California's Fourth Climate Change Assessment: Conceptual Sketches of Projects for the Non-Energy Research Portfolio

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Introduction

California's leadership in climate change policy is built on a strong foundation of research addressing the changing climate's impacts on the state as well as strategies to dramatically reduce greenhouse gas emissions. The State's research agenda, in turn, responds directly to policy needs related to safeguarding California from climate change impacts and reducing greenhouse gas emissions responsible for climate change.

California's recently released *Climate Change Research Plan*[1] articulates near-term climate change research needs to ensure that the State stays on track to meet its climate goals. The Fourth Climate Change Assessment is the first inter-agency effort to implement a substantial portion of this *Climate Change Research Plan*. The Fourth Assessment builds on the success of three prior assessments to address California-specific policy questions and information needs. The Fourth Assessment is being supported through two funding streams, one managed by the California Energy Commission and another managed by the California Natural Resources Agency (CNRA). The former focuses on energy-related research needs and the latter on non-energy research needs. This proposed research focuses on the CNRA-managed, non-energy funding stream.

This document identifies the key research themes included in the Fourth Assessment and provides detailed conceptual sketches of projects included in each theme. Additionally, this document indicates how the proposed research portfolio will be integrated with a suite of energy-related studies that will also support the Fourth Climate Change Assessment but draw on different funding sources from the projects identified here. This document is ultimately intended to supplement the Request for Proposals (RFP) to be released by the Berkeley Energy and Climate Institute on behalf of the California's Natural Resources Agency.

The research portfolio organizes research projects into seven themes, namely:

1. Climate Change, Habitat, and Wildfires: Impacts and Management Options
2. California's Working Lands: Carbon Sequestration for Adaptation and Mitigation
3. Sea Level Rise, California's Coast and Ocean Ecosystems
4. Water Security and Long Droughts
5. Forecasting to Support Climate-Resilient Decision-Making
6. Preparing for Emergency Management in a Changing Climate
7. Funding Adaptation Projects and Measures in California

Each of these themes is described below along with a description of proposed research projects in each area. Each description also includes a figure that illustrates how the work of the California Energy Commission-funded work and CNRA-funded work are being integrated to address the research theme.

To ensure that 4th Assessment research results are internally consistent and amenable to cross-sectoral integration, all research projects will use a common set of primary (climate, sea level rise, socioeconomic, and

[1] http://www.climatechange.ca.gov/climate_action_team/reports/CAT_research_plan_2015.pdf

land-use) as well as secondary (e.g., wildfire) scenarios. The following considerations will apply to scenario use and development:

- Both energy and non-energy research projects will use primary scenarios of projected climate change (including sea level rise), socio-demographic factors, and land use developed through planned and ongoing research supported by the California Energy Commission;
- The California Energy Commission will engage all agencies and researchers involved in the Fourth Assessment in selection of representative climate scenarios;
- California's Ocean Protection Council and Coastal Conservancy will work very closely with the California Energy Commission in developing primary sea level rise scenarios;
- Additional secondary scenarios will be needed (e.g., projected changes in wildfire risks), and the California Energy Commission will be involved with funding secondary scenarios for use in both energy and non-energy research projects.

The climate and sea level rise scenarios are being developed for California's 4th Climate Assessment by the Scripps Institution of Oceanography. Their researchers have developed a new statistical technique for downscaling global climate models to regional scale suitable for California assessments and adaptation planning. This technique, known as Localized Constructed Analogs (LOCA), funded by the California Energy Commission is a substantial advance from previous downscaling methods because it is better at simulating extreme events and producing more realistic geographical distributions of precipitation. For the 4th Climate Assessment, Scripps will be enhancing the prior work done with LOCA by adding the simulation of additional variables such as relative humidity and wind velocity. In addition to new climate change projections, they will be developing probabilistic sea level rise projections and drought and wildfire scenarios. Scripps researchers will coordinate with other researchers in the 4th Assessment to ensure that scenario products meet their needs to the maximum extent practical.

Research Themes and Project Conceptual Sketches

1. Climate Change, Habitat, and Wildfires: Impacts and Management Options

Interactions between changing wildfire regimes, habitat, and landscapes will impact several sectors, including California's insurance industry, public health, the energy sector, as well as urban users of natural resources. Ecological resources will also be affected by climate change, and forest management practices must evolve to contend with projected changes in wildfire risks in California.

Research is needed to shed light on the magnitude, timing, distribution, and economic implications of these changes and to inform management decisions at the state and local levels. Studies in this area will leverage a common set of "secondary" wildfire scenarios that are based on the most up-to-date downscaled climate projections for California (see Figure 1).

CLIMATE CHANGE, HABITAT, AND WILDFIRES

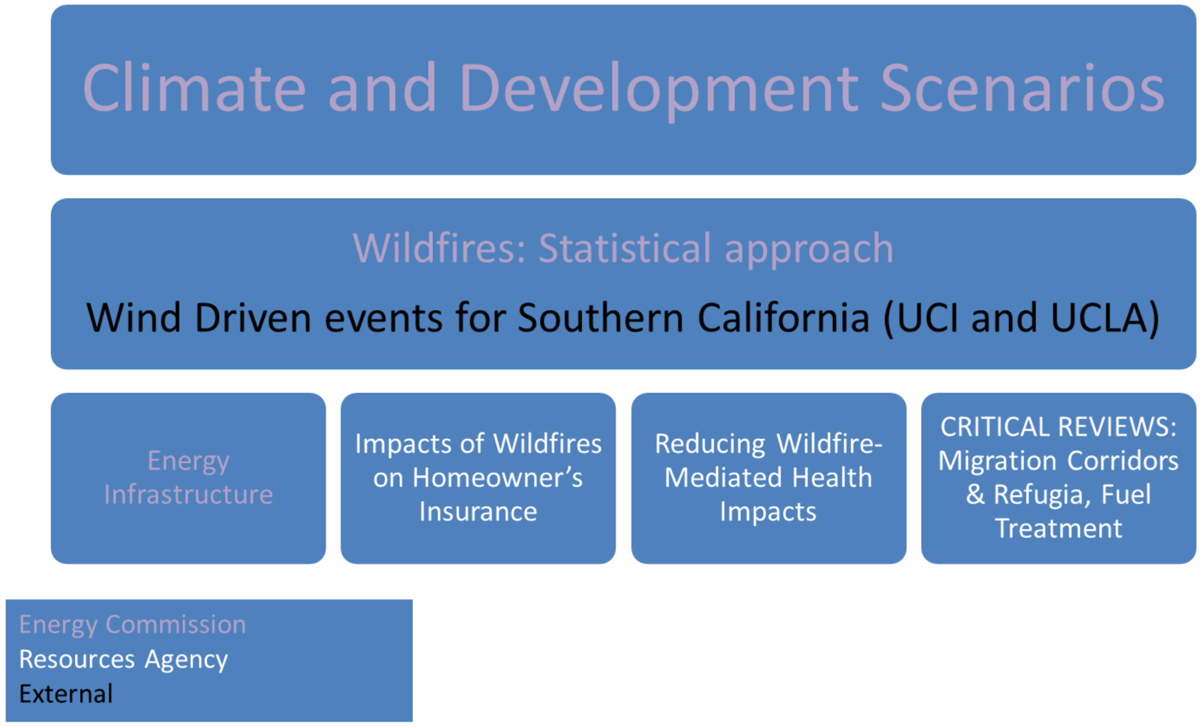

Figure 1: Research projects in the area of "climate change, habitat, and wildfires" will draw on a common set of wildfire scenarios (middle tier) that are derived from climate and development scenarios developed by the California Energy Commission in collaboration with California's Natural Resources Agency as well as other state agencies involved with the Fourth Assessment.

As an example, of the external products that will be available for the Assessment, please check the following publication from researchers at UCI, UC Davis, UCLA, and JPL (Jin et al. 2015).[2]

A. Impacts of Wildfires in California on Homeowners' Insurance

Goal: This research will inform policymakers of additional steps needed to protect against the risk of wildfire-mediated insurance losses and will assist insurers in maintaining affordable and available coverage where and when this is possible, and encourage coordination to address changing risks and potential market failures. The research will make use of updated climate scenarios and regional wildfire projections to estimate when the homeowners' insurance market may start to be significantly impacted by the effects of climate change. The research will also analyze the likely set of industry responses, including changes in rates and availability.

Problem Description: Climate change represents a significant challenge for the insurance industry and consumers. Accordingly, it is essential to assess, and to the extent possible, protect against the impact climate

[2] http://iopscience.iop.org/article/10.1088/1748-9326/10/9/094005/pdf

change will have on insurers and consumers. The most significant losses resulting from climate change that can affect the insurance industry and consumers in California are from wildfires. While it is understood that climate change will result in increased wildfire events, there has been no research on the future affordability and availability of insurance to assist homeowners and their communities recover after a wildfire event. Without this knowledge, California may not be able to adequately plan for recovery following wildfire events.

Proposed Work: Communities rely on affordable and available property and casualty insurance to rebuild and re-establish themselves after catastrophes. When risks are too great or undefined, insurers may withdraw from at-risk market segments, increase prices, or limit coverage, and this creates undesirable societal vulnerabilities. Today, climate change is causing an increase in the frequency and severity of wildfires. For insurers providing fire and homeowners insurance, this increase will affect rates and underwriting. But, there is little information available to understand when and where it is likely that climate change will cause homeowners' fire insurance rates to significantly increase or when the risk of wildfire may be too great for insurers to assume.

The lack of affordable and available insurance may have wide-ranging effects for homeowners and their communities. Generally, mortgage companies require homeowners to maintain homeowners' fire insurance during the life of their loans. Some homeowners may be unable to comply with that requirement without resorting to the California Fair Plan. The Fair Plan issues homeowner's insurance as a last resort when coverage in the voluntary market is unavailable. However, it is usually more expensive and provides less coverage than a standard homeowner's policy. Moreover, as the risk of fire increases, the Fair Plan's rates will increase accordingly and may become so prohibitively expensive that homeowners may find that they can no longer afford any insurance. Indeed, homeowners whose mortgages are paid may choose to go without insurance at all. This puts the recovery of communities of affected homeowners at risk.

Effective insurance regulation must strike a balance between allowing insurers to earn a return on their business activities while ensuring their solvency in the event of major losses, and maintaining the affordability and availability of insurance for the public. Continued investments in climate science can help improve data and risk analysis supporting the insurance industry.

This research should integrate climate change scenarios and regional wildfire projections with insurance modeling to estimate when the homeowners' fire insurance market may start to be significantly impacted by the effects of climate change and the likely set of industry responses, including changes in rates and availability. Applications should address the following areas:

1. Climate Change and Wildfire Projections: In alignment with other 4th Assessment studies, use California-specific wildfire modeling and current climate projections to assess the risk of future wildfire events associated with various time horizons.

2. Modeling of Losses: Calculate the range of potential losses from forecasted events, using one or more industry-accepted wildfire models that reflect insurance industry exposure information. This effort may also consider how the maintenance of defensible space and fire planning can enhance the ability to obtain and maintain homeowners' insurance in high-vulnerability spaces.

3. Impact on Insurance Affordability & Availability: Analyze the impact of such losses on the insurance industry and the likely set of industry responses. To the extent possible, this analysis should also consider the possible need for a fundamental redesign of property insurance in light of climate change and extreme events (see, e.g., H. Kunreuther and E. M. Kerjan, 2009).

In addition to improving data and risk analysis supporting the insurance industry, this research could assist policymakers in maintaining the balance when drafting or amending laws and regulations. Policymakers could compare the predicted losses against the steps insurers are taking to adapt to the predicted changes to determine whether insurers' actions alone are sufficient to prevent the loss of affordable coverage or whether additional steps need to be taken to maintain the balance. Furthermore, it could inform policymakers of the risks that are beyond the control of the insurers. From this information, policymakers could take additional steps to protect against the risk of insurance losses in a manner that may assist insurers in maintaining affordable and available coverage. Additionally, this information could help insurance markets send the "right" signals about risks associated with particular properties and settings, while making social equity adjustments for vulnerable populations that have legacy vulnerability (e.g., long-standing property ownership in particularly (and increasingly) fire-prone areas.

Due to limited funding, this research will focus on a regional study in a high-risk area rather than perform a statewide analysis.

Background: Insurance is one of the final pieces of the safety net that protects Californians from the impacts of extreme events. It provides a way of pooling risk and facilitating recovery from losses and disasters, providing important financial relief. Since 2009, the California Department of Insurance has surveyed insurers to determine the steps they have been taking to adapt and provide resilience to climate change. The results have been made available to the public on the Department's website, and in 2013, the Department created a new database to enable easier searching and tabulating of the reports. Ceres, a nonprofit organization, analyzed the results of a number of the surveys and published reports that assess insurers' preparedness and vulnerabilities. In its most recent report, Ceres found that "more damaging wildfires are demonstrably trending upward as predicted by climatological assessments, yet insurers describe loss experience as departing dramatically from their own historical underwriting experience" (Leurig et al. 2013). It is therefore crucial that insurers begin preparing for the effects of climate change, ensuring that rates adequately reflect evolving risk while working to keep insurance available and affordable despite increased climate risks.

