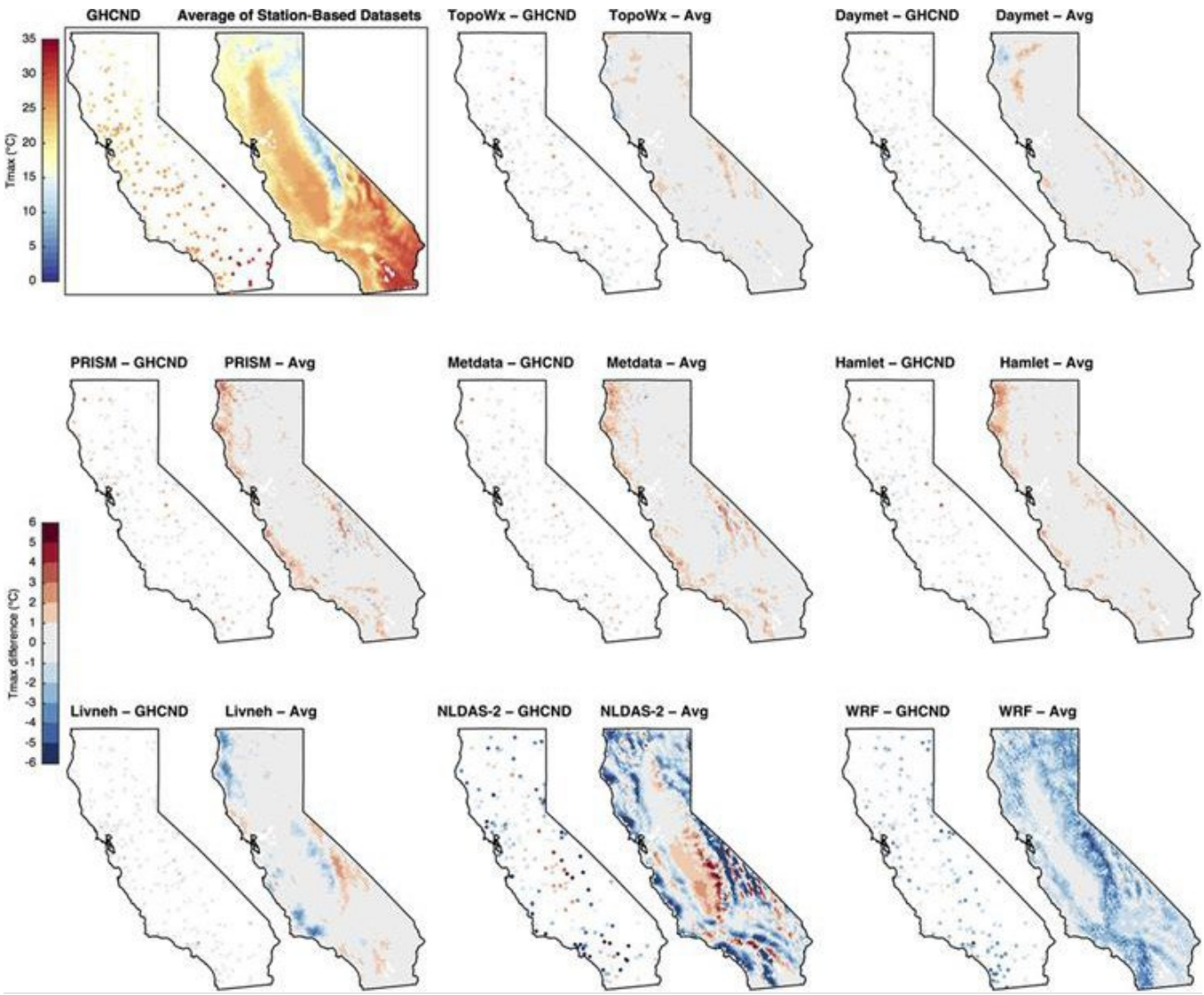

Figure 1. Biases in maximum temperature of multiple climate data products. Livneh is the current data product used on Cal-Adapt. Metdata (now gridMET) is proposed moving forward.

b. Homogenization of Climate Data

Long-term climate records can be categorized as homogenized or non-homogenized depending on how raw observations are statistically merged into the larger data product. Homogenized data products correct the jumps in a historical time series that emerge from the movement of weather stations, changes in instrumentation, weather stations being added or removed from a network, and other non-physical sources of different observations. From a climate resilience perspective, homogenized data products are best for long-term trend analysis, but come at the cost of potential removal of real local trends that arise from microclimates. Non-homogenized records are best for in-situ, short term analyses.

