APPENDIX H
Fire and Fuels – A CABY Climate Change Case Study

MC-1 Modeling

The California Climate Change Center's "Climate Scenarios" project, initiated in 2005 in response to then Governor Schwarzenegger's Executive Order S-3-05, analyzes potential climate change impacts on vegetation changes throughout the state, using the US Forest Service's MC1 model forced with lower (B1) and medium-high (A2) emissions scenarios. MC1 is a dynamic vegetation model (DGVM) with three components, including: 1) a simulation of plant type mixtures and vegetation types; 2) a description of the movement of carbon, nitrogen, and water through ecosystems; and 3) fire disturbance. The scenarios used for this work (B1 and A2) and the models feeding the climate forcing (GFDL and PCM1) are the same ones used in the state's Cal Adapt modeling scenarios. (Lennihan, 2008)

The CABY Climate TAC judged the MC1 model to be a useful one for the region for two main reasons: 1) it would build on information already collected regarding fire occurrence and vegetation change within the CABY region, and 2) large scale vegetation change can be analyzed from a general perspective, allowing a diverse stakeholders to talk about overarching management and adaptation strategies. The MC1 vegetation types discussed are described in **Table 1**.

Table 1. MC1 Vegetation Community Types [1]

MC1 Vegetation Type	Regional Examples
Boreal Conifer Forest	Lodgepole Pine forest, Whitebark Pine forest
C3 Grasslands	Valley grassland
C4 Grasslands	Desert grassland
Continental Temperate Coniferous Forest	Mixed conifer forest, Ponderosa Pine forest
Mediterranean Shrubland	Chamise chaparral
Temperate Arid Shrubland	Sagebrush steppe
Temperate Conifer Savanna	Canyon Live Oak woodland
Temperate Mixed Xeromorphic Woodland	Blue Oak woodland
Warm Temperate/Subtropical Mixed Forest	Douglas Fir/Tanoak forest, Ponderosa Pine-Blackoak forest, Tanoak-Madrone-Oak forest

[1] The **biogeography module** simulates the potential life-form mixture of evergreen needle-leaf, evergreen broadleaf, and deciduous broadleaf trees, as well as C3 and C4 grasses. The tree life-form mixture is determined at each annual time-step as a function of annual minimum temperature and growing season precipitation. The C3/C4 grass mixture is determined by reference to their relative potential productivity during the three warmest consecutive months. The tree and grass life-form mixtures together with growing degree-day sums and biomass simulated by the biogeochemistry module are used to determine which possible potential vegetation types (~20) occurs at each grid cell each year.

