California Energy Commission
Draft Report

Long-term Risk Projections Baseline Needs Assessment Summary

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Table of Contents

1. Introduction

The impacts of wildfires in California have intensified in the past decades. Community development patterns near wildlands has increased the amount of wildland-urban interface (WUI) in the state. Climate change and past forest management has led to wildland fuel conditions that have increased the likelihood of fire behavior that exceed the predictive power of existing wildfire models (i.e., existing fire models underestimate the intensity and spread characteristics of wildfires observed in recent years). Expansion of the risk of high severity wildfires burning in developed urban areas in recent years has also expanded the spatial extent of what is considered WUI at risk from wildfire. Additionally, the impacts of wildfire on the investor-owned utilities' (IOUs) electric grid have resulted in increased costs, reduced safety, and weakened reliability to ratepayers — a situation that will likely worsen in a changing climate without improved mitigation strategies.

Wildfire science currently lacks sufficient information to forecast risk to natural and developed landscapes across California and is not able to predict extreme fire behaviors resulting from prolonged heat release by large woody fuels and deep duff layers typical of modern California forests. For long-term wildfire risk mitigation planning, there is a lack of a comprehensive modeling framework to make mid- to late-century projections of fire risk. Consequently, IOUs, State agencies and stakeholders relying on the electric grid lack scientifically robust information and actionable insights to make effective near-term tactical and long-term planning decisions.

One of the goals of this project is to develop updated wildfire models capable of producing long-term projections of various wildfire characteristics outputs that are relevant to end-users. In Phase 1 of the project, the project team will advance wildfire science by incorporating the dynamics of tree mortality fuels and weather information into updated wildfire models. The project team endeavors to develop computationally efficient and updated wildfire risk models to demonstrate the potential of the technologies to reduce the impacts of wildfire on the electricity grid. In Phase 2, the project team plans to integrate long term wildfire risk projection outputs into the Fifth Climate Change Assessment. The wildfire risk models developed as part of the project will be deployed on an open-source platform providing free access to IOUs and other stakeholders.

The purpose of this *baseline needs assessment* is to identify and document the needs of anticipated end-users of scientific results, model outputs and associated tools related to long-term wildfire projections. Anticipated users of project outcomes include investor owned electric utilities (IOUs), tribal land and fire managers, and various State and federal agencies with a role in either natural resources management and/or emergency services.

We reviewed relevant documents and met with IOUs and tribal, state and federal stakeholders in order to identify gaps and needs associated with long-term projection modeling efforts.

This summary addresses and is organized around the following areas related to baseline needs for long-term risk wildfire risk projections:

- Existing practices and current priorities for projecting fire risk at IOUs and a sample of State agencies,
- Information flow from risk projections to information providers (e.g., analyst at State agency) and to decision-makers (e.g., planning department at State agency),
- Planned and potential adaptation strategies to be incorporated into the fire risk projections,

- Scenarios for land-use change and urban/rural development,
- Climate Action Team's Research Working Group's objectives and needs for fire risk projections to support the Fifth Assessment, and
- Cal-Adapt's objectives and opportunities for communicating fire risk projection outputs.

2. Existing Practices and Current Priorities for Projecting Fire Risk at IOUs and Sample of State Agencies

Investor Owned Utilities

A review of available Investor Owned Utilities (IOU) Wildfire Mitigation Plans generally indicates that IOUs currently tend not to use information related to long-term (greater than 5 years out) wildfire risk projections to inform operations or to mitigate future wildfire risk, thus specific priorities or methodologies for projecting risk from these documents was lacking. More typically derived from these documents was generalized descriptions of utilities 'wildfire hazard and risk assessments approach and how it is used to inform shorter term (<5 years) wildfire mitigation actions and capital improvement planning. For example, according to their 2019 Wildfire Mitigation Plan, Pacific Gas and Electric (PG&E) has assembled an internal cross-functional team of professionals for projecting future wildfire risk. This team works in consultation with risk assessment professionals, management consultants, and other utilities in California, the United States, and Australia. PG&E, however, indicates it has an increasing focus on climate resilience and has an awareness of the threat climate change poses to crucial sectors of the U.S. economy and impact to and from the electricity grid. PG&E has identified the following primary climate change hazards to its business:

- Increased frequency and severity of storm events
- Sea level rise
- Change in temperature extremes and mean (average) temperatures
- Change in precipitation patterns and drought
- Increased wildfire frequency and intensity

State Agencies

CalFire and Office of Emergency Services

New State legislation, Senate Bill 209, requires the Office of Emergency Services and the Department of Forestry and Fire Protection (CalFire) to jointly establish and lead the Wildfire Forecast and Threat Intelligence Integration Center (WFTIIC), comprised of representatives from specified state and other entities. The bill requires the center to serve as the state's integrated central organizing hub for wildfire forecasting, weather information, and threat intelligence gathering, analysis, and dissemination and to coordinate wildfire threat intelligence and data sharing. The bill also requires the center to develop a statewide wildfire forecast and threat intelligence strategy to strengthen wildfire emergency preparedness and response, standardize the implementation of environmental monitoring and assessment, enhance forecasting and detection capabilities, maximize the use of science and technology, and expand public knowledge and awareness of wildfire risks. Planned outcomes from this project appear to be in alignment with this new law, where long-term wildfire risk projection model outputs and tools could be integrated into WFTIIC operations.