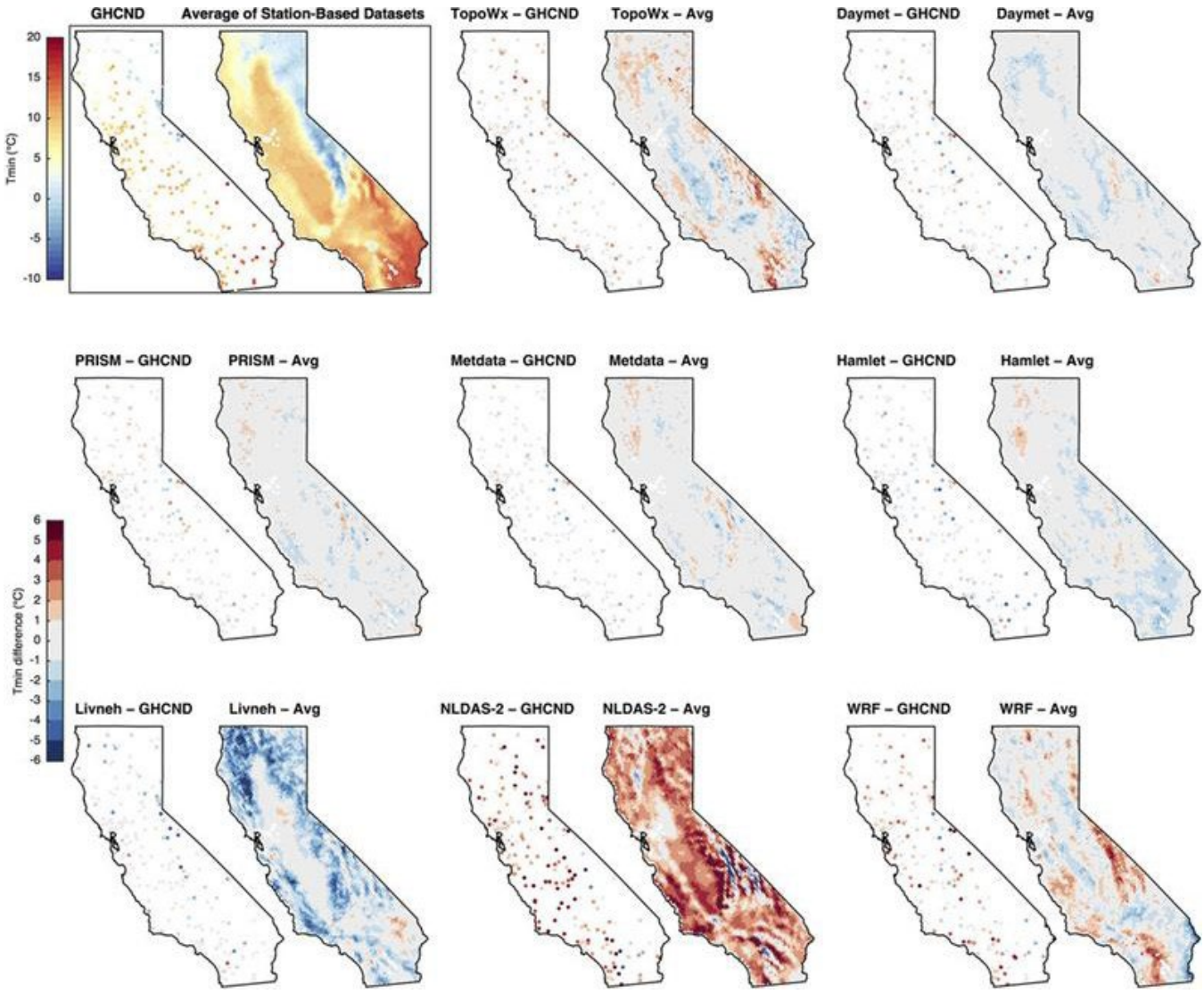

Figure 2. Biases in minimum temperature of multiple climate data products. Note the near statewide extreme cold bias in minimum temperatures in the Livneh product. Livneh is the current data product used on Cal-Adapt. Metdata (now gridMET) is proposed moving forward.

In California, it is particularly important to explicitly consider the merits of homogenized and non-homogenized records due to California's complex and diverse microclimate and the addition of a large number of weather stations from the RAWS network in the late 1990s, which greatly increased the coverage across rural locations, the incorporation of which can lead to jumps in the record. Newer data products may also include the thousands of new weather stations installed by electric utility companies after the year 2010, with similar impacts to the climate record.

A homogenized data product will meet the needs of the majority of Cal-Adapt users.

3. Discussion

a. Recommendation - GridMet

We recommend that Cal-Adapt include GridMet as a "bridge product" to span the data gap between the Fourth and Fifth Climate Assessments. It provides daily representation of all the key variables from the 4th Assessment, at an improved resolution relative to historical products used. It is produced continuously at UC Merced. We are unaware of any stakeholder requirements that this data product would not meet.

	4th Assessment	Bridge Product	5th Assessment
	Liveneh	gridMET	PIR-19-007
Temporal Resolution	Daily	Daily	Hourly
Spatial Resolution	~6km	~4km	2km
Update Frequency	Never	Daily	Never
Start Date	1950	1979	1980
End Date	2005*	present	2019
Variables	Max Temp, Min Temp, 24H-Precip, RH, Solar Insolation, Wind Speed	Max Temp, Min Temp, 24hr-precip, RH, specific humidity, Insolation, Wind Speed	?
Dataset Type	Observational	Hybrid (Obs & Reanalysis)	Regional Model forced by Reanalysis
On Cal-Adapt	2015 – present	Present – 2022	2022/23 - ?
Dataset Size	?	?	800 TB

Table 1. Comparison of climate data products.

b. Known Data Limitations

gridMET has some known limitations, which are well described on the gridMET website and summarized below. gridMET will likely not capture microclimates below 4km in expanse. gridMET wind fields and solar radiation originate from a 32km grid, and the statistical methods used to generate them cannot characterize local effects. gridMET's definition of a "day" is midnight-to-midnight, whereas many standard products (including those from the World Meteorological Organization) are 8:00 a.m. to 8:00 a.m. Pacific time; therefore, some differences may arise with reanalysis products.

gridMET's precipitation fields may contain inhomogeneities, making it inadvisable to use this for trend analysis in certain circumstances. The most recent 3 to 4 days use a different dataset to initialize some variables, so if the dataset was updated in near real time, the most recent days would not be consistent with the older data product. gridMET's surface radiation fields have a potential positive bias over much of North America (due to the original product being downscaled).