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B. Reducing Wildfire-Related Health Impacts

Goal: This research will explore public health vulnerabilities and adaptation options to wildfires by making use of updated climate scenarios and regional wildfire projections to explore regional transport of pollutants; ambient concentrations of fine particles (PM2.5) and other pollutants; and impacts to public health. Results can be used as a basis for public health adaptation measures to climate change. Ultimately, results should form a basis for specific recommendations for protecting public health in given scenarios.

Problem Description: Climate change poses considerable threats to public health in the 21st century. Substantial increases in wildfire risk are predicted for California, and wildfire plumes threaten local communities, adding the burden of cardio-respiratory disease and other health outcomes. Additionally, regional transport of combustion products interact with air sheds in major population centers in California, affecting vulnerable populations. A substantial share of the current California population have multiple chronic diseases, mobility limitations, demographic factors (pregnant, very old, very young), or live in social conditions that heighten their vulnerability. Research is needed to predict how sources of wildfire smoke and regional atmospheric transport give rise to elevated ambient concentrations of fine particles (PM2.5), and to estimate the resulting impacts on public health under future climate change scenarios.

Proposed Work: The recent influx of wildfires in California has turned the state's attention to the potential impacts of smoke and other air-borne pollutants on public health. During the King Fire in El Dorado Hills, affected counties issued a smoke advisory, warning of hazardous air conditions from wildfire smoke and notifying vulnerable populations such as the elderly, children, and those with respiratory problems to stay indoors. Not only are wildfire events costly (Knowlton et. al. 2011), but resulting air pollutants are transported across the state, interacting with air sheds in major population centers to generate intense air pollution episodes with substantial public health impacts (Kinney 2008).

This project should examine the increasing wildfire risk in California due to climate change and the resulting impacts on public health. Specifically, applications should address the following areas:

1. Climate Change and Wildfire Projections: In alignment with other 4th Assessment studies, use California-specific wildfire modeling and current climate projections to assess the risk of future wildfire events associated with various time horizons.

2. Modeling of Regional Transport: Model the regional transport of combustion products from wildfire and calculate the resulting predicted ambient concentrations of PM2.5 in air sheds in California. However, since wind fields are not reliably modeled by regional climate models, it would be acceptable to use past information about the transport of wildfire pollution to assess human exposure.

3. Impact on Public Health: Analyze health impacts of ambient PM2.5 on to assess the burden of disease.

4. Explore Adaptation Options: This will require particularly close coordination with ongoing work at CDPH. Additionally, identified options for adaptation should form a basis for specific recommendations to specific audiences charged with protection of public health in California.

In addition to assessing impacts to public health, this project must explore potential vulnerability reduction programs that reduce susceptibility to wildfires and increase resilience through emergency preparedness. Such disaster resilience could address public health adaptation measures to climate change, including prioritizing investments in public health infrastructure, effectively responding to wildfire-related public health emergencies, and informing health care services delivery and facility operations. Preliminary research suggests substantial reductions in human health damages with the implementation of forecast-based interventions (Rappold et al., 2014)

This research could benefit state and regional agencies, whose missions include air quality management, emergency response, public health, and medical services, and other researchers, including economists, could also potentially use this information to project costs due to health and non-health related outcomes of increased wildfire activity.

Due to limited funding, this research will focus on a regional study in a high-risk area rather than perform a statewide analysis.

Note: This research will be coordinated with a CDPH effort supported by a 4-year grant (2012-2016) from the Centers for Disease Control and Prevention that allows CDPH to work with local health departments in each of ten California Adaptation Impact Regions to conduct vulnerability assessments, project the burden of disease and injury from climate impacts, identify interventions, and build capacity.

Background: With the prediction of increasing wildfire risk in California from climate change, it is crucial to understand the potential consequences of smoke and other wildfire-related air pollutants on public health. Air quality is affected spatially and temporally by meteorological variables, as air pollutants can be transported, diluted, and chemically transformed before being deposited. Assessment of potential future climate conditions and their influence on the attainment of air quality objectives is therefore vital to understand the implications for human health (Keim 2008).

To address the increased exposure to dangerous hazards like wildfires, adaptation strategies are needed to build human resilience to such events. Planning preparedness and response programs on the local level will aid mitigation of the effects from wildfires.

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Rappold, Ana, Neal Fann, James Crooks, Jin Huang, Wayne E. Cascio, Robert B. Devlin, and David Diaz-Sanchez. 2014. “Forecast-based interventions can reduce the health and economic burden of wildfires.” *Environmental Science & Technology*, 48(18): 10571-10579. http://pubs.acs.org/doi/abs/10.1021/es5012725

C. Migration Corridors and Refugia as Adaptation Strategies: Critical Review

Goal: This research will critically review existing efforts designed to identify migration corridors and temporary refugia that may dampen the deleterious effects of climate change on species of concern in California. If matching funds are available, this work will identify critical habitat linkages (or corridors) and climate refugia to increase the likelihood of species survival and reduce overall climate risks to California biodiversity in one or more regions in California informed by the critical review. Maintaining connectivity through migration corridors and “stepping-stones” will facilitate the movement of species between currently suitable areas and to newly suitable areas over time as the climate changes.

Problem Description: The *Safeguarding California Plan* (CNRA 2014, p. 20) directs resource managers to “create, maintain, and support tools that help resource managers determine when and where to focus conservation activities that will protect biodiversity in the face of climate risks.” As regional climate changes, the conditions that made habitat suitable for a species will shift to new geographic locations, often northward or upward in elevation. To survive, species must migrate across the landscape to follow the shifting habitat conditions that they require. Two factors now make this more urgent for active adaptation strategies. First, the rate of climate change is unprecedented. Species that have evolved to migrate with moderate or slow rates of change must now move at greater speeds to keep pace with the climate. Second, for the first time, the landscape through which they must now move at greater speeds is highly modified and fragmented by infrastructure, development, and agriculture. Resource managers need to know where potential corridors are located that may need to be protected and where bottlenecks or gaps in these corridors occur that may need restoration as part of a biodiversity adaptation strategy. Some species may not persist without active management to protect and restore pathways for movement that they would naturally pursue. Alternative strategies to assist species would tend to be much more expensive and more experimental.

Refugia “retain conditions that once were common in the landscape. Hence, refugia are habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions” (Keppel et al. 2012, page 394). Some scientists argue that refugia are a critical element for adapting to climate change so that they should be protected from conflicting human uses. Others maintain that refugia that helped species persist during cyclical climate change are unlikely to perform the same role under a monotonically changing climate (Hannah et al. 2014). The latter view suggests that temporary refugia (e.g., holdouts, stepping-stones) will be a more effective adaptation tool. A critical review is needed to guide resource managers on the most effective adaptation strategies. One potential issue that should be investigated in this critical review paper is the fact that different species distribution models (DSM) can produce different views of the future (Smith et al., 2013) making harder to evaluate their usefulness to inform management practices.

Proposed Work: The proposed research would result in a critical review paper of these potential adaptation strategies for biodiversity and current methods used to identify potential corridors. The proposed research would include the following:

- Migration corridors—critically review the literature on habitat connectivity and corridors to develop a set of criteria resource managers could use to identify and protect effective corridors specifically in California. Note that this is more complex than mapping wildlife corridors in a static landscape where the habitat features are constant. The research team should address potential differences in such criteria between the state's ecoregions, both in terms of habitat types and land use, and how these interact with climate change. The review should also address the differences in corridor needs for different groups of species.
- Refugia—critically review the literature on climate refugia as a climate adaptation strategy for California. The review should carefully distinguish the taxonomy of types of refugia (e.g., microrefugia, stepping-stones, holdouts) and characterize if and when each type may be effective in California and over what period of time and for what groups of species. The review should also consider how effective these types of refugia may be given their likely size and persistence.
- Climate velocity—critically review the literature on climate velocity as a metric for estimating the vulnerability of species and for identifying places with low velocity that could serve as refugia. The review should identify which climate variables are most suited for measures of velocity (e.g., temperature, precipitation, aridity, or synthetic indexes) and whether these vary between ecoregions.
- Modeling—if resources permit, the research team may also develop and test spatial models to identify potential corridors and/or refugia and to map climate velocity. In this endeavor, the project should use the projected climate scenarios being developed for the Fourth California Climate Assessment, and ideally either the probabilistic climate projections or the set of representative climate scenarios to estimate how robust the identified corridors and refugia are under uncertain future conditions. The applicant should propose and justify a particular study area and may choose to consult with scientists and managers to determine the best region for analysis. We suggest excluding the areas where analyses are already being carried out (e.g. Sierra Nevada Foothills, Desert region).
- Barriers to adaptation—the results of this study will likely illuminate potential barriers to adaptation, both physical and otherwise. When highlighting critical habitat linkages and refugia, it may become clear that while these features are critical for conservation, they may not be feasible to protect due to natural or built infrastructure, monetary issues, land-use/ownership, etc. The analysis and could provide some very valuable information on barriers to addressing climate risks to biodiversity.

Additional Background: Habitat connectivity analyses have been carried out in California at both the statewide level and the regional level. At the statewide level, the California Essential Habitat Connectivity Project (http://www.dfg.ca.gov/habcon/connectivity/) was an effort to identify large remaining blocks of intact habitat or natural landscape and model essential connectivity areas between them that need to be maintained, particularly as corridors for wildlife.

Corridor prioritization exercises have also been carried out regionally in the northern Sierra Nevada Foothills, the Desert regions of California, the South Coast region, and the North-Central Coast. The northern Sierra Nevada Foothills wildlife connectivity-modeling project began in 2012 at CDFW with a goal of identifying connections between this region and the adjacent lands in the Central Valley and the Sierra Nevada using species data-driven models. The project team developed guidance on minimum standards for fine-scale connectivity modeling needed to meet CDFW mission and mandates. Science and Collaboration for Connected Wildlands has overseen several regional connectivity projects in recent years. In the Desert region they conducted a comprehensive connectivity assessment to develop 23 Linkage Designs based on several science-based models (e.g., landscape permeability, habitat suitability, and patch size and configuration analyses) and fieldwork to evaluate the habitat suitability and movement needs of over 40 selected focal species. Similar projects have been carried out in the South Coast (the South Coast Missing Linkages project) and the Bay Area (Bay Area Critical Linkages).

As discussed in the Yale Framework (http://yale.databasin.org/), there are three scales at which refugia can be assessed: the species scale, ecosystem scale, and landscape scale. Several State efforts already address the species scale – e.g., vulnerability assessments carried out under previous Climate Change Assessments, and the forthcoming Vulnerability Assessment component of the State Wildlife Action Plan. These types of assessments identify regions that are – or are not – suitable for target species or macrogroups (communities) under future climate conditions.

Climate velocity is a measure of the rate of climate change over the landscape that can be compared to the speed at which species can migrate (Loarie et al. 2009). The original introduction of the concept of climate velocity was done at coarse resolution for the entire planet. Ackerly et al. (2010) also mapped climate velocity for much of California. Higher resolution studies of climate velocity in California include the Desert Renewable Energy Conservation Plan (http://www.drecp.org/draftdrecp/files/Appendix_P_DRECP_Climate_Change.pdf) and Serra-Diaz et al. (2013).

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D. Fuel Treatment for Forest Resilience and Climate Mitigation: Critical Review

Goal: This critical review of prior research will clarify what is known about the effects of fuel treatments on carbon cycling in California's forests and outline what new knowledge will be needed to make sound fuel treatment decisions to increase both forest resilience and carbon sequestration. This critical review will support improved estimates of the effects of forest management activities on forest carbon sequestration and avoided wildfire emissions. Ultimately, this work will help agencies, fire safe councils and land management companies decide how to optimally allocate limited funds for forest management activities to achieve the co-benefits of improved resilience and climate mitigation**.**

Problem Description: The forest sector plays an important role in climate change policy due to its ability to act as a carbon sink or source. Managed forests can create a carbon pool by storing large amounts of carbon. Forest lands left unmanaged, however, can become decadent, prone to insects or disease, and overstocked with trees and other vegetation that create huge sources of carbon emissions in the event of wildfires. Moreover, climate change is expected to increase wildfire frequency and intensity, making these overstocked forests even more vulnerable. Denser forests also decrease runoff through greater evapotranspiration rates (Goulden and Bales et al. 2014).

The fate of carbon in forested ecosystems is a complex interaction between many variables, such as wildfire emissions, tree mortality from various sources including drought, disease and wildfire, timber harvests, and forest growth and development. Ironically, while fire suppression has led to increase in tree density, one study found that these denser stands of younger trees actually store less carbon than less dense stands of larger trees (Fellows and Goulden 2008). Forest thinning and other fuel treatments can restore forest resilience for multiple benefits (e.g., habitat, watershed, and public health and safety) now and especially under future climatic conditions. The effects of forest management actions such as fuel treatments on forest carbon pools and avoided greenhouse gas emissions from wildfire are not well known. The science of the effects of fuel treatments on forest carbon balances, however, is not highly developed, yet fuel treatments are increasingly being promoted in part to achieve increased carbon sequestration in forests and avoidance of greenhouse gas emissions from wildfire. We need to better understand the extent to which forest thinning and other fuel treatments for improved resilience can also benefit climate mitigation. Making the situation even more complex is when the biomass removed by the fuel treatment is used to generate bioenergy, offsetting emissions from fossil fuels.