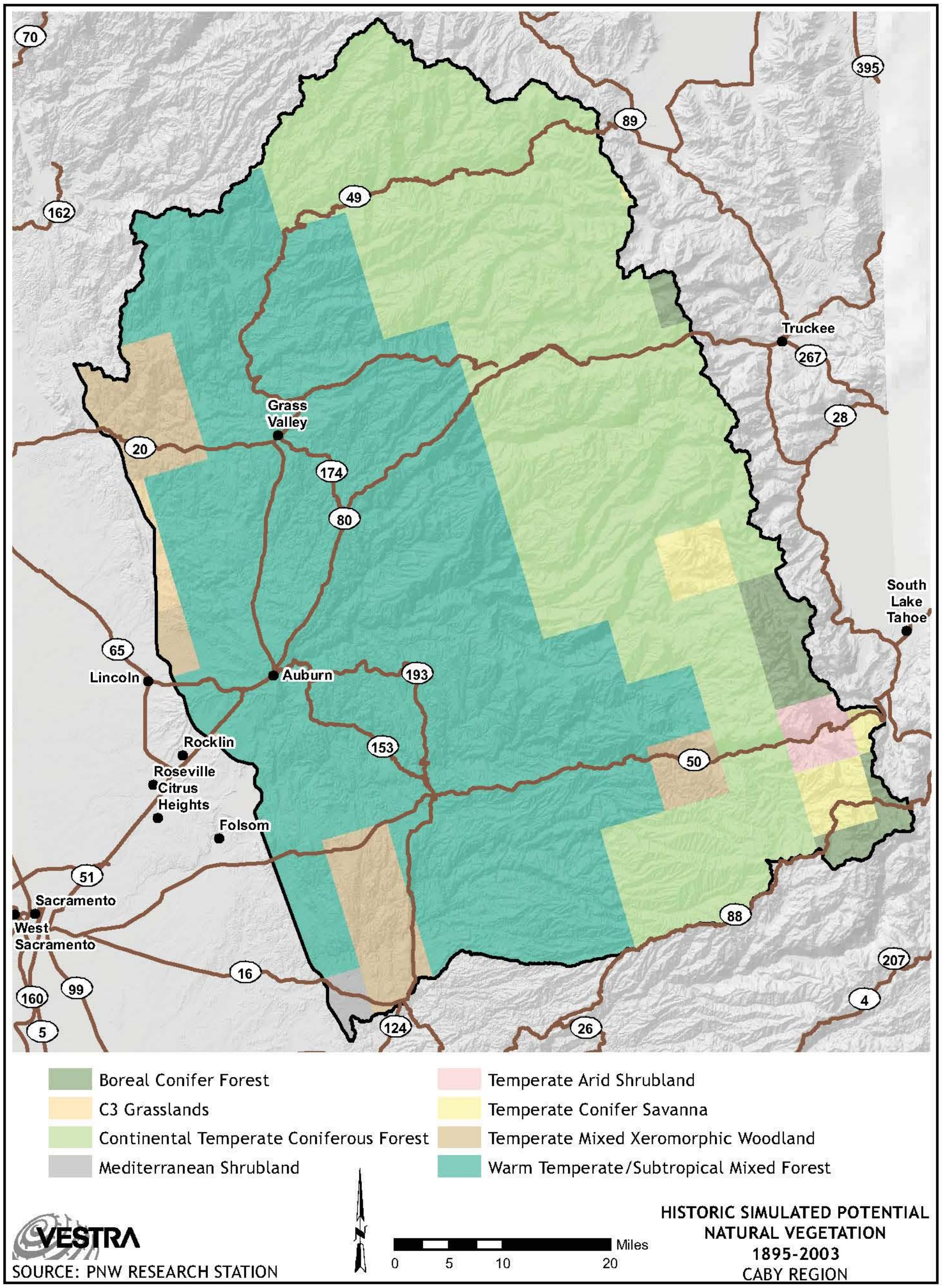

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Figure1: Historic simulated potential natural vegetation from 1895-2003.

All future scenarios project an increase in the number and severity of fires, but the change becomes more significant toward the end of the century (Lenihan, 2008). The future scenarios modeled for the CABY Climate TAC show an increase in and general upslope movement of the warm temperate/subtropical mixed forest. This is largely displacing the boreal conifer forest, which is less tolerant of heat and drought. The temperate mixed xeromorphic woodland moves upslope from the foothills just outside of the western edge of the CABY region, further into the region (displacing the warm temperate/subtropical mixed forest, which is also moving upslope). In addition, the vegetation communities at the highest elevations in the CABY region become more complex in terms of variety and generally drier, moving to temperate arid and/or Mediterranean shrubland, expanded xeromorphic woodland, and C3 grasslands[2]. The figures below show these changes.

[2] Perennial grasses can be classified as either C3 or C4 plants. These terms refer to the different pathways that plants use to capture carbon dioxide during photosynthesis. These differences are important because the two pathways are also associated with different growth requirements: C3 plants are adapted to cool season establishment and growth in either wet or dry environments, and C4 plants are more adapted to warm or hot seasonal conditions under moist or dry environments. C3 species also tend to generate less bulk than C4 species, but the C3 feed quality is often higher.