User engagement meetings with CalFire identified the following needs associated with long-term wildfire risk projection modeling:

- There is a need to collaborate on regional and statewide models for climate reconstructions. CalFire remarks that all the IOUs are relying on historical reconstructions of fire weather patterns using reanalysis modeling and numerical downscale models. However, there are questions about how these various products were developed, the consistency and comparability to other products for the same areas (e.g., WRF version, initialization and parameterization of variables, and post-process bias correction adjustments will all influence outcomes, boundaries and comparisons). Bias correction on winds is essential to match predictions with actual reliable measured data.
- Fire Hazard Severity Zone (FHSZ) mapping – The revised model for long-term fire potential based on fuel climax and severe fire weather patterns should include discrete dry wind into the model for mapping hazards in non-wildland land cover types. The next generation long-term projection model likely will have relevance for fire vulnerability modeling (e.g., providing projection of impacts to communities/populations, air quality, natural resource, utility assets, etc.). The improved spatial representation and incorporation of wind and relative humidity input data on hourly timescales, along with the greater integration with dynamic vegetation models, is expected to result in an enhanced ability to characterize risks of extreme fire events and the impact of diverse management strategies on climate change related fire risks.
- CalFire is primarily interested in the analysis and learning from large, extreme wildfire events, even events that pre-date the large increase in fire size and intensity (e.g., 2013 King Fire). A critical question is: *Can we manage large wildfires and/or mitigate their impacts*? Fire in urban and WUI areas is important, but also atypical wildfire behavior in the wildlands is important to forecast as well. This general topic is a large science gap - where data and analytics is lacking to adequately inform policy making.

- CalFire along with other organizations express needs related to the temporal resolution or time-cadence of outputs produced by long-term wildfire projection models. Most valuable would be having the ability to generate long-term wildfire activity outputs projected 1 to 3 years out - this capability would especially be important for informing State (and Federal) agency strategic/work planning documents. Projections capable of predicting wildfire outputs out 10 to 20 years was also identified as a need for longer term strategic planning. Wildfire forecasts beyond that is informative for climate change vulnerability and resilience assessments, but beyond typical planning horizons for most organizations interviewed. An important consideration for stakeholders, that will be incorporated into our outreach communications, is that most impacts from wildfire are accounted for by a relative handful of extreme events that are highly localized in time and space, and not well-represented by long term average risks. The modeling framework employed here allows us to simulate large numbers of individual extreme events under a wide array of future climate and land use scenarios. Our work will characterize what the upper range of extremes could look like under present and near-term conditions, as well as for longer term projections, and what the probabilities of these events are over different time horizons. An extreme wildfire event that might be relatively common after midcentury, could still occur now or in the near future, just with lower probability. CalFire and others need to plan for resilience to these extreme events, rather than for the most likely event or average conditions, especially given inherent uncertainties about near term climate.

California Department of Insurance

Through user engagement meetings, California Department of Insurance (CDI) indicated that a state-wide risk platform is needed. An example application would be tools that could be used to identify where the FAIR Plan program[1] could be offered in highest wildfire risk zones, as opposed to how it is currently applied on a more even distribution around the state. The gap needs to be filled between projecting fire over near- and long-term (3 to 5-year horizon). CDI needs data that can support the assessment of damage probability – for example, how many and what percent of homes will likely burn in a specific location at a period in time? Similarly, CDI needs wildfire risk data to support evaluating insurance company's requests to increase rates and distribution of policies. CDI indicated that they will need help from the project team in developing the appropriate questions to ask to evaluate vulnerabilities, location of structures, etc. and what information is needed to help CDI's review of insurers 'books.

In summary, a state-wide map of wildfire risk is needed to support CDI to regulate and set rules for insurance companies' rates and to contribute inputs into managing the FAIR Plan Program.

California Public Utilities Commission

The California Public Utilities Commission (CPUC) has recently created a Wildfire Safety Division (WSD) charged with addressing the growing wildfire risk associated with electric utility infrastructure. In 2021, the WSD will transition to the California Natural Resources Agency (CNRA; per AB 1054 and AB 111), where the WSD mission will continue as the Office of Energy Infrastructure Safety (OEIS). To direct their efforts, the WSD is seeking to define longer-term objectives that can support the WSD, IOUs, and other relevant stakeholders in working toward both near-term and longer-term solutions.