Proposed Work: This project will conduct a critical review of the existing literature addressing the effects of alternative fuel treatments on long-term carbon balance in California forests. For forest types or regions where studies are scarce for California, comparable studies from western US forests can be used with the appropriate caveats. The review should synthesize studies to identify the range of carbon emissions or sequestration associated with fuel treatments for major forest types, and ideally by region of the state. Carbon flux should be estimated in these studies relative to control areas of similar type and geographic area that were not treated.

This project should take a long view of the carbon cycle, considering initial release of carbon from the treatment, expected loss of a fraction of the remaining carbon to wildfire, and rates of carbon sequestration in new growth or loss from mortality and decay.

The critical review should develop estimates of net carbon flux for various fuel treatments by forest type and region when reliable studies provide a basis. The project will also identify gaps where types have not been studied or the studies have not been sufficiently rigorous or where the results of previous studies are ambiguous whether treated forests have better effects on carbon flux than untreated forests. The project should also characterize the types of studies needed to overcome any limitations of past research efforts, such as lack of control sites.

Results from this study can be used directly to improve decision-making on how to allocate funding to actions that capture synergies of climate mitigation and adaptation. This research can help optimize the allocation of funding for fuel treatments to areas where they will have maximum beneficial effect in avoiding greenhouse gas emissions and increasing the stored carbon pool in forests. While there is some expert and professional firefighter support for fuel treatments being the most effective in areas of high fire risk, typified by specific weather patterns, climate, moisture regimes and vegetation types and configurations, no models exist to objectively make decisions on optimal funding of treatments under all possible combinations of these variables in individual management situations.

Additional Background: Little direct research has been done on fuel treatment effects in a climate change context. Most of the research has been done by the Pacific Southwest Research Station of the USDA Forest Service, and researchers at UC Berkeley and Oregon State University. Much of the research has been opportunistic, in areas where fuel treatments had been implemented and a fire later happened to occur. There is often concern over the validity and extent of applicability of findings.

Winrock International and the West Coast Regional Carbon Sequestration Partnership Fire Panel developed a methodology for estimating greenhouse gas benefits of fuel treatment activities to reduce emissions from wildland fires in low- to mid-elevation California mixed conifer forests (Pearson et al. 2010). The task of developing a rigorous methodology to quantify baseline emissions from wildland fires and emission reductions attributable to fuel reduction proved complex. Given current hazardous fuel removal technologies and the low probability of fire on any given acre in any given year, hazardous fuel reduction treatments in the forest types addressed in the Pearson report could not directly generate offsets.

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2. California's Working Lands: Carbon Sequestration for Adaptation and Mitigation

Increasing temperatures, changes in precipitation patterns, and other climate changes affect the distribution of vegetation, health of ecosystems, carbon storage potential, and disturbance regimes, including wildfire. The fate of carbon in forested ecosystems and in California's rangelands is a complex interaction between many variables. For example, the fate of carbon in forests is affected by wildfire emissions; tree mortality from various sources including drought, disease, and wildfire; timber harvests; and forest growth and development. Additionally, climate change will lead to the conversion of forested land to other land types, including shrub and grasslands. Climate change also poses risks to existing grasslands, rangelands, and working landscapes in California.

Disturbances as a result of climate change will affect the health of forested ecosystems, rangelands, and croplands, and thus the services that they provide through habitat and carbon storage and water supply for urban communities, among other services. While forests and rangelands (and, to a lesser extent, croplands) have been demonstrated to have high potential for sequestering carbon, successfully managing these working lands for carbon storage will require developing California-specific understandings of ecosystem dynamics in a changing climate as well as economic dimensions of and institutional barriers to preserving working lands in a manner that provides adaptation benefits while sequestering carbon.

Additionally, this area of research includes economic and environmental analysis of adaptation options for the agricultural sector.

CALIFORNIA'S WORKING LANDS

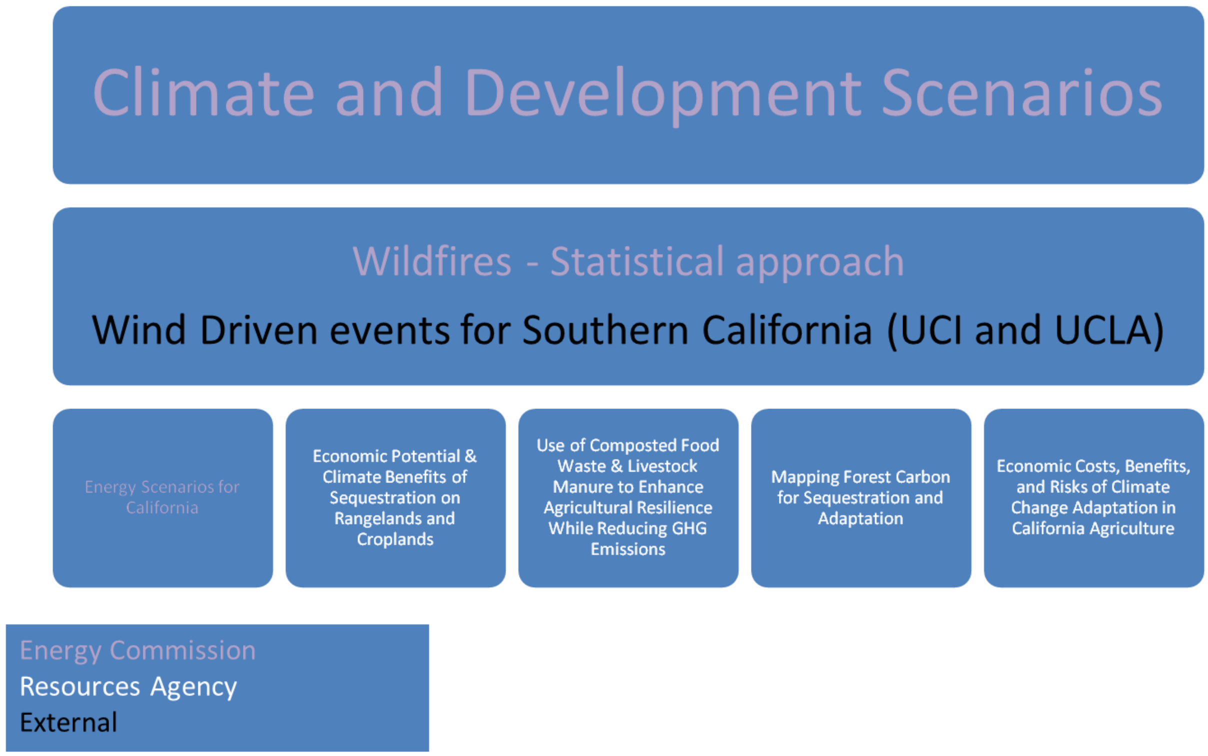

Figure 2: Research projects in the area of "California's working lands" will draw on a common set of wildfire and vegetation change scenarios (middle tier) that are derived from climate and development (including land use) scenarios developed by the California Energy Commission in collaboration with California's Natural Resources Agency as well as other state agencies involved with the Fourth Assessment.

A. Economic Potential and Climate Benefits of Carbon Sequestration on California's Rangelands and Croplands

Goal: This research will assess the economic and climate benefits of management techniques for rangelands and, if possible, croplands that maximize carbon sequestration and build resiliency to climate impacts. Past work has focused on the potential to sequester carbon in rangelands but very little has been done to explore its adaptation benefits. Similarly, the scientific community has established that increasing soil carbon results has the co-benefit of increased crop yields; but clarification is needed to optimize the carbon sequestration potential of programs designed to conserve farmland and adapt to a changing climate.

Problem Description: Rangeland comprises a significant portion of the land base in California. Both private land and public land are managed extensively for livestock production. Rangeland is calculated to be among the lowest GHG emissions per unit area among the productive uses of land, particularly when compared to urban development which has been calculated to result in up to 217 times the GHG emissions of rangeland per unit area (Jackson, L., et al. 2012). Varied research has been conducted on the capacity of rangeland soils to store carbon and to reduce net GHG emissions (DeLonge et al., 2013). The diversity of soil and climate conditions found in California requires a synthesis and parsing of the various investigative results, to reflect which soil/climate combinations are well studied, which will require further studies, where the evidence indicates significant potential, where the evidence indicates little to no benefit to enhanced management, and where the information is lacking.

The State of California has two farmland conservation programs (the Land Conservation (a.k.a. Williamson) Act and the California Farmland Conservancy Program) that incentivize farmland conservation. In the wake of the recent recession, these bond-funded programs are being questioned as to whether they should continue; and if so, how they should evolve to provide greater benefits through, e.g., enhancing ecosystem services such as carbon sequestration. The next generation of California's farmland investments could require management agreements similar to the USDA's Agricultural Conservation Easement Program (ACEP) or affirmative farming clauses. Data from this study would assist the State in design of an updated Williamson Act program. Despite the Williamson Act's success at maintaining more than 16 million acres under conservation contracts, taxpayer investment has been substantial. In an era of increased risk due to climate change, additional investments should be linked to performance that will increase long-term agricultural sustainability.

Proposed Work: This study will quantify the economic and climate benefits (mitigation and adaptation) of rangeland management regimes. It should address the barriers to rangeland preservation, such as challenges integrating rangeland into the cap-and-trade program, and the adaptation and mitigation benefits of various management regimes. For example, certain management options may increase the amount of carbon sequestered by the ecological system or may make the system more resilient to prolonged droughts or changes in rainfall patterns. To the extent that funding (including match funding) allows, economic and climate adaptation benefits of various cropland management regimes, as well as barriers to farmland conservation, will also be investigated in regionally-representative counties in the critically important coastal and central valley regions. Additionally, use of bio-char as a soil treatment to increase water retention and carbon retention in range soils may be explored. An Energy Commission study on bio-char use in the agricultural soils in California should be considered in the execution of this project.

Background: Grasslands, globally, account for about one-third of stored soil carbon (Silver, W., et al. 2013). Carbon sequestration in rangeland results primarily from forage vegetation growth (ibid). Additional soil carbon sequestration can occur through additions of manure and compost, with a related increase in emission of nitrous oxide and methane (ibid). Rates of carbon sequestration are sensitive to precipitation, with higher precipitation leading to greater soil moisture, increased plant growth, and increased levels of soil carbon (ibid). California precipitation is temporally and spatially highly variable, with modeled future scenarios showing a likelihood of increased variability (ibid). This underscores the need for more complete and ongoing assessment of statewide potential for enhanced management of rangelands for increased sequestration of atmospheric CO_2, where feasible.

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B. Use of Mulch and Composted Food Waste and Livestock Manure to Enhance Agricultural Resilience While Reducing Greenhouse Gas Emissions

Goal: This research will investigate the potential of application of aerobically composted livestock manures and food wastes to agricultural lands to enhance climate resilience (e.g., improve soil water retention). The research will also quantify the greenhouse gas emissions reductions associated with this strategy compared to existing management practices.

Problem Description: It is unclear to what extent composting of food waste and livestock manure can lead to substantial reductions of greenhouse gas emissions while also providing numerous other environmental benefits compared to direct application of manures to agricultural lands and disposal of food waste in landfills. This information is needed to determine whether composting these waste streams can be used for both adaptation and mitigation for the agricultural and waste management sectors. The long-term impacts of climate change on California are projected to include increased frequency, intensity, and duration of droughts, a large decrease in snowpack, and occasional periods of intense rainfall resulting in erosion and flooding. The state of California is currently in an extreme drought, and agricultural operations are experiencing a lack of water for food crop production. California must find ways to adapt to these conditions and more efficiently use existing water resources. Soil water retention is one solution to address future droughts and adapt to climate change. Water conservation and water use efficiency are key measures in the State's Climate Adaptation plan, and anecdotal data shows that the use of compost and mulches made from recycled organic materials can help California adapt to drought and minimize the erosion and water quality impacts from a deluge. Due to the complexities of soil types, application conditions, growing seasons, and climate, there is a need for comprehensive research to provide quantifiable data for water savings attributable to the widespread use of composted products.

Proposed Work: This research will:

- Determine, on a statewide level, the benefits of and potential for using manure and food waste derived composts as a climate change adaptation tool for enhancing soil health and improving preparedness of climate change-related droughts and increased temperatures; Quantify emissions of nitrous oxide and methane from aerobically composted food waste and manure, compared to emissions associated with direct application of manure to land, anaerobic degradation, and landfilling of food waste;
- Compare water use efficiency for soils with and without compost amendments. Compare water use efficiency for soils with and without mulch applications. Monitor irrigation, crop available moisture and yields. Potential variables include soil type, irrigation method and crops;
- Identify and quantify whether food waste and manure-derived composts can be used to effectively sequester carbon and produce stable long-term organic matter pools in soil.
- Determine the plant nutrient content distribution and variation of these composts produced using food waste and manure.
- Quantify, through modeling and mapping (e.g., system connectivity's from use to processing to land application), the potential for collecting, processing, and using manure and food waste compost to improve soil health on a statewide scale.