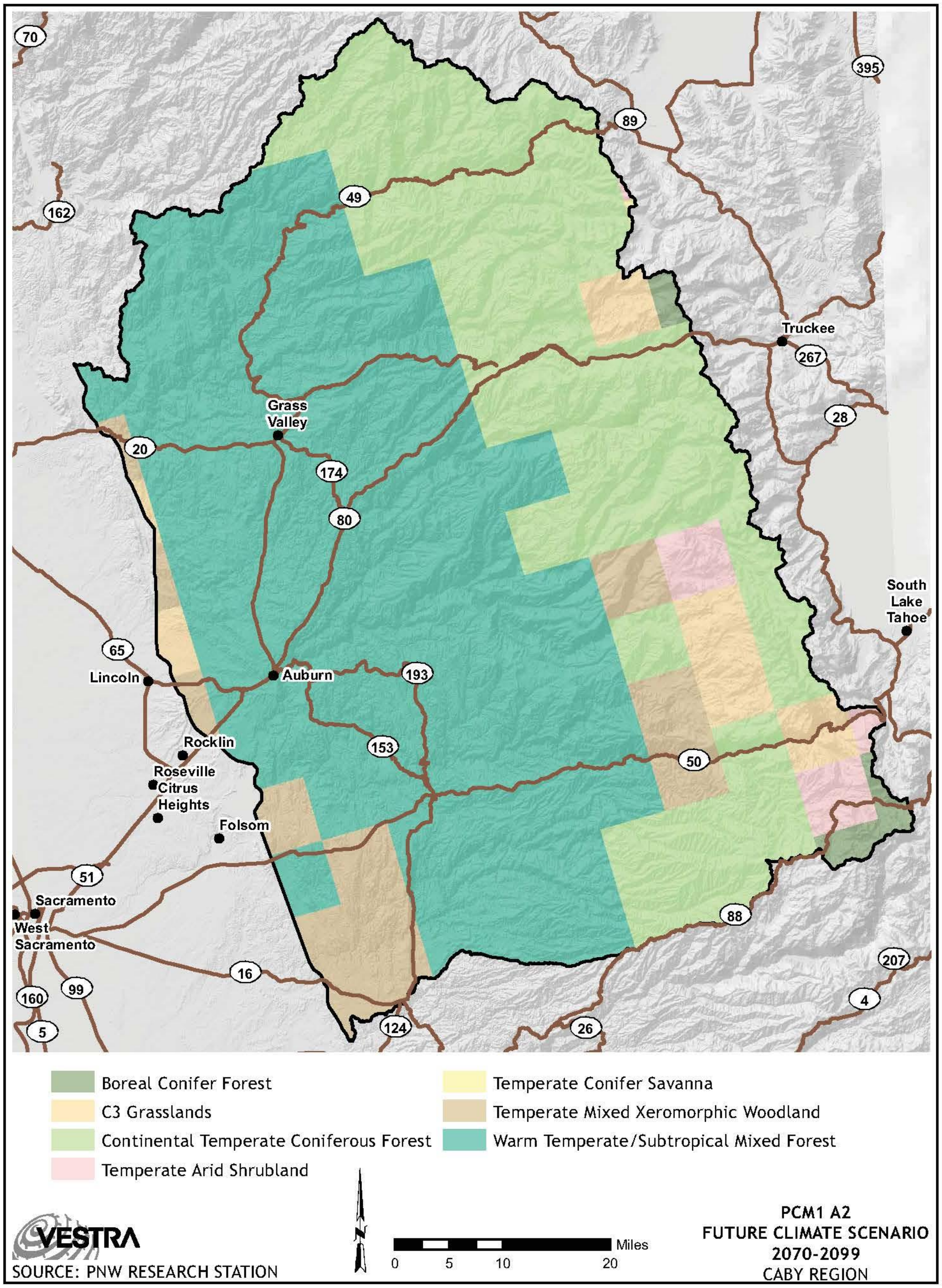

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