As part of this transition, the CPUC commissioned a consultant to develop a *Utility Wildfire Mitigation Strategy and Roadmap for the Wildfire Safety Division* report[2]. In this draft report, it is recognized that a culture shift towards long-term adaptation and resilience has not yet been realized in utility wildfire prevention. Instead the draft report indicates that utilities continue to prepare for the next wildfire season – notably on forecasting Public Safety Power Shutoff (PSPS) events or otherwise reducing the likelihood or preventing electric utility associated ignitions. While short-term actions are an important element for prevented utility-related wildfires, WSD recognizes that efforts are needed to develop and integrate longer term projection information into utility Wildfire Mitigation Plan efforts. The draft report identifies that future WSD activity needs to focus not only on what should be done next year, but also on what is required to prepare for the next 10, 20, or 30 years to mitigate risks associated with wildfire. One of the four action items identified in the draft report includes developing a data and analytics strategy to *enable information sharing across stakeholders to support processes such as the WMP*

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[1] The FAIR Plan (https://www.cfpnet.com/) is an association comprised of all insurers authorized to transact basic property insurance in California. Coverage is available to all California property owners, provided submission guidelines are met. The FAIR Plan provides insurance as a last resort and should be used only after a diligent effort to obtain coverage in the voluntary market has been made.

[2] BCG. 2020. Reducing utility-related wildfire risk: utility wildfire mitigation strategy and roadmap for the wildfire safety division (Draft). https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/WSD/Report_WildfireMitigationStrategy_WSD_DRAFT_vF.pdf. Accessed May 2020.

evaluation in the near-term, and drive analytics in the longer-term that will support prevention, response, and recovery activities.

3. A Diagram of the Information Flow from Risk Projections to Information Provider (e.g., analyst at State Agency) to Decision-Maker (e.g., Planning Department at State Agency)

The best example from a State agency of information flow to decision-making we found comes from a Draft CPUC-WSD Report[3]. In this report, State legislation that created *Wildfire Forecast and Threat Intelligence Integration Center* (SB 209, Dodd) is referenced as a "promising development" because the centers mission is to collect, assess and analyze fire weather data, atmospheric conditions and other threat indicators information that could systematically lead to on-the ground and policy decisions to mitigate utility associated ignitions that turn into large wildfires. The Draft CPUC-WSD Report used Wildfire Mitigation Plans (WMP) as the focal program to illustrate their proposed data to the decision-making structure.

Wildfire Mitigation Plans are the primary mechanism that the CPUC-WSD uses to hold utilities accountable for reducing wildfire risk and the use of Public Safety Power Shutoff (PSPS). To frame the proposed decision-making structure, WSD established "principals" for utility wildfire mitigation activities, including:

- Effective and inclusive coordination among stakeholders to deepen collaboration with communities, research institutions, applicable State agencies and other stakeholders as part of their data sharing, fire prevention and mitigation strategies.
- Provide for localized perspectives to adapt mitigation activities.
- Maintain a long-term resilience planning perspective
- Adopt data-supported decision making as core tenet for risk-informed natural disaster preparedness and response.

The four principles are considered essential building blocks for WSDs approach to evaluate and assess utility compliance with regulations designed to reduce wildfire risk. In addition to these principles, and before pursuing actions, WSD has articulated the vision and objectives for the organization, and problems to be solved through the decision-making process.

With respect to the proposed WSDs decision-making process, a "Long-term Use Case" is presented in Appendix 3 of the Draft CPUC-WSC Report[4] - where WSD wants to be in the future, after other critical data strategy components are put in place (Figure 1). The process is designed to fulfill WSD proposed vision: "*to utilize the richness of data and possibilities of insights to make well-informed utility safety regulation decisions that are actionable, accessible, aligned, and auditable.*" According to the WSD

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[3] BCG. 2020. Reducing utility-related wildfire risk: utility wildfire mitigation strategy and roadmap for the wildfire safety division (Draft). https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/WSD/Report_WildfireMitigationStrategy_WSD_DRAFT_vF.pdf. Accessed May 2020.

[4] BCG. 2020. Appendix 3. Utility wildfire mitigation data strategy. Utility Wildfire Mitigation Strategy and Roadmap for the Wildfire Safety Division (Draft). https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/About_Us/Organization/Divisions/WSD/Appendix_3_DataStrategy_WSD_DRAFT_vF.pdf. Accessed May 2020.

report[4], the process laid out in Figure 1 would enable the WSD to review WMP submissions and determine whether utilities have allocated resources optimally to decrease utility-related wildfire risk, in the highest need areas, by estimating:

- **Residual risk level by location:** Baseline utility wildfire risk level in a location or zone (assuming no mitigation measures).
- **Risk reduction impact by measure in each location:** Degree to which a given measure lowers utility wildfire risk for the area of interest, multiplied by the number of years the measure is effective.
- **Risk-spend efficiency (RSE) by measure in each location:** Ratio of risk reduction efficacy to the cost of such measure.