Background: Agriculture in California includes and is dependent upon large herds of cows for the production of milk and dairy products. California is home to the largest number of dairy cows in the country, which has positioned the state as the largest milk producer in the nation. Milk and dairy products are substantial parts of the human diet and important sources of protein, especially for infants and children. However, manure from dairy cow operations is not without environmental impacts. In general, dairy manure releases into the atmosphere nitrous oxide, a greenhouse gas that is, pound for pound, 310 times more potent than carbon dioxide; and methane, a greenhouse gas that is 21 times more potent than carbon dioxide. These environmental impacts from manure stem from anaerobic conditions (which produce methane) under which manure is stored or managed as a plant nutrient on crop production lands (which produce nitrous oxide). The same is true for food waste. Food waste is typically disposed of in landfills and, given anaerobic conditions, quickly produces methane gas. Aerobic, aerated composting systems, in concept, offer the potential to reduce methane emissions and stabilize nitrogen so that it does not release easily as nitrous oxide. An added benefit of composting manures and food waste is that the finished product is a material that can be effectively utilized to improve soil health. Use of composts in agriculture has been shown to have numerous environmental benefits such as increasing soil water holding capacity and contributing to carbon sequestration.

Recently, CalRecycle funded a study to identify methane and nitrous oxide emissions from composting of green waste (no food waste or manure was included in this study). The study considered potential changes in nitrous oxide emissions from agriculture lands after the application of green waste compost. However, at noted above, the study was limited to green waste. Manure and food waste are also composting feedstocks, with food waste a focus of statewide efforts to divert materials from landfills. Potential emissions from food waste are poorly understood. Food waste and manure composts can have higher nutrient content than composts made from green waste. Research is required to understand the potential greenhouse gas emission reductions from diverting manures and food products away from direct land application and landfilling and into managed, aerated composting systems.

C. Mapping Forest Carbon for Sequestration and Adaptation

Goal: This research will help resource managers better understand the co-benefits or trade-offs of mitigation and adaptation strategies involving forest carbon. The research will estimate carbon stocks under management treatments to stabilize or reduce emissions and create more resilient forests (e.g., thinning overstocked forests) in comparison to untreated stands. The research will develop and evaluate innovative, repeatable methods to improve mapping of carbon stocks of California forests.

Problem Description: A century of aggressive fire suppression has resulted in California forests that are excessively dense with undergrowth and small-diameter trees. This build-up of highly flammable biomass is making California's forests and communities particularly vulnerable to catastrophic wildfires, which are predicted to become more frequent and intense with climate change. Not only do these fires have a high financial cost, but they also release a substantial amount of greenhouse gases, damage habitat, and degrade watersheds and their ecosystem services. In fact, recent research indicates that wildfires may be contributing to California forests and shrublands becoming a source of greenhouse gases rather than a sink (Battles et al. 2013). Ironically, while fire suppression has led to an increase in tree density, one study found that these denser stands of younger trees actually store less carbon than less dense stands of larger trees (Fellows and Goulden 2008). Management practices to improve forest resilience may result in net emissions of greenhouse gases (Campbell and Ager 2013, Restiano and Peterson 2013). There is substantial uncertainty regarding how to quantify and balance short-term carbon losses with long-term carbon sequestration as well as avoided greenhouse gas emissions from wildfire. The science of predicting the effects of fuel treatments on forest carbon balances is unsettled, yet fuel treatments are increasingly being marketed and implemented in part to achieve increased carbon sequestration in forests and avoidance of greenhouse gas emissions from wildfire as well as making forests healthier and more resilient to the impacts of climate change. Thus being able to accurately map carbon density and monitor changes over time is of critical importance for guiding state mitigation and adaptation policies.

Proposed Work: The proposed research would include the following:

- Develop and evaluate innovative methods involving remote sensing (e.g., aerial survey using LiDAR and hyperspectral sensors) technologies and ancillary data (e.g., field plots) to map carbon stocks with appropriate measures of accuracy and uncertainty. The project may also use these methods to compare pre- and post-treatment carbon stocks in currently overstocked, fire-prone forest stands. Alternatively the project may compare previously treated stands with nearby untreated control stands. The purpose of such comparisons is to demonstrate that the methods are sensitive enough to detect the impacts of fuel treatments. No particular forested ecoregion is required for this project, but the applicants should justify their proposed study region where fuel management activities (e.g., thinning, prescribed fire) are practiced. It will be advantageous to plan a study in a region with a legacy of data collection on forest stocking conditions. Shrub vegetation is also an appropriate type for this study, especially as some shrublands are being converted to grassland by wildfire.

- Demonstrate that the methodology is feasible and appropriate for GHG emissions accounting and carbon cycling monitoring purposes. Specifically, the study should demonstrate that the methods would be replicable by others and repeatable over time, cost-effective for annual or frequent monitoring, and of sufficient accuracy of estimates of carbon stock (i.e., within 10% accuracy at 95% confidence at 1 ha scale).

- Compared the results with the findings of alternative methods for the same study area (e.g., Battles et al. 2013, Zhu and Reed. 2012) that used satellite data. In addition, this work should shed light on the preliminary finding that less dense forests could store more carbon.
- Discuss limitations of the methods and suggestions for further improvements and R&D.

The completion of the proposed research will aid managers who wish to "redistribute" forest carbon from flammable undergrowth and small-diameter trees to larger and more resilient size classes. Managers who are able to balance carbon goals with forest health goals will be more likely to help forests transition as the climate changes. Results from this study can be used directly to improve decision-making on how to allocate funding to affect climate change. This research can help optimize the allocation of funding for fuel treatments to areas where they will have maximum beneficial effect in avoiding greenhouse gas emissions and increasing the stored carbon pool in forests as well as making forests more resilient. Users of the information generated by this research will include agencies, fire safe councils, and land management companies faced with deciding how to optimally allocate limited funds for forest management activities. The researchers will work with ARB staff to ensure that the products are in a format that could be used by ARB for the GHG inventory tool.

Background: In 2011, ARB contracted with researchers from University of California (UC) Berkeley to develop a new data-driven methodology for assessing carbon stock changes for forests, woodlands, shrub lands, grasslands, and wetlands. The new methods use California-specific land based data sets and satellite remote sensing data (Battles et al. 2013). Data sources for the new method include Forest Inventory and Analysis (FIA) ground-based data (vegetation type, tree species and dimensions, percent canopy cover, etc.) from the USDA-Forest Service, remote sensing products from NASA's MODIS sensor, geospatial vegetation data (vegetation community type, canopy height, percent canopy cover) from the federal Landscape Fire and Resource Management Planning Tools Project (Landfire), geospatial fire and harvest occurrence data from CalFIRE, and ancillary data on shrub lands and grasslands. The method enables analysts to retrospectively assess ecosystem carbon stock changes resulting from fire, human activities, and other processes. It will enable monitoring of changes on the land over time and periodic quantification of the GHG flux associated with changes in ecosystem carbon stocks. Additional work is needed to evaluate the data provided by the UC Berkeley research, to incorporate additional new data, and to identify further research needed to expand use of these tools. The sources and methods for quantifying ecosystem carbon and GHG flux in this sector are complex. Continued refinements will advance carbon quantification and attribution of GHG flux by disturbance process with greater certainty.

Asner et al. (2013) were able to generate a map of aboveground carbon density for the entire country of Panama at 1-ha resolution with estimated average pixel-level uncertainty of 20.5 Mg C ha-1 nationwide. The researchers integrated measurements of vegetation structure collected by airborne Light Detection and Ranging (LiDAR) and field inventory plots with satellite-based measurements of vegetation cover and condition, topography and precipitation. The LiDAR data was gathered through sampling along transects and then extrapolated using the satellite data. Sonoma County is using LiDAR data to create automated forest structure metrics, such as tree height and canopy density. Forest structure metrics will be combined with forest plot data to produce accurate models of forest biomass and aboveground carbon sequestration. The models will be used to create a map in 2015 of aboveground carbon density at 30-meter resolution with 10% accuracy at 95% confidence at 1 ha scale (http://sonomavegmap.org/).

To alleviate the risk of catastrophic wildfire and associated release of greenhouse gases, funds for fuel reduction have been made available from a variety of sources, including the Greenhouse Gas Reduction Fund (see Governor's proposed 2014-15 budget). These funds are targeted towards projects that improve forest health and reduce greenhouse gas emissions; thus, the funds are intended to address the dual goals of climate change adaptation and mitigation.

Land managers recognize that fuel treatments—including thinning and prescribed burns—have tremendous benefits for forest health and wildfire risk reduction. They are increasingly managing forests to reduce fuel accumulation; for example, California State Parks has an active prescribed fire and forest management program in 15 park units across 9 of its 25 districts. It has been suggested that these treatments also improve carbon sequestration (North et al. 2009), although it remains unclear how and whether short-term losses of carbon from fuel management are balanced with long-term gains from reduced wildfire and the growth of larger-diameter trees (Restiano and Peterson 2013, Campbell and Ager 2013).

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D. Economic and Environmental Costs, Benefits, and Risks of Climate Change Adaptation in California Agriculture

Goal: Results from this project will help facilitate development of agricultural management practices for specific crops and locations in California to address climate change. The outcome of this research, therefore, is expected to be primarily used by landowners to make climate change-related management decisions on food production. Other users of this information include local government agencies, state agencies, federal agencies (e.g., USDA NRCS), county agriculture commissioners and agriculture associations and commodity groups.

Problem Description: Agriculture is an important economic and social component of California. For example, California agricultural production leads the nation in gross cash receipts and produces a diversity of crops, about eighty of which are not produced anywhere else in the nation. The state is home to several unique environmental zones and a Mediterranean climate which allow for a diversity of “specialty crops” to be grown, some of which are produced throughout the year. Specialty crops are defined as “fruits and vegetables, tree nuts, dried fruits, horticulture and nursery crops (including floriculture)” by the United States Department of Agriculture. California agriculture is an important part of food security discussions. Recent reports indicate that climate change is expected to have significant effects on California agriculture (CDFA, 2013). Climate change effects that are expected to impact California agriculture include decreased yields due to increased temperatures, flooding, more intense droughts, increased pests and reduced pollination services. Increased temperatures have already been observed in regions of California. For example, the Berkeley Earth Surface Temperature monitoring results has observed increased temperatures since 1850 in the San Joaquin Valley near Modesto, Merced and Turlock (BEST, 2013). Adaptation to climate change is critical to ensuring the productivity and viability of California agriculture into the future (Safeguarding California Report, 2014). However, there are wide outcome-based research gaps that exist for ensuring the adaptation of California agriculture to climate change impacts. For example, there is a lack of any information on the economic and environmental costs, benefits and risks of crop relocation in California as an adaptation strategy. This and several related research needs are identified in a recent report based on grower feedback (CDFA, 2013). Filling these research gaps is critical to identifying effective short- and long -term strategies for California agricultural adaptation.

Proposed Work: One of the high-priority recommendations noted in the CDFA Climate Change Consortium final report (CDFA, 2013) is to determine the economic and environmental costs, benefits, and risks of several potential adaptation measures through a comprehensive research strategy. The results that should be delivered from the proposed research include:

- Identification of where specific major crops grown in the state are vulnerable to climate change impacts including potential economic loss;

- Potential practical barriers and economic cost (including potential resources to cover the costs) for specific large acreage specialty crops to be relocated (including infrastructure considerations) to other regions of the state if climate change-related impacts (e.g., increased temperature, flooding, reduced winter chill hours) render the current growing regions unsuitable in the future;
- Evaluation of current California conditions and climate analogs (at 50 years and 100 years in the future) through modeling to determine if specific adaptation measures can be used and potential economic cost of those measures;
- Model projections of where specialty crops will be best-suited under future climate conditions in consideration of agronomic variables and natural resources (e.g., soil type, topography, water availability);
- Development of a literature resource on more crop-specific and location-specific studies regarding susceptibility to climate risks, including model projections of productivity effects and impacts that will help facilitate development of specific management practices to reduce climate risks;
- Benefits of maintaining wild or restored habitat in agriculture areas to lessen climate change impacts to agriculture and help adapt to a changing climate (e.g., quantifying in dollar amount the benefits of establishing native pollinator or beneficial predator habitat);
- Impact of climate change on rural and urban food security in disadvantaged communities throughout the state;
- Identify regions of California with the greatest vulnerability to loss of agricultural employment opportunities;
- Identification of potential partnerships and resources (e.g., conversion of food processing facilities to accommodate crop shifting) as adaptation measures to address climate change impacts to specialty crop agriculture in California.

Background: In 2013, the California Energy Commission funded a study titled “Vulnerability and adaptation to climate change in California Agriculture”. The study was led by Dr. Louise Jackson and completed by a group of scientists at the University of California, Davis. The study used a statistical method called Principal Component Analysis, along with several agronomic and environmental variables, to determine regions of the state that would be vulnerable to climate change. However, this information was not translated to major or minor specialty crops grown in the vulnerable regions of the state. Further, no economic analysis was included as it was beyond the scope of the proposal. Finally, the completed studies focus their research on a specific county. Extrapolating this data to a statewide basis or regions with the highest vulnerabilities would be valuable and informative. Thus, although foundational, the completed research work on the vulnerability index does not satisfy what the growers require and have requested through the Climate Change Consortium final report recommendation on economic and environmental studies on the cost, benefits, and risks of crop relocation.

It is well understood that climate change adaptation in agriculture is going to require financial resources. It is also well understood that any adaptation measures that are going to be implemented will be managed and implemented through farmers on their working lands. The new information will inform farmers on potential costs and provide them with decision-making information as to which adaptation measures can be implemented based on crops and location. Farmers will then be able to make management decisions to determine if adaptation measures can be adopted, not only based on crop and location within the state but also based on the intensity of potential impacts from climate change. At the same time, resources at the state level can be identified to incentivize the adoption of climate change adaptation practices on working lands. The proposed work requires outcome-based research that can have immediate as well as long-term impacts on food security.

These crop and location specific studies on agricultural climate risks through model projections would help facilitate the development of management practices to address climate change. The outcome of this research, therefore, is expected to be primarily used by landowners to make climate change-related management decisions on food production. Other users of this information include local government agencies, state agencies, federal agencies (e.g., USDA NRCS), county agriculture commissioners, and agriculture associations/commodity groups.

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Safeguarding California, 2014. http://resources.ca.gov/climate_adaptation/

3. Sea Level Rise, California's Coast and Ocean Ecosystems

The geography of California's coastline is changing with sea level rise. Rising salt water combined with patterns of prior development and outdated infrastructure puts residents, ecosystems, and property at risk. Sea level rise and salt-water intrusion likewise creates major adaptation challenges for the inland communities of the Sacramento-San Joaquin Delta. Similarly, climate change impacts in the form of ocean acidification and hypoxia are threatening California's Marine Protected Areas.

Sea level will continue to rise along California's coasts. More research must be done to help facilitate beneficial adaptation measures to the consequences of that change across multiple sectors and geographies. This research can then be used to inform planning decisions at multiple levels across both the public and private sectors.

At the same time that sea level rise threatens freshwater and terrestrial resources, marine ecosystems will be challenged by acidification and hypoxia. Developing early indicators for ongoing monitoring and management strategies will be crucial to maintaining oceanic ecosystems.

SEA LEVEL RISE, CALIFORNIA'S COAST AND OCEAN ECOSYSTEMS

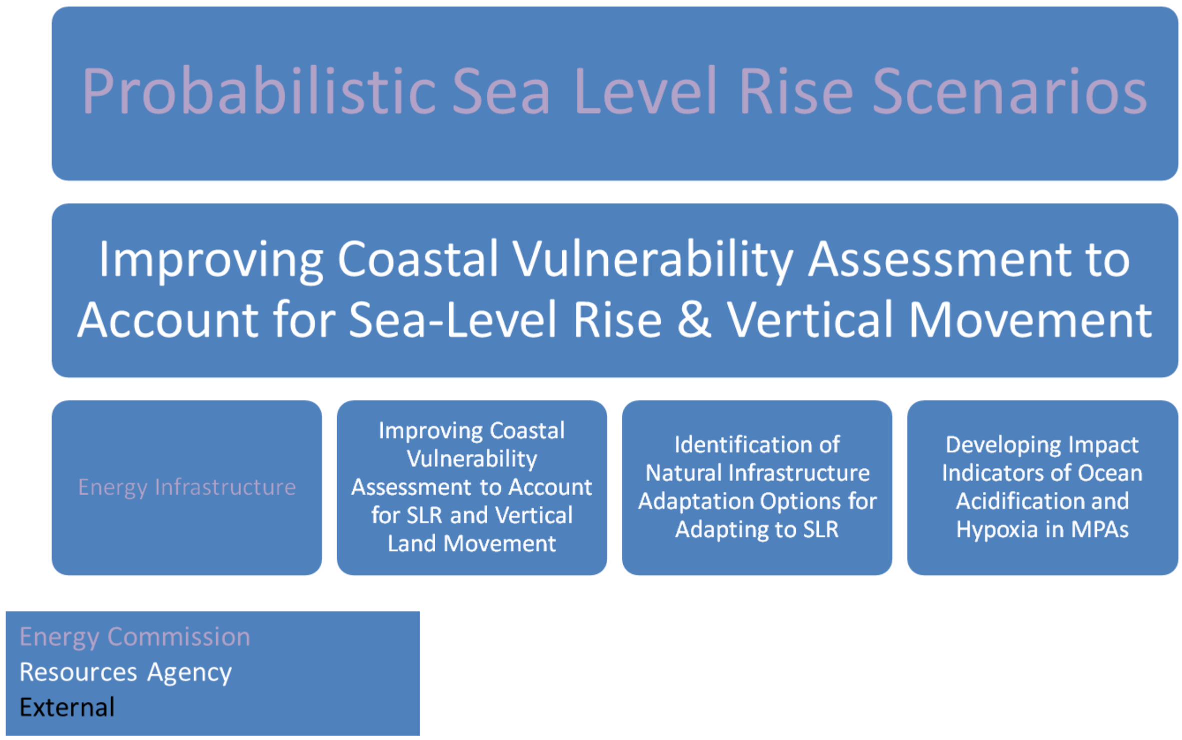

Figure 3: Research projects in the area of "sea level rise, California's coast, and ocean ecosystems" will draw on secondary scenarios that involve process modeling to portray how climate change and other factors such as vertical land movement will affect California's coast. These secondary scenarios will be derived from climate and sea level rise scenarios developed by the California Energy Commission in collaboration with California's Natural Resources Agency as well as other state agencies involved with the Fourth Assessment and coastal issues in California.

A. Improving Coastal Vulnerability Assessment to Account for Sea Level Rise and Vertical Land Movement

Goal: This research will develop methods to support site-specific, project level assessments of coastal vulnerabilities to sea level rise through integration of models of projected sea level rise and climate scenarios, coupled with local and regional-scale erosion rates and vertical land motion estimates. This over-arching goal can be subdivided into three lesser themes:

- Continued development of a process model (e.g., the Coastal Storm Modeling System (CoSMoS)) to provide integrated flood, erosion, and shoreline change predictions to support coastal hazard and sea-level rise vulnerability assessments in the Southern California area (Point Conception to the U.S.-Mexico border, including the Channel Islands, harbors, and coastal embayments).
- Deliver a peer-reviewed, site specific methodology or methodologies to estimate beach, dune, and bluff erosion rates for coastal projects, incorporating projected sea level rise through a process model.

- Refine current state-wide sea level rise projections to account for local and regional-scale vertical land motion estimates.

Problem Description: To accurately predict the threat posed by sea level rise and intense storms to coastal infrastructure, a synergistic approach accounting for changing climate patterns, erosion rates, shifting beach forms, and vertical land movement needs to be developed. Coastal flood risks depend on several factors including tidal stage, storm surge, sea level, and beach form vulnerability due to erosion. Providing more realistic scenarios for planning in coastal regions requires understanding synergies between coastal hydrodynamics, protective structures, shoreline changes, and fluvial input. Although an ongoing project (CoSMoS) is addressing some of these issues through an integrated process modeling approach, more research is needed on the effects of sea level rise and coastal storms on local erosion rates of various beach forms, as well as refinement of the state-wide sea level rise predictions to account for local and regional vertical land movement.

Proposed Work: Several outcomes of this work are proposed:

1. Process modeling efforts (e.g., CoSMoS) will expand to the entire Southern California region. The model will utilize various sea level rise scenarios, physical factors (e.g., tides, wind, waves, fluvial discharge), shoreline change, fluvial input, and the latest global climate models. The modeling will produce coastal change and coastal flooding results for a full range of plausible sea level rise and storm scenarios (approximately forty) to support coastal planning. The work will result in a guidance document to support land planners and managers, as well as development of a user-friendly model interface.
2. Establish a peer reviewed, site specific methodology or methodologies to incorporate sea level rise in estimating beach, dune, and bluff erosion rates. The methodology/ies would be coordinated with and possibly derived from the process model of (1) above and would be used in support of coastal management projects.
3. A peer-reviewed methodology to estimate local vertical land motion at the regional level and identify:
    a. Instances when it will be important to modify the regional sea-level rise projections for local vertical land motion,
    b. Types of existing information on land motion (tide gauge records, satellite data, land-based GPS stations, etc.) that provide the best estimates of local land trends,
    c. A procedure for adjusting state or regional sea-level rise projections for sub-regional or local conditions, and
    d. Additional data that are needed to implement the methodology.

Results of this work (model results, guidance documents, and methodologies) will be publicly available to a variety of audiences, including other stakeholders such as the insurance industry.

Background: The National Research Council's 2012 report *Sea-level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* concludes that over the next several decades the most significant impacts will come from the combined effects of sea-level rise and storms, "…particularly the confluence of large waves, storm surges, and high astronomical tides during a strong El Nino." Critical state infrastructure is at risk, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants, and power plants, as well as wetlands and other natural systems. The cost of replacing property at risk of coastal flooding under a 1.4 meter sea-level rise (SLR) scenario could reach $100 billion (in year 2000 dollars).

Going beyond simple modeling of sea-level rise, to incorporate the effects of storm surges, erosion, and long-term shoreline change, is critical to provide more realistic scenarios for planning in coastal regions**.** Local, project specific analytical methodologies are needed to complement the detailed regional process modeling. Therefore, a need exists to establish a peer-reviewed, site-specific methodology or methodologies to incorporate sea level rise in estimating beach, dune, and bluff erosion rates for coastal projects. The methodology/ies would be coordinated with and possibly derived from the CoSMoS model.

Additionally, sea level rise projections in California need to account for local and regional vertical land motion in their predictions. Several independent processes, including glacial isostatic rebound, groundwater withdrawals, plate movements and seismic activity; influence vertical land motion. The 2012 NRC report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*, makes an adjustment for vertical land motion north and south of Cape Mendocino for the sea-level rise projections put forth in the report. These adjustments do not properly address locations that are moving differently from the region, such as Humboldt Bay. This research proposal would build on that work, thus leading to more accurate and regionally-specific SLR projections that would be used to inform planning and permitting decisions made by the State and local governments.

References:

Barnard, P.L., O'Reilly, B., van Ormondt, M., Elias, E., Ruggiero, P., Erikson, L. H., Hapke, C., Collins, B. D., Guza, R. T., Adams, P. N., and Thomas, J., (2009). The framework of a coastal hazards model: a tool for predicting the impact of severe storms. U.S. Geological Survey Open-File Report 2009-1073, 19 pp. http://pubs.usgs.gov/of/2009/1073/

National Research Council (2012). *Sea-level rise for the coasts of California, Oregon, and Washington: Past, present, and future*. Washington, DC: National Academies Press. Print, ISBN 978-0-309-25594-3, 250 pp. www.nap.edu/catalog.php?record_id=13389

B. Identification of Natural Infrastructure Adaptation Options for Adapting to Sea Level Rise

Goal: The proposed research will provide scientific, economic, and other analysis that will support on-the-ground adaptation initiatives for California's shorelines in the context of sea-level rise driven coastal erosion. This study will produce actionable recommendations involving natural infrastructure (also known as "soft" adaptation options) for coastal areas managed by the California Department of Parks and Recreation owned by the State of California. If necessary for in-depth studies, this project may consist of a series of case studies.

Problem Description: Coastal erosion driven by wave and wind action is expected with increased sea-level rise. Extensive coastal urban development will be increasingly vulnerable as sea-level rise continues to affect wave patterns and inundation zones, leading to the need for coastal protection adaptation strategies. Hard strategies such as sea walls, jetties, etc. are effective at protecting structures they are built around, however these strategies lead to increased erosion and degradation of the coastal system as beaches are not allowed to replenish naturally. Consequently there is significant interest in soft management strategies such as beach nourishment, wetland restoration, and managed retreat for mitigation of the effects of sea-level rise on coastal urban development.

Proposed Work: This research will address practical barriers to non-structural stabilization as well as regulatory and ecological concerns. Overall, this research is expected to produce valuable information about 1) the feasibility of various non-structural stabilization techniques, and 2) the likelihood that these techniques will be suitable under sea-level rise projections. State and local entities will be able to use this information to scale up strategies that are expected to produce long-term benefits.

The proposed work will deliver an analysis of non-structural methods for stabilizing shorelines at California State Park (CSP) units, perhaps focusing on a specific region of the state. CSP is a primary landholder along the California coastline and is well-positioned to implement coastal adaptation strategies. Moreover, California State Park’s broad range along the coastline will make it an ideal model for a study that assesses how existing strategies can be augmented to address climate risks.

We suggest that the following components be included:

1. analysis of the extent to which the described strategy will reduce the risks associated with sea-level rise and extreme events,
2. analysis of the economic costs and benefits of large-scale implementation,
3. evaluation of political and logistical barriers to large-scale implementation, and
4. analysis of ecological benefits and risks for each of the alternatives, including impacts to protected species.

Below, we present several examples of questions that we consider important to address for this study to have an actionable outcome.

Beach nourishment

- How effective is this strategy at reducing coastal erosion? What is the amount, scale, and timing to which beach nourishment would need to occur to effectively protect shoreline resources under existing and projected conditions?
- Will this strategy have significant ecological impacts – positive or negative? How will this strategy affect protected species, such as the Western Snowy Plover?
- Are there any co-benefits or negative consequences to this method, such as impacts to public access and recreation?