To implement this process, the WSD will need to be able to access and utilize a well-organized data that includes risk drivers (e.g., climate, forest fuels, vegetation, topography, asset conditions, and maintenance practices), historical wildfire ignitions related to utility infrastructure, and the realized impact and cost-effectiveness of different mitigation measures. Advances in data-gathering and analytics procedures have the potential to change how decision-makers receive intelligence, coordinate activity with partners, and provide greater transparency to CPUC and stakeholders – and better inform policy and regulatory decisions.

Interpreted from Figure 1, the process begins with risk assessments (e.g., long-term wildfire risk projections from this project), stakeholders (e.g., wildfire management agencies, CPUC-WSD, fire safe councils), and utilities. Wildfire risk maps are prepared for locations of interest, along with risk reduction estimates that can be achieved and cost estimates for different mitigation measures. In the diagnostic stage, a prioritized list of mitigation measures is prepared based on level of risk, risk reduction potential, and cost of risk reduction. Through this process, decisions on what mitigation should be implement at different locations can be made by the CPUC, supported by consultation and concurrence with stakeholders and others engaged during the process.

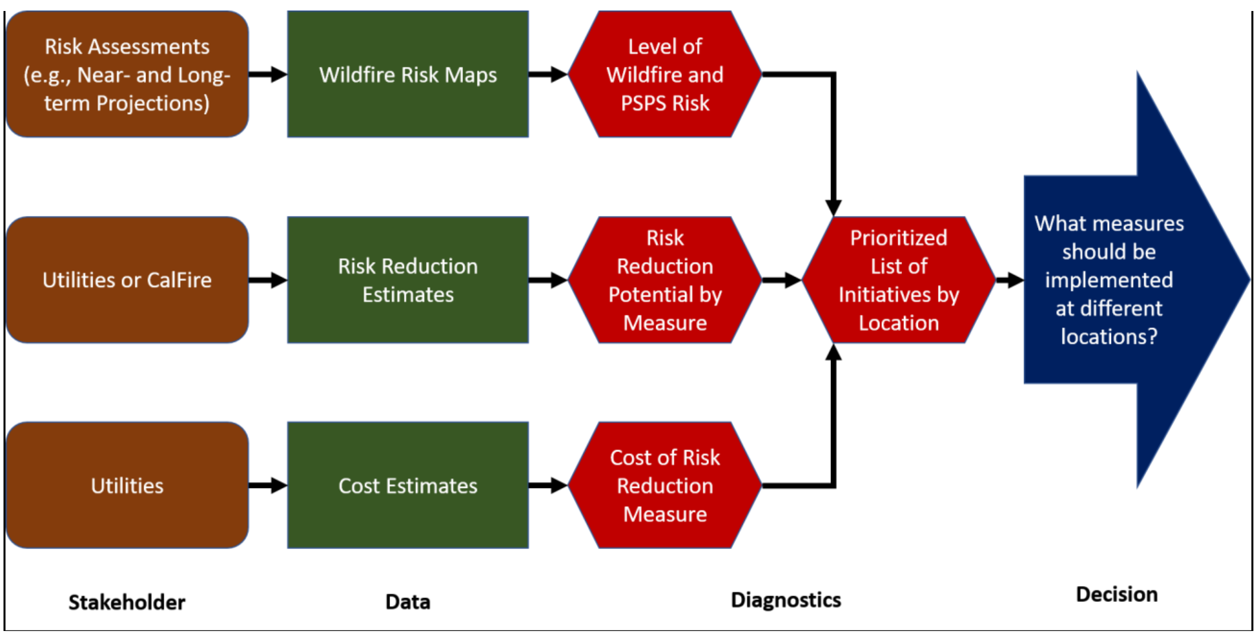

Figure 1. Proposed decision-making process to optimize the selection and implementation of wildfire risk reduction measures for electric utilities.

4. A Review of Planned and Potential Adaptation Strategies at IOUs to be incorporated into fire projection models

Information on planned and potential adaptation strategies was gathered from stakeholder/user engagement efforts and through the review of relevant documents (e.g., utility wildfire mitigation plans, forest planning guidelines and documents).

Utilities

Adaptation strategies identified in WMP by utilities that are relevant to long-term wildlife projection modeling included:

- Vegetation Treatments - Fuels reduction activities along transmission and distribution corridors that co-occur in area deemed to have a high wildfire threat (e.g., lands designated by CPUC as Tier 2, Tier 3 and High Fire Threat Districts). Most utilities suggest a 3,000-foot buffer, within which different treatment intensity would occur – the highest treatment intensity (i.e., tree removal) occurring within the utility corridor itself, sheltered fuel breaks thereafter.
- System Hardening - and improvements design to reduce or eliminate electric utility associated ignitions.
- Operational Practices **-** Specific to the operation and setting of equipment, modification to the operational mode of automatic reclosers at appropriate times and locations during fire season and location.
- Inspection and Maintenance **-** inspection and correction programs designed to identify and correct situations in which the infrastructure may no longer be able to operate per engineered specifications.
- Public Safety Power Shut-off (PSPS) **–** Fire threat zones, terrain, potential for impact to WUI/populations, fire history, fuel characteristics and climate/weather are used to determine de-energization zones. These factors are used to inform PSPS decisions.