Tidal wetlands and other “living shorelines”

- To what extent can this approach be implemented on public versus private land?
- Are there geographic or ecological limitations to broader implementation?
- How do the costs of wetland restoration compare with the benefits?

- Will increased plantings trap enough sediment to be sustainable over time? For this, researchers may wish to refer to pilot studies in a particular area under specific oceanographic and sediment conditions.
- Are there any co-benefits or negative consequences to this method, such as changes to wildlife habitat?

Managed retreat

- How feasible is this strategy in terms of political and public support?
- How feasible is this strategy for public versus private landholders?
- How do the costs of relocation compare with the benefits?

Background: Sea-level rise and extreme events are expected to dramatically reshape California's coast over the coming decades. The coast has always been influenced by geologic processes, coastal erosion, and oceanographic factors; however, climate change and associated sea-level rise are expected to produce impacts well beyond the conventional boundaries of change. In fact, the best available science projects up to 55-66 inches of sea-level rise along the California coast this century (NRC, 2012).

In light of this, state agencies have been directed through Executive Order S-13-08 to consider Mean Sea Level Rise (MSLR) while assessing the vulnerability of projects, reduce risks, and increase resilience to MSLR. Accordingly, guidance documents have been released or are being developed by the Ocean Protection Council, Coastal Commission, and California State Parks. These documents generally provide guidance from the perspective of reducing risks at the project scale or local scale—for example, by evaluating potential sites based on the likelihood of future inundation.

In addition to more strategic project planning, it will likely be necessary to implement proactive, larger-scale actions that address sea-level rise and associated coastal erosion for larger sections of the coast. Shoreline hardening (e.g., building sea walls, installing rip rap, or putting in place other structures to redirect wave energy) has been a popular strategy for reducing wave impacts and preventing erosion; however, this practice increases erosion in non-hardened sites, and accordingly it is highly discouraged through various policies and regulations.

Various non-structural solutions exist that may reduce the impacts from coastal erosion and sea-level rise. For example, beach nourishment allows wave energy to dissipate over a larger area of the shoreline. "Living shorelines" like coastal wetlands may be able to dissipate energy in addition to capturing sediment that allows shorelines to keep pace with sea-level rise. Managed retreat—or the relocation of near-shore infrastructure—allows shorelines to migrate naturally and therefore preserves beach area and public access. These methods have been extensively researched, but more research and synthesis is necessary to determine how economically, politically, logistically, and ecologically feasible they are to stakeholders and project managers who may be willing to implement these solutions on a large scale.

References:

Feagin, R., W.K., Smith, N.P. Psuty, D.R. Young, M.L. Martinez, G.A. Carter, K.L. Lucas, J.C. Gibeaut, J.N. Gemma, and R.E. Koske, 2010. Coastal barrier islands: Coupling anthropogenic stability with ecosystem sustainability. *Journal of Coastal Research*, 26: 987-992.

Jones, H. P., Hole, D. G., & Zavaleta, E. S. (2012). Harnessing nature to help people adept to climate change. *Nature Climate Change*, 2(7), 504-509.

National Research Council (2012). *Sea-level rise for the coasts of California, Oregon, and Washington: Past, present, and future*. Washington, DC: National Academies Press. Print, ISBN 978-0-309-25594-3, 250 pp.

TNC, 2013. *Reducing Climate Risks with Natural Infrastructure*. The Nature Conservancy. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/california/ca-green-vs-gray-report-2.pdf

C. Developing Impact Indicators of Ocean Acidification and Hypoxia in Marine Protected Areas in California

Goal: This project will develop indicators relevant to ocean acidification and hypoxia that can be incorporated into ongoing marine protected areas (MPA) monitoring efforts in California. Indicators will be designed to assess impacts of ocean acidification and hypoxia on ecosystem condition. When used in monitoring the statewide MPA network, indicators can illuminate how California's marine ecosystems are affected by acidification and hypoxia in absence of other stressors (e.g. fishing pressure). Indicator development will better define the scope of monitoring programs associated with adaptive management of the MPA network and ecosystem climate adaptation strategies.

Problem Description: Ocean acidification and hypoxia, two phenomena often coupled for a variety of biological and oceanographic reasons, have the potential for profound impacts on California's living marine resources. Scientists have already demonstrated serious impacts on shell-building organisms, among others, and severe effects on the shellfish industry have been documented in the Pacific Northwest. In California, resource managers, stakeholders, tribes and citizens are beginning to express concerns about these emerging threats to local ecosystems, communities, and coastal economies.

California's investment in a network of marine protected areas (MPAs) provides opportunities to study the early impacts of ocean acidification, hypoxia and other stressors, while bolstering the resilience of California's ocean ecosystems in the face of these emerging threats. MPAs can serve as "living laboratories" to document how acidification and hypoxia are affecting marine ecosystems, and can potentially bolster ecosystem resilience by serving as refuges from these phenomena and other stressors.

Further research is necessary to understand how California's MPAs can be used as a strategy for adapting to the effects of ocean acidification and hypoxia. Adaptive management of the MPA network, as called for in the Marine Life Protection Act, requires monitoring to provide rigorous science for informed decision making about MPA design and management. The proposed research would merge ongoing efforts on ocean acidification, hypoxia and MPA monitoring, with the end goal of providing decision makers with the knowledge needed to rigorously evaluate effective management actions.

Proposed Work: Research will focus on developing indicators relevant to ocean acidification and hypoxia that can be incorporated into ongoing MPA monitoring. Indicators will also be developed to better understand how MPAs can potentially reduce ecosystem vulnerability to acidification and hypoxia. Long-term implementation of

MPAs in other countries has shown that they are an effective tool in bolstering marine ecosystem resilience to climate change impacts. By acting as refuges from other stressors, MPAs can reduce ecosystem vulnerability to acidification and hypoxia. MPA networks are already a ‘tool in our toolbox’ for ecosystem-based management in California; understanding how they serve to protect ecosystems and potentially increase resilience offers an immediate path forward for considering ocean acidification and hypoxia within current management frameworks.

California has started to put in place the pieces necessary to understand ocean acidification and hypoxia impacts to MPAs, and conversely MPA effectiveness at bolstering resilience to impacts, but further investment is necessary to merge these issues and develop an appropriate set of indicators to inform decision making. Observations of key physical, chemical and biological parameters, both inside and outside of MPAs, can support management efforts at the state and federal levels to predict how marine ecosystems will respond and refine existing management strategies for adapting to the consequences of ocean acidification. Strategically selected indicators that can be incorporated in to ongoing MPA monitoring and climate change assessments will allow California to balance cost with the utility of information collected.

Background: Research on ocean acidification and hypoxia impacts to California’s marine ecosystems is occurring along the coast. For example, researchers from UC Davis Bodega Marine Lab are working with shellfish operators in Tomales Bay to identify how acidification may affect their operations. The Ocean Margin Ecosystem Group on Acidification (OMEGAS) are among a host of research programs currently underway, and the California Current Acidification Network (C-CAN) brings industry, resource managers and scientists together on this issue.

California is collaborating with Oregon, Washington and British Columbia on convening the West Coast Ocean Acidification and Hypoxia Science Panel, a high-level ocean acidification and hypoxia science panel that will provide decision makers with knowledge needed to thoughtfully evaluate effective management actions. The panel is charged with addressing information and data gaps critical to resource management decisions, and identifying research and monitoring needs.

The Ocean Protection Council has invested in baseline monitoring of the regional MPA networks, and is working with the California Ocean Science Trust (OST) and California Department of Fish and Wildlife (CDFW) on ongoing monitoring of the statewide MPA network. MPA monitoring is guided by regional monitoring plans, developed by OST and CDFW, to identify strategically selected ‘pulse points’ of ecosystems and habitats that give the greatest insight into ecosystem condition. Focused management questions will address key aspects of MPA management and network design to increase the effectiveness of this management tool.

Additionally, the Office of Environmental Health Hazard Assessment (OEHHA) has a contract with the University of California, Davis Bodega Marine Laboratory to develop indicators addressing acidification and its impacts on marine organisms, oxygen concentrations, and coastal ocean temperature. Although the focus of OEHHA’s effort is to study present trends, rather than to inform management and adaptation, the proposed research should be closely coordinated with OEHHA’s effort.

A process is necessary to bring these ongoing efforts together to identify a common set of indicators that can be integrated into MPA monitoring to better inform how to ‘put the MPAs to work’ for addressing ocean acidification and hypoxia. As the state moves into long-term monitoring of the MPAs, it is necessary to identify indicators to answer shared questions and key research priorities that are important to decision makers and local communities about the effects of, and adaptation strategies to respond to, ocean acidification and hypoxia. The innovative approach to MPA monitoring that has been put in place, which is already engaging a network of scientists in cutting-edge research, means that the state and partners are poised to bring new science to bear to address acidification and hypoxia.

4. Water Security and Long Droughts

Extreme events, including prolonged drought, exacerbated by climate change have significant consequences for the quantity and quality of available fresh water resources in California. Water scarcity places increased pressure on multiple competing uses, from aquatic ecosystems and agriculture to urban water delivery.

Lessons can be learned from the current drought to better adapt water utilities, modeling tools, and California's allocation system to extreme events. Studies will include both quantitative and qualitative analysis of select case studies to clarify what can be learned from this and prior extreme events, as well as to create tools for adaptation planning.

The three proposed research projects in this area are described below. Climate and hydrologic scenario(s) will be available with realistic decadal and multi-decadal droughts that recent research suggests are more probable with a warming climate in California. This "worst" case scenario (s) will also include years with very heavy precipitation conducive to flooding.

WATER SECURITY AND LONG DROUGHTS

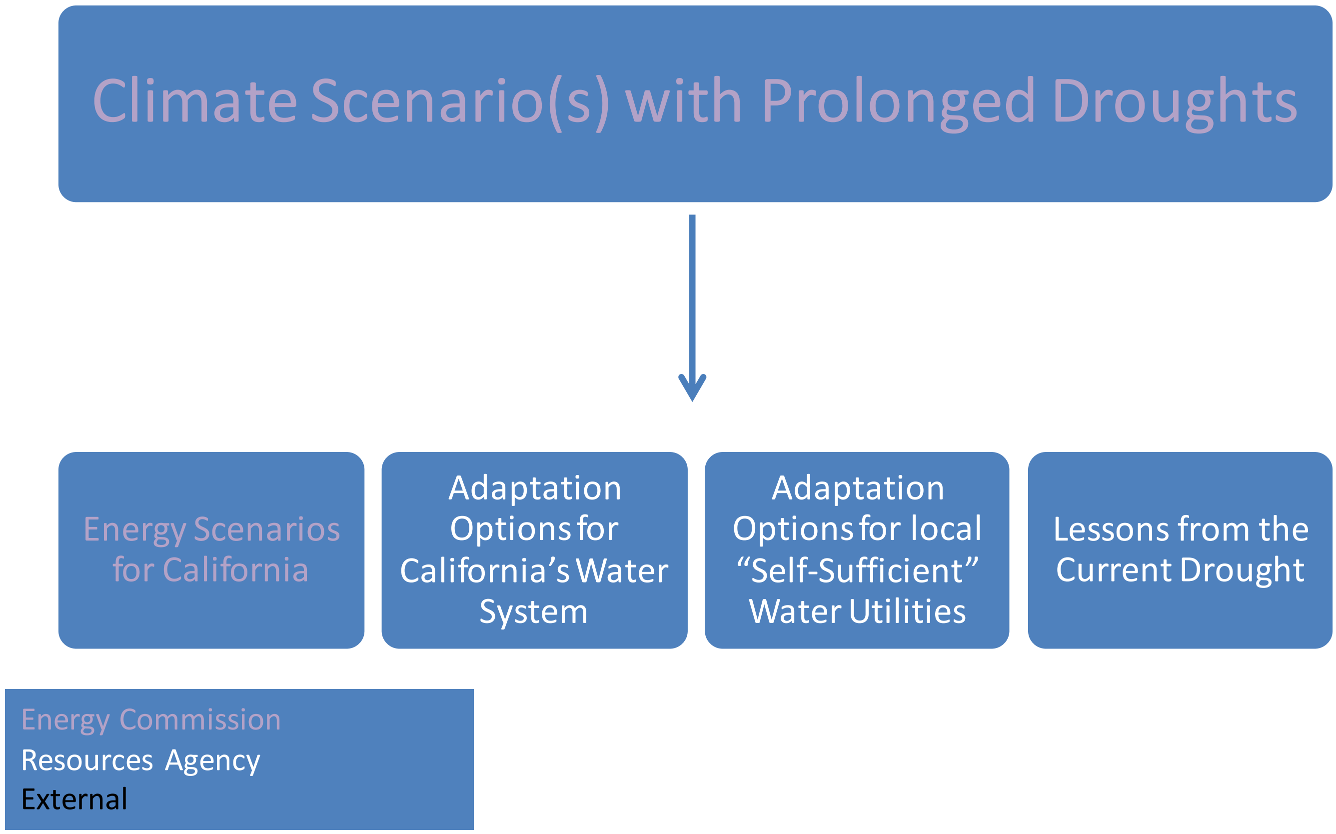

Figure 4: Research projects in the area of "water security and long droughts" will draw directly on regionally downscaled climate scenarios that portray long droughts in California, such as the multi-decadal droughts evidenced in the paleo record. These primary regional climate scenarios will be developed by the California Energy Commission in collaboration with California's Natural Resources Agency as well as other state agencies involved with the Fourth Assessment.