CalFire

CalFire has identified five general forestry strategies for reducing or mitigating greenhouse gas emissions, including:

- Fuels reduction treatments to reduce wildfire risk surrounding communities and wildfire emissions.
- Reforestation to sequester more carbon.
- Forestland conservation to avoid forest loss to development.
- Urban forestry to reduce energy demand through shading, increase sequestration, and contribute biomass for energy generation.
- Improved management to increase carbon sequestration benefits and protect forest health.

Federal Agencies and Tribes

Federal agencies and Tribes work with utilities to implement wildfire risk reduction measures on managed lands, for example:

- Vegetation treatments with 3,000 feet of utility infrastructure.
- Utility system hardening.

- Fuel reduction treatments implemented in strategic locations surrounding WUI (within 1.5 mile of developments).
- Currently exploring policy options for more prescribed/managed burning to reduce fuel loads outside of the WUI.

5. Review of Third-party Scenarios Used for Land-use Change and Urban/Rural Development

Through a user engagement meeting with representatives from California's Strategic Growth Council and Governor's Office of Planning and Research, our workgroup learned that additional interactions are needed to pin down land-use change and urban/rural development scenarios for long-term modeling. Internal discussion amongst workgroup members has generally outlined scenarios for long-term modeling associated with population growth, urban land use and development and wildfire mitigation, including:

Human population growth projections scenarios:
- Status que
- Decrease
- Increase

Potential urban land use/development scenarios:
- Compact/infill mixed-use development
- Status que urban development
- Expanded urban sprawl (into forested WUI and agricultural lands)

Wildfire mitigations scenarios:
- Status que forestry and vegetation treatments on state and federal lands
- Increased/decreased forestry and vegetation treatments on state and federal lands surrounding WUI.
- Increase/decrease in electric utility corridor fuel treatments
- Increase/decrease of land allocation for conservation
- Combinations thereof

Studies Reviewed

Two studies were reviewed to illustrate how future land use scenarios have been developed, including one for the United State Geological Survey (USGS) and one from Environmental Protection Agency (EPA).

USGS - *Future Scenarios of Land Change Based on Empirical Data and Demographic Trends*[5]

[5] Sleeter, B. M., Wilson, T. S., Sharygin, E., and Sherba, J. (2017). Future Scenarios of Land Change Based on Empirical Data and Demographic Trends, *Earth's Future*, *5*, 1068–1083, https://doi.org/10.1002/2017EF000560

The goal of this study was to develop an approach for projecting changes in Land Use Land Cover (LULC) based on land use histories and demographic trends. For this project, a set of stochastic, empirical-based projections of LULC change were developed for the state of California, for the period 2001–2100. Land use histories and demographic trends were used to project a "business-as-usual" (BAU) scenario and three population growth scenarios. For the BAU scenario, projected developed lands would more than double by 2100. When combined with cultivated areas, researchers projected a 28% increase in anthropogenic land use by 2100. As a result, natural lands were projected to decline at a rate of 139 km^2 yr^{-1}; grasslands experienced the largest net decline, followed by shrublands and forests. The amount of cultivated land was projected to decline by approximately 10%; however, the relatively modest change masked large shifts between annual and perennial crop types. Under the three population scenarios, developed lands were projected to increase 40–90% by 2100. Study results suggest that when compared to the BAU projection, scenarios based on demographic trends may underestimate future changes in LULC. Furthermore, regardless of scenario, the spatial pattern of LULC change was likely to have the greatest negative impacts on rangeland ecosystems.

Environmental Protection Agency - *Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines (Final Report)*[6]

This report describes the scenarios and models used to generate national-scale housing density scenarios for the conterminous US to the year 2100 as part of the Integrated Climate and Land Use Scenarios (ICLUS) project.

Climate change interacts with existing and future land uses, such as residential housing and roads. Up to now, there have been no scenarios of land-use changes for the U.S. that are consistent with the storylines of population growth, greenhouse-gas emissions, and socio-economic changes used by climate-change modelers. The lack of these consistent scenarios has impeded progress of integrated assessments of climate and land-use change on endpoints of concern, such as water quality, aquatic ecosystems, air quality, and human health. The ICLUS project created an initial set of housing density scenarios.

This EPA report describes the methods used to develop land-use scenarios by decade from the year 2000 to 2100 that are consistent with these storylines. A demographic model feeds the population projections into another model that distributes new housing across the landscape. The scenarios cover the 48 contiguous U.S. states. The report also describes the conversion of housing density to impervious surface cover and provides an initial analysis of changes in watersheds across the United States. Other analyses include regional trends in population growth and in housing density. This final report provides technical modeling details and describes potential next steps to integrate climate change variables into the model.

[6] U.S. EPA. Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines (Final Report). EPA/600/R-08/076F, 2009.

6. A Review of Climate Action Team's Research Working Group's Objectives and Needs for Fire Risk Projections

A review of The Climate Action Team Report Brief on Climate Change Research Plan for California[7] builds on past research. The research plan is framed around the follow goals for California including:

- Reducing GHG emissions
- Preparing for impacts resulting from climate change
- Conducting research that informs policy

Research questions included in the plan that are relevant to fire risk projections being developing under this project fall under following categories and associated questions:

- Monitoring
    - How is climate changing in California?
    - What monitoring strategies and capabilities will be necessary to track variations and changes in climate, including extreme events?
    - What improvements in climate modeling are needed to support vulnerability assessments that lead to better adaptation planning at multiple levels and across sectors?
- GHG Emissions
    - What are the most effective strategies and technological innovations to significantly reduce GHG emissions in all sectors of the economy?
    - What are their economic, public health, and environmental impacts and co-benefits?
- Climate Change Risks
    - How vulnerable are the people, resources, and infrastructure of California to climate change impacts?
    - How is this vulnerability distributed among groups and geography?
    - What are the most effective strategies and technological innovations to safeguard California from these impacts?

The Research Plan places a priority on answering how to create healthier forests for both mitigation and adaptation purposes. The research plan recommends the following:

- Using higher resolution data and downscaled climate data such that long-term projections are more useful for local decision makers.
- Developing improved accounting methods for carbon stocks on California lands to determine if a less dense forest stores more carbon than the currently overgrown forest.
- Exploring other ways in which climate change would affect public health, investigating options to ameliorate realization that climate change must be considered in long-term planning for State resources, such as water supply, energy generation, and ecosystem impacts.
- Studying forecast-based interventions that could be used to reduce the health and economic impacts of wildfires.
- Studies are needed to allow in-depth estimation of economic costs and benefits related to the implementation of risk management strategies.

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[7] CalEPA: Climate Change Research Plan for California (2015) *Climate Action Team: Report Brief.* *https://research.fit.edu/media/site-specific/researchfitedu/coast-climate-adaptation-library/united-states/west-coast-amp-hawaix27i/california---statewide/Brown--Rodriquez.--May-2015.--CAT-Research-Plan.pdf*

- Crosscutting issues require more attention in climate change studies – for example, disadvantaged communities and certain racial/ethnic groups could experience disproportionate public health risks and economic burdens resulting from the effect of climate change.
- Research that supports planning for extreme weather-related events – what are the best options to prepare for, respond to, and recover from these events?

7. A Review of Cal-Adapts Objectives and Opportunities for Communicating Fire Risk Projection Outputs

Cal-Adapt (http://cal-adapt.org/) was launched in 2011 to address the scarcity of readily accessible scientific information to illuminate local climate risks in support of adaptation initiatives and planning efforts. Drawing from California's peer-reviewed, State-sponsored climate change research, Cal-Adapt is an interactive website that allows users to explore climate risks associated with low- and high-emission scenarios, projected temperature changes, wildfire risks, sea level rise, and snowpack at the local level. All data presented are freely available for download to support further analysis. California's recently released Adaptation Planning Guide directs users to Cal-Adapt, which has established itself as a primary tool enabling resource managers; city, county, and tribal governments; and other public and private decision-makers to find locally relevant information to facilitate planning for climate risks. Here we briefly describe how the Project Team workflow and product development pathway can leverage existing Cal-Adapt resources, and where technical challenges may require the Project Team to look outside of Cal-Adapt.

Cal-Adapt serves two primary purposes: (1) public facing tools for the visualizations of climate information and (2) a centralized repository for State sanctioned data products. As such a repository, Cal-Adapt maintains the capacity to store up to 200TB of climate and environmental data to be served via three delivery pathways: (1) direct download via FTP, (2) access via an API and (3) an interactive download tool. We view storage and dissemination of data products produced during this project as both feasible and desirable, as key stakeholders will look to Cal-Adapt as a source of climate information by default. Our data products will be formatted in Cal-Adapt friendly formats of netcdf or geoTIFs (reference to Cal-Adapt data transfer plan if appropriate), making transfer to the repository straightforward. Project Team members will be provided with Cal-Adapt's metadata requirements (after being made available to project management) well ahead of submission deadlines so that our team can produce data products that will easily sit within the Cal-Adapt data architecture.