A. Adaptation Options for California's Water System: Improving models of human-hydrological interaction for climate adaptation

Goal: The purpose of projects in this area is to enhance reliability of models related to water security in California (e.g., CALVIN, WEAP, CALSIM, etc.) by making their parameters more realistic in response to a changing climate, and to use these enhanced models to explore realistic adaptation options. Realistic parameters are broadly defined to include, for example, considering changes in laws and regulations that affect water security as well as changes to physical infrastructure (including effects of climate change) and patterns of purchasing behavior.

Problem Description: Prior optimization models based on engineering and economic considerations (e.g., CALVIN), which were developed to represent most of the California water system, suggest that the water system is adaptable, though not without monetary and possibly environmental costs. However, problems with credibility arise if the models have rigid social assumptions like a perfect statewide market (see Coase, 1988), or perfect information about future water availability (Doremus and Tarlock, 2005). Prior work using simulations models (e.g., CalSIM) may, on the other hand, be too pessimistic with regard to potential impacts, because they assume that existing rules, regulation, and policies do not change in the rest of this century.

Proposed Work: Projects in this area should therefore,

- Include relaxed assumptions about a statewide market to render models more realistic. Projects should investigate whether a "less optimum" but more politically and sociologically feasible set of regional markets could still reduce the net economic and environmental costs to California from changing hydrology and use patterns.
- Incorporate common practices for water purchasing. It is common practice among water purchasers (especially urban water agencies) to purchase water on a seasonal basis and commit themselves before the start of the irrigation season to purchase a given volume of water for the upcoming season (see Hanak and Stryjewski, 2012). Projects should bring their assumptions about water purchasing closer in line with actual practices by imposing a constraint that, if a purchase occurs, it entails an equal quantity of water being purchased by the buyer from the seller every month during the main irrigation season (say, April – September), rather than allowing the quantity to vary from one month to another.
- Investigate, through results of runs, the parts of the water infrastructure (e.g., pipelines transferring water from location A to location B) most vulnerable to climate change. It is conceivable that a physical upgrade to the water system (e.g., increased water delivery capacity of a given conveyance system) would significantly reduce the vulnerability of the water system. As much as possible, these situations should be investigated.
- Include in the scenarios modeled the "worst" case climate scenario that will include prolonged droughts and extreme flooding events.

Simulations models, such as WEAP and CALSIM, estimate the behavior of a given water system, obeying existing water management rules and physical constraints. The water rules can be relaxed to investigate adaptation opportunities. Prior work has developed indices (e.g. conditions under which flooding is likely to occur) to estimate the vulnerability of specific water services to climate change. Those indices, however, used only a rudimentary set of climate change hydrologies to estimate vulnerabilities, which limits the usefulness of existing models. To offer more reliable tools for decision making, projects in this area should therefore:

- Address which facilities have the least operational capacity for change by transforming the daily VIC hydrology provided into model inflows for infrastructure (e.g. reservoirs, powerhouses, penstocks, etc.) to assess vulnerability of specific facilities and suites of facilities to changing hydrologies by sensitivity analysis of infrastructure options.
- Translate findings from above into a sector level assessment of potential adaptation strategies—operational and/or institutional—to minimize potential impact.

Background: Examples of existing human-hydrological models include the following:

- The WEAP (Water Evaluation and Planning) model is a user-friendly software for managing water resources. The software allows for allocation of water resources between agricultural, municipal and environmental uses integrating water supply, demand, quality, and ecological considerations.
- CALVIN is a statewide economic-engineering water allocation optimization model, based on historic hydrologic datasets, designed to represent seasonal and annual variability in the California hydrologic system.
- CalSIM is a water resources integrated model for evaluating operational alternatives for large, complex river systems, such as the Central Valley of California.

References:

Coase, R. *The Firm, the Market, and the Law*. Chicago: University of Chicago Press.

Doremus, H. and Tarlock, A.D. 2005. Science, Judgment, and Controversy in Natural Resource Regulation. *Pub. Land & Resources L. Rev*. 26: 1-50.

Hanak, H. and Stryjewski, E. 2012. *California's Water Market, By the Numbers: Update 2012*. Public Policy Institute of California.

B. Adaptation Options for Local "Self-Sufficient" Utilities

Goal: The purpose of projects in this area is to investigate the barriers to and possibilities for adaptation for "at risk" water utilities that are not connected to California's major water delivery systems, the Central Valley Project (CVP) and the State Water Project (SWP).

Problem Description: Smaller utilities that are not connected to California's major water delivery systems (CVP and SWP) face multiple challenges in adapting to water scarcity, saltwater intrusion, and the myriad effects of climate change.

Proposed Work: Projects should take a social science approach to studying the problems smaller utilities face in periods of prolonged water scarcity, as in the recent drought.

In light of recent changes, both legal and hydrological, follow up work needs to be done to establish the following:

- What do small utilities need in order to adapt to water scarce conditions (e.g., what types of information, models, capacity, cooperation, etc.)?
- What prevents them from overcoming barriers to adaptation (whether legal, social, or physical)?
- What do they consider to be lessons-learned from the recent drought?
- What adaptation measures appear to be working?
- Investigate the implications of the "worst" case climate scenario that will be available for the Fourth California Climate Assessment that includes prolonged droughts and flooding events.

Projects should focus on a small number of case studies in favor of in depth qualitative interviews, and should build on prior work done for the California Energy Commission and the Department of Water Resources.

Background: Prior work in this area was done in a PIER-funded study for the California Energy Commission by researchers at UC Santa Cruz (Langridge et al. 2012). They surveyed five "self-sufficient" water districts and one groundwater basin region. That study proposed that small utilities invest in groundwater banking, or saving, to use during drought years, as an adaptation measure. They concluded that one of the barriers to investing in groundwater banking was the lack of clear state regulation of groundwater. Since the publication of that report, Governor Brown has signed a package of groundwater bills S.B. 1168, S.B. 1319, and A.B. 1739, that will change how groundwater is managed in California.

References:

Langridge et al. 2012. *Climate Change and Water Supply Security: Reconfiguring Groundwater Management to Reduce Drought Vulnerability*. Prepared for the California Energy Commission. CEC-500-2012-017. http://www.energy.ca.gov/2012publications/CEC-500-2012-017/CEC-500-2012-017.pdf

C. Lessons from the Current Drought: Adapting to Increased Water Stress

Goal: This project will address legal, regulatory, and institutional barriers to preparing for and responding to climate risks to California's water systems. Research will improve understanding of the vulnerabilities and strengths of California's water allocation system in the face of non-stationarity to provide water for both in-stream uses (e.g. aquatic habitat) and out-of-stream diversions (e.g., agriculture and urban use).

Problem Description: Climate change will increase the frequency and severity of drought in California. The potential impact on water supply reliability for agricultural and urban water users is one key concern. Aquatic ecosystems are another. Two key challenges face California's water management system in a future likely to bring higher demand and more variable supply: allocation of water between in-stream and out-of-stream uses and among diverters. In the current drought, water managers have struggled to make, explain, and gain acceptance of some of their decisions—issues which are likely to intensify with climate change. Research on where, how, and under what constraints water management decisions are made is crucial to improving water allocation decisions.

Proposed Work: By using the most recent extreme drought as a "stress test"—projects should consider climate adaptation options for California's water system and reveal how it does and does not function effectively during times of water scarcity. This study will be mostly a review of actions taken in the most recent drought to critically review what worked and what improvements are needed for potential similar or more extensive droughts and periods of water scarcity. The emphasis should be on practical measures for a continued drought or if a similar drought materializes in the near future.

Projects should examine not just what the laws and regulations are that determine water allocation, but also what the realities of allocation decision-making in practice. Projects should therefore be grounded in rigorous empirical work with a qualitative social-science focus. To the extent possible, research should consider the interconnections between surface water and groundwater, and highlight future issues for research in climate adaptation for conjunctive management. Ultimately, research should synthesize data from their findings to make recommendations for adaptation in the water allocation system.

Although not an exclusive list, projects may study a combination of any of the following aspects of the water allocation system:

- Discrepancies between actual and stated projections for deliveries from the Central Valley Project and State Water Project
- Environmental restrictions on water diversions or deliveries, and the use of flexible mechanisms to relax them
- "Calls" or "curtailments" of water rights made by the State Water Resources Control Board (SWRCB), requiring junior users to discontinue use in favor of senior rights holders and in-stream flows
- Voluntary water transfers

In conserving these aspects of the water system, proposals should examine the extent to which the relative priority of water rights correlates in practice with the risk of reductions in water supplies; whether environmental flexibility decisions are made with appropriate consideration of environmental impacts and other consequences; and the potential of water markets to increase climate resilience.

Background: This research proposal would fill key gaps in our understanding of the institutional vulnerabilities in the water sector. Hanemann et al. (2012) initially explored issues of legal barriers to adaptation in California's water sector in a report for the California Energy Commission. That report, while groundbreaking, took a broad and distant view of the interaction between law and society, with only minimal interviews to support conclusions about how water management decisions are made and constrained. Furthermore, while there have been numerous reports on prior droughts, the current extreme drought provides an opportunity to learn from disaster and plan for adaptation.

References:

Hanemann, M., D. Lambe, and D. Farber. 2012. *Climate Vulnerability and Adaptation Study for California: Legal Analysis of Barriers to Adaptation for California's Water Sector*. California Energy Commission. CEC-500-2012-019. http://www.energy.ca.gov/2012publications/CEC-500-2012-019/CEC-500-2012-019.pdf

5. Forecasting to Support Climate-Resilient Decision-Making

By the end of this century, climate patterns are expected to have substantially deviated from their historical norm. Accordingly, new decision support tools and management protocols must be developed to support climate resilience. For example, "probabilistic" seasonal and decadal forecasts can aid decision makers in a variety of climate-sensitive sectors that must adapt to unfamiliar climatic conditions.

Prior state-sponsored research has established that probabilistic seasonal and decadal forecasting based on state-of-the art regional climate projections could be incorporated into water resource management in a manner that reduces risks, enhances benefits, and saves money. Moreover, the results indicate that integration of probabilistic forecasting into water management protocols would be "no regrets", as it would improve outcomes both under current <u>and</u> expected future climate variability.

The proposed research project in this area will leverage planned energy-sector research that will produce probabilistic forecasting to improve energy sector planning.

FORECASTING TO SUPPORT CLIMATE-RESILIENT DECISION MAKING

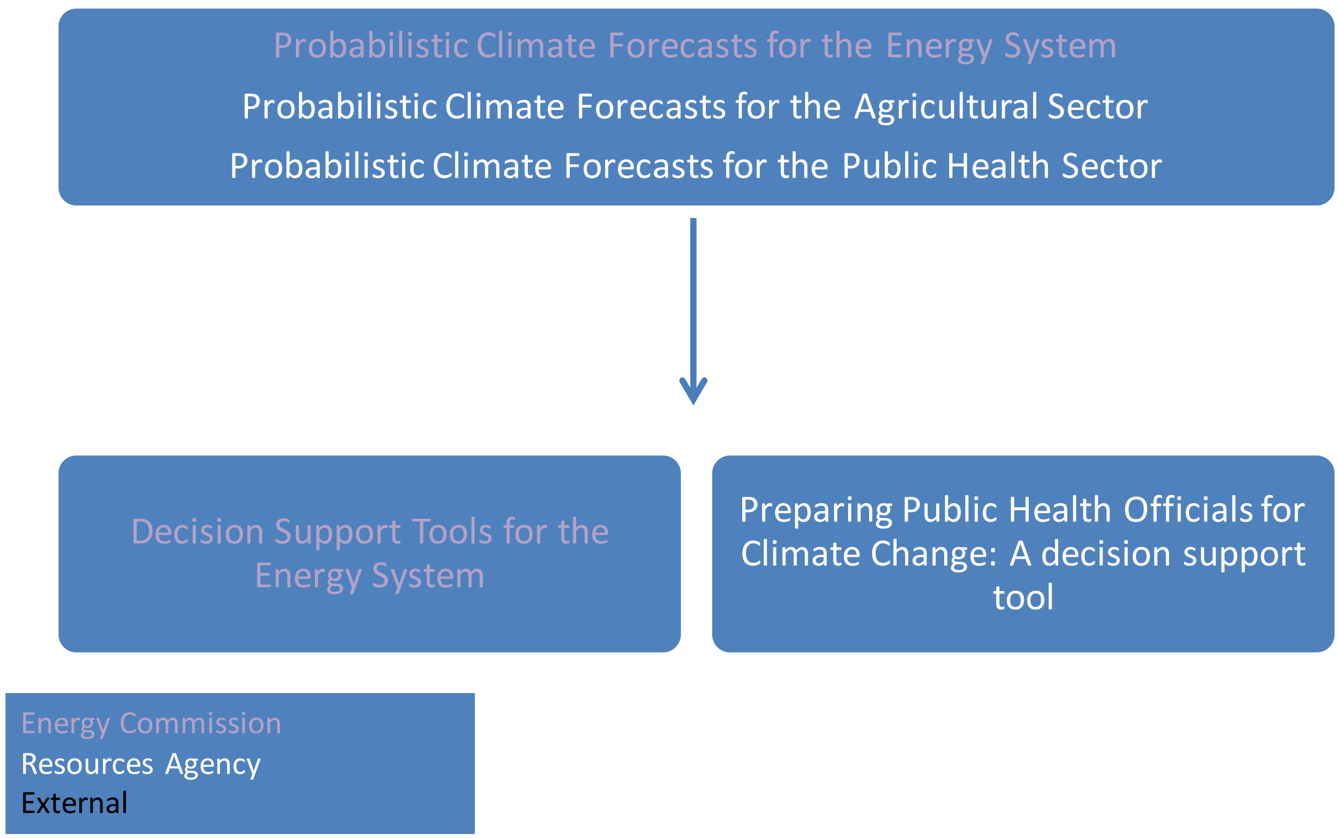

Figure 5: Research projects in the area of "forecasting to support climate-resilient decision making" will draw directly on probabilistic climate forecasts tailored to meet the needs of the energy system and public health. These primary probabilistic forecasts will be developed by the California Energy Commission and California's Natural Resources Agency in collaboration with other state agencies involved with the Fourth Assessment.