Tools and visualizations produced within this project cannot be directly transferred to Cal-Adapt. Cal-Adapt has a closed development procedure, in which the platform developers do not make publicly available the architecture and coding requirements for tools. Therefore, the Project Team cannot design tools to Cal-Adapt specifications, as they are not publicly available. A second limiting factor is that Cal-Adapt is developed primarily in Python while our Project Team scientists are expected to utilize languages beyond Python (i.e. R, java, c++), precluding direct incorporation into the Cal-Adapt platform. We propose to produce each tool and visualization in an open source, container like procedure so that the Cal-Adapt team can utilize the code base in their closed development environment on their own development schedule. Outreach and coordination with the Cal-Adapt team could be helpful, but absent a change from closed development environment of the platform, technical challenges are unlikely to be overcome through such discussions, and development and hosting of tools external to Cal-Adapt will be necessary to bring the tools online in the timeframes specified in the Agreement.

8. Conclusions

Our conclusions focus on the long-term fire and vegetation model developments planned for this project to support California's Fifth Climate Change Assessment. Enhancements attempt to address several of the baseline needs identified by the project team and input provided through user engagement interviews. Updates will encompass multiple improvements in datasets and model outputs that will improve the ability of fire projections to better represent changes in extreme events and their impacts. The following highlights planned enhancements to the long-term wildfire projection modeling effort.

Improvements to data inputs

- The spatial resolution of the gridded historical and downscaled projected climate data is changing from a 1/16th degree lat/long grid to an anticipated 1/32nd degree lat/long grid. The grid will be an Albers projection centered on California, with constant area in each grid cell, whereas the projections used in previous assessments had the area per grid cell vary by latitude. A fixed number of 30m pixels with a uniform coordinate system is nested within each 1/32nd degree grid cell, which facilitates linking data sets with different spatial resolutions and modeling at multiple spatial resolutions.

- The temporal resolution of the gridded historical climate data and downscaled projected climate data are anticipated to be hourly, rather than daily as was the previous practice. This is facilitating modeling that has the potential to better represent extreme conditions that drive rapid fire spread, allowing fire projections in turn to better represent extremes in wildfire.

- Gridded historical and downscaled projected climate data are anticipated to include hourly 1/32nd degree windspeed and direction, and relative humidity, in addition to the temperature and precipitation variables previously included. Wind and relative humidity data at these resolutions is extremely important for capturing extremes in fire.

- In the absence of a validated, comprehensive, historical hourly 1/32nd degree gridded climate data set to be used as a reference for both model development and climate projection downscaling, we are using the 1/24th degree GridMet data developed by Dr. Abatzoglou. These data have been interpolated to the 1/32nd degree grid to support model development and testing. Creating an historical reference data set that meets the needs of both the fire and vegetation modeling communities, and the climate projection downscaling team (to be awarded under a current CEC RFP), is a critical unmet need.

- Historical fire data have been updated and extended from what was previously available. For the 1st, 2nd and 3rd state climate assessments, documentary point fire records were used. For the 4th assessment, Monitoring Trends in Burn Severity (MTBS) geospatial records mapping fire severity at 30 m were used. MTBS melds algorithms that estimate severity from satellite imagery some documentary information about individual fires. Fire severity is calculated with different parameterizations for different vegetation types, with extensive manual correction of modeled severities undertaken by individual operators. This means there is no uniform approach to calculating severity across vegetation types, and even within vegetation types, operator-specific differences may arise. We developed and are testing algorithms for uniform, automated estimation of severity for fires in California to be used for fire and vegetation model development and testing.

Improvements to Fire Risk Simulation Model (FRSM)

- The domain of statistical fire modeling is expanding to include all of the WUI. Prior iterations excluded local protection responsibility areas (LRAs), whereas recent large severe wildfire events have burned extensive areas within communities that were excluded as part of the LRA for fire protection. The LRA is not masked out in the modeling updates.

- Fire simulations from models parameterized on historically observed conditions need to be constrained when applied to climatic conditions outside the range of historical observations, because the relationship between climate and fire is nonlinear and the response of these models to novel climate conditions cannot be validated against observations. One aspect of this is that modelers do not have an empirical guide for what the maximum fire size should be under novel future conditions. Consequently, prior simulations used the 2013 Rim Fire in California as an upper limit on fire size, as this was the largest known fire in observed or reconstructed fire histories for the state. However, we have observed multiple fires exceeding this previous record by a significant amount in the last few years, and the average area burned from fire simulations is sensitive to the maximum fire size. We are updating our approach, first producing fire simulations without imposing a maximum on the extent of individual fires, and then post-processing these situations with a range of assumptions about possible max fire sizes extrapolating from recent observations.

- Simulated area burned in previous model iterations tended to under-predict the size of the very largest fires in the observed record. The processes that govern the extent of the most extreme fires may be different from what drives the size of more moderate fires, whereas very few examples of the most extreme fires were available in the historical records available for model estimation supporting previous assessments. Drawing on the assessment of historical fires undertaken by working group 1 and taking advantage of both additional years of data with more extreme conditions, the finer spatial and temporal scales of the input data, and the availability of validated wind and relative humidity, we anticipate that the models under development may better represent the most extreme fires in the record, which are expected to become more common in the future.

- Statistical fire models previously simulated fire presence, number and size monthly at 1/8th and 1/16h degree resolutions. Updated models are simulating fire presence, size, and severity (low, moderate, high and other) at 1/32nd degree resolution. Fire number is no longer needed as a separate modeling step, as the finer spatial and temporal resolutions for modeling preclude multiple large fires originating from the same grid cell in a single time step. We are experimenting with a bimonthly time step, and final simulations will either be monthly or bimonthly. Simulations will also be summarized at 1 km resolution to facilitate input into the LUCAS vegetation model.

- Previous statistical modeling also included an experimental methodology for downscaling high severity burn area from observed and simulated fires to 30 m resolution in Sierra Nevada forests. Model updates are extending this methodology to all vegetation types across the state, and downscaling low, moderate, high and other (unburned, increased greenness, barren, etc) for each fire at 30 m. The exact number of scenarios and simulations per scenario that will be downscaled will depend on data storage and computation capacity constraints.

- Emissions were estimated for fires simulated on a 1/8th degree grid, both statewide and for Sierra Nevada forests, using scenarios and fire simulations from the 3rd State Climate Assessment. Model updates for the 5th Climate Assessment have revised the fuel consumption and pollution emissions parameterizations for vegetation types across the state using the latest literature and field data, implementing these at 1/16th and 1/32nd degree resolutions, and comparing to an implementation at 30m resolution, for all large historical fires burning in the state since 1984. Prior models made strict assumptions about fire severity and provided a broad range of possible emissions values for a comprehensive suite of pollutants, whereas the current update incorporates observed or simulated fire severity combined with coarse vegetation characteristics to more accurately estimate emissions.

LANDIS model improvements and integration with FRSM

- LANDIS-II integration with simulations from statistical fire models used simulated area burned to parameterize fire size distributions within the model, using simulations at 1/8th degree spatial resolution. We are using a similar approach for updating these models but taking advantage of greater temporal and spatial resolution of data. Also, most of the integration of LANDIS-II with statistical fire models was one-directional before this: fire simulations were used to update fire spread parameters every 10 years, but the resulting changes in fuels did not feed back into the fire risk models, except for a limited set of scenarios on three transects through the Sierra Nevada due to constraints on data and processing capacity. We are working on porting LANDIS-II code to run on a more powerful data processing platform, as well as looking at the potential to improve computational efficiency required by the LANDIS-II simulations, with the goal of running a broader suite of scenarios over a larger area.

- LANDIS-II was parameterized for Sierra Nevada tree species, with no representation of competition from shrub species post-fire, for the entire mountain range. The current implementation is incorporating competition from shrubs, which is expected to further reduce forest area at low to mid elevations and influence fire behavior as demonstrated by a watershed-scale study in the Sierra Nevada that included shrubs.

- LANDIS outputs include biomass, above and below ground carbon, species level information on number and age of cohorts, fire number, area burned, and severity.

LUCAS model improvements and integration with FRSM

- LUCAS integration with statistical fire models was also previously unidirectional: a static fire risk layer was created from simulated area burned and incorporated into LUCAS. The current iteration of the modeling will incorporate periodic updates to the fire risk layer derived from the simulated area burned, and we are testing biomass and fuels characteristics layers generated from LUCAS as predictors of fire presence, extent and severity in statistical fire models.

- The version of LUCAS that will be used to support simulations for the fifth climate assessment incorporates improvements that allow realistic simulations of above and below ground carbon and fuel characteristics, and incorporates more realistic depictions of development footprints in the WUI, than what was available for the 4th state climate assessment. Specific updates to the LUCAS model include:
    - Expansion of the land use/cover classification scheme to better represent the diversity and variability of California ecosystems. The forest class has been expanded to include up to 24 forest type-groups as defined by the U.S. Forest Service; shrublands have been

expanded into three classes; and development is now classified based on impervious cover using the National Land Cover Database classification scheme.

- Carbon storage and flux modeling will now be based on methods developed for the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) as opposed to the process-based Integrated Biosphere Model (IBIS). The use of the CBM-CFS3 structure within LUCAS allows for significantly greater detail in the tracking of carbon flows through a range of live and dead organic matter pools which will improve our ability to provide estimates of changes in fire fuels.
- Future land use scenarios will now be based on Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). Additionally, future scenarios will explore a range of natural climate solutions (NCS) designed to meet California's greenhouse gas reduction targets.
- LUCAS results will also be provided within a web-based interactive dashboard.

Urban Landuse and Forest Management Scenarios

- A critical need is for consensus from IOUs and state agencies on the range of fuels management scenarios and the range of development footprint scenarios to be incorporated into modeling for the 5th Assessment. The modeling team proposes to incorporate scenarios that represent bounding extremes on what is likely to occur, as well as "business as usual" scenarios that lie in between these extremes. Policy makers, managers, and investors may hold other preferences that would need to be accounted for early in the development of scenario datasets.