A. Preparing Public Health Officials for Climate Change: A Decision Support Tool

Goal: This project will develop a decision support tool for public health officials using probabilistic short-and medium-term weather/climate forecasts[3] designed to assist the public health sector with adapting to climate variability and change. Tool development will involve close collaboration with the California Department of Public Health (CDPH), the Office of Environmental Health Hazard Assessment (OEHHA), and local public health agencies, whose needs and preferences will be incorporated into design of this decision support tool.

Problem Description: The National Oceanic Atmospheric Administration (NOAA) generates short- and medium-term (e.g., few months in advance) climate forecasts for the United States, but these products are not fully utilized by the public health sector. One of the primary reasons is because the NOAA data has not been fully tailored for the use by public health officials in California. For example, past public health warnings about heat waves do not necessarily cover events that have been found to have deleterious public health effects. It is not fully understood how improved weather/climate forecasts would actually help public health officials adapt to current levels of climate variability; this research will explore possible benefits. For other applications (e.g., management of water reservoirs), decision support tools that make use of probabilistic weather/climate forecasts have been found to be extremely useful (HRC-GWRI, 2011).

Proposed Work: The selected research team must work very closely with the public health agencies listed above and other institutions interested in this activity. The proposed research would include the following:

- Gathering information from public health officials about weather/climate parameters (e.g., days with temperatures above the historical 98 percentile with high nighttime temperature) that are important for them to anticipate potential weather-related impacts with negative public health outcomes;
- Determine the availability of this information at the necessary temporal and geographical resolutions and make this information available to participating public health groups in a user-friendly format delivered via Cal-Adapt and using, as a starting point, the data available from NOAA. At a minimum, the research team will enhance publically available information available from NOAA and other entities to improve the probability forecasts using, for example, bias correction methods. Development of new, improved forecasting methods is not required but is also an accepted approach.
- Coordinate with similar efforts for the 4th California Climate Change Assessment for the energy and agricultural sectors.
- Develop a decision support tool with the active participation of selected public health officials and estimate the potential use of this tool as an adaptation tool for current levels of climate variability and future climate change. If possible, this tool could also be used with the climate scenarios developed for the 4th California Climate Assessment.

The proposed research would help identify and overcome barriers to climate adaptation in the public health sector by supporting development of a decision-support tool that is responsive the needs of this group.

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[3] Forecasts one more than about a week in advance are identified as "climate forecasts." Weather forecasts refer to forecasts for the next several days.

The proposal must indicate what areas of the state would be covered with this research.

Background: The documents listed in the references provide substantial background information on this topic.

References:

Preparing California for Extreme Heat: Guidance and Recommendations. October 2013.
http://www.climatechange.ca.gov/climate_action_team/reports/Preparing_California_for_Extreme_Heat.pdf

Safeguarding California: Reducing Climate Risk. An update to the 2009 California Climate Adaptation Strategy. Natural Resources Agency.
http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf

6. Preparing for Emergency Management in a Changing Climate

California's capacity to respond to disasters depends on the integrity of critical facilities such as emergency operation centers (EOC's), fire stations, hospitals, transportation routes, utilities, government buildings, and hospitals; as well as the functionality of transportation systems, including public transit and active modes, both of which can be critical during and after disasters or extreme events. Although prior research based on seismic vulnerability identifies and seeks to address risk in state-owned buildings with critical functions that are vulnerable to earthquakes, no such effort has been undertaken to identify state-owned and operated critical facilities that are subject to risks associated with climate change. Ultimately, the state must integrate the prospect of climate-related extreme events into its efforts to prepare for handling simultaneous incidents that may rapidly exceed the State's routine capacity for emergency response.

A. Climate Change and Emergency Management in California

Goal: This project will undertake a regional or statewide risk assessment of existing state-owned and state-operated structures critical to response and recovery operations that are currently located in areas of high risk and subject to impacts of climate change. A secondary goal is to investigate ways to make critical transportation systems more resilient to weather-related emergency events.

Problem Description: The President's Executive Order, Federal Emergency Management Agency (FEMA), Safeguarding California Plan, the State of California Multi-Hazard Mitigation Plan (SHMP) and other resiliency strategies emphasize that critical infrastructure is essential to the state's ability to provide assistance to the people of California. Facilities critical to response and recovery operations such as emergency operation centers (EOC's), fire stations, hospitals, transportation routes, utilities, government buildings, and hospitals provide the State with the capacity to respond to disasters. California's resiliency (capacity to survive and recover from a disaster) strongly depends on its ability to maintain or restore infrastructure operations in disasters. Systematically assessing the condition of infrastructure is an essential step toward enhancing California's capacity to endure and recover from a natural disaster, or multiple natural disasters, the risk of which may be substantially increased by climate change.

Robust and diverse transportation options, especially public transit and active transportation options, are also critical for building community resilience. For example, research shows that lack of access to transportation is a critical risk factor for exposure to extreme heat. These transportation options are particularly important for those at highest risk, including the elderly (especially those living alone) and disadvantaged communities.

Reliable, accessible transportation options are also critical both during and following climate-related extreme events. Transportation is a critical lifeline service for resilient communities. Public transit options are important for aiding evacuations (e.g., Hurricane Katrina), while active modes can provide transportation reliable option following a disaster. For example, bicycling became an important transportation choice following Hurricane Sandy in New York, when public transit systems were out of service.

Proposed Work: This proposal's focus will be to: 1) Identify state-owned or operated critical facilities and lifelines necessary for post-disaster and recovery operations, and assess which of those facilities are most vulnerable to damage and loss; 2) Evaluate vulnerability levels threatening continuity of operation and timely recovery of operations of those facilities in a disaster; 3) Estimate potential dollar losses to state-owned and operated buildings, infrastructure, lifelines and critical facilities located in identified high hazard areas subject to climate change; 4) Establish and implement an ongoing system to prioritize projects in relation to their relative importance to the continuity of state government and recovery operations following a natural disaster, with particular emphasis on providing resilience to disadvantaged communities; and, 5) Develop and recommend project selection criteria for the Active Transportation Program that prioritize climate change adaptation.

Background: Prior research based on seismic vulnerability was the California Vital Infrastructure Vulnerability Assessment (Cal VIVA) Project, a hazard-mitigation project funded by National Earthquake Hazard Reduction Program (NEHRP) through the Federal Emergency Management Agency (FEMA) and sponsored by the California Governor's Office of Emergency Services (Cal OES).

Cal VIVA is an implementation element of the 2010 California State Multi-Hazard Mitigation Plan (SHMP). The new program identifies and seeks to mitigate risk in state-owned buildings that house critical functions and are vulnerable to earthquakes. The Cal VIVA project began with the challenge of determining seismic vulnerability for over 24,000 state-owned buildings. The screening approach/methodology was tested on 19 buildings from four departments: Department of Forestry and Fire Protection (CAL FIRE), California Highway Patrol (CHP), California Department of Transportation (Caltrans), and California Department of Water Resources (DWR). For these selected facilities, the project made recommendations and developed associated costs for mitigating structural and nonstructural seismic vulnerabilities should funding become available. There is, however, a remaining gap to identify state-owned or operated critical facilities and to consider California's highest risk hazards that are also subject to impacts of climate change.

7. Funding and Implementing Adaptation Projects and Measures in California

A critical pragmatic need felt at all levels of government is the question of how to fund adaptation initiatives. The California Adaptation Advisory Panel offered initial ideas, but they have never been examined systematically.[4] State, regions, and local governments have identified funding constraints as among the biggest

[4] *Preparing for the Effects of Climate Change—A Strategy for California*. A Report by the California Adaptation Advisory Panel to the State of California on Critical Steps Needed to Adapt to the Effects of Climate Change. Pacific Council on International Policy. Available at: https://www.pacificcouncil.org/climatechange/report.

barriers to adaptation. To address this void, a suite of alternative options should be explored through systematic research, including private sector contributions, payments for ecosystem services, public goods charges, fees, and insurance.

Proposed research in this area is in the form of a wide-open solicitation to identify practical, California-specific opportunities for supporting adaptation measures and projects.

A. Investigation of Practical Opportunities to Fund Adaptation Measures in California

Goal: In response to the dearth of information at the state, regional, and local level regarding how to support implementation of adaptation measures, this research will (1) investigate economically and politically realistic funding possibilities for climate adaptation and (2) explore potential barriers to financing as well as ways to overcome them.

Problem Description: In general, state-wide economic studies conducted so far strongly suggest that climate change costs could be substantially lower if proper adaptation measures were adopted in a timely fashion (e.g., Franco et al., 2009). However, there is almost no information about potential funding mechanisms that could be implemented to make sound adaptation measures a reality. The level of funds required is most likely in the billions of dollars. For example, the estimated cost of the Napa River-Napa Creek flood protection project is about $500 million, which as of June 2013 is roughly 70 percent complete (TNC, 2013). This project makes use of green infrastructure to increase flood protection and ecological services. The Nature Conservancy's 2013 report also includes other case studies in California suggesting that natural or green infrastructure can be a relatively low-cost and effective adaptation tool. At the same time, from this report, it is clear that substantial amounts of funds will be needed.

Proposed Work: This is a broad solicitation for the identification of financially and politically sound approaches that could be used to fund adaptation projects and measures at local, regional, and/or state-wide scales. This work must include options to involve both the private sector and public institutions.

References:

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TNC, 2013. Reducing Climate Risks with Natural Infrastructure. The Nature Conservancy. http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/california/ca-green-vs-gray-report-2.pdf

B. Overcoming Barriers to Adaptation

Goal: At present, little is known regarding barriers to adaptation, or options for overcoming them, in California. This study will identify sector-specific barriers, which may be regulatory, legal, scientific, socioeconomic, institutional, and/or financial. The study will also explore options for overcoming the identified barriers.

Problem Description It is now clear that to translate adaptation studies into practical implementation of adaptation measures, it is necessary to identify regulatory, legal, scientific, socio-economic, institutional, and financial barriers and options to overcome them. Here we define barriers "as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, institutions…" (Moser and Ekstrom 2010). One of the potential barriers to adaptation is a legal framework that may impede or at least create obstacles to the implementation of technically attractive adaptation options. For example, studies have shown that the use of groundwater reservoirs to store water during wet years and making this water available during dry years is an attractive adaptation option (Medellín-Azuara et al. 2008; Langridge et al. 2012). However, a legal analysis conducted by researchers at the Center for Law, Energy & Environment in UC Berkeley found the current interpretation of water law would not allow the implementation of this measure. In addition, the lack of information about the amount of water obtained from groundwater resources would impede the implementation of this measure at the needed scale (Hanemann et al. 2012). Similar studies are sorely needed to identify similar obstacles in other issues and sectors.

Proposed Work: This is a broad solicitation for a sectoral case study that identifies barriers to adaptation as well as viable strategies for overcoming these barriers.

References:

Moser, S. C., and J. A. Ekstrom. 2010. A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences*. 107:22026-22031.

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Langridge, R., A. Fisher, A. Racz, B. Daniels, K. Rudestam, and B. Hihara. 2012. *Climate change and water supply security: Reconfiguring groundwater management to reduce drought vulnerability*. A white paper from the California Climate Change Center, Publication Number: CEC-500-2012-017. http://www.energy.ca.gov/2012publications/CEC-500-2012-017/CEC-500-2012-017.pdf

Hanemann, M., D. Lambe, and D. Farber. 2012*. Climate vulnerability and adaptation study for California. Legal analysis of barriers to adaptation for California's water sector*. California Climate Change Center. California Energy Commission, Publication Number: CEC-500-2012-019. http://www.energy.ca.gov/2012publications/CEC-500-2012-019/CEC-500-2012-019.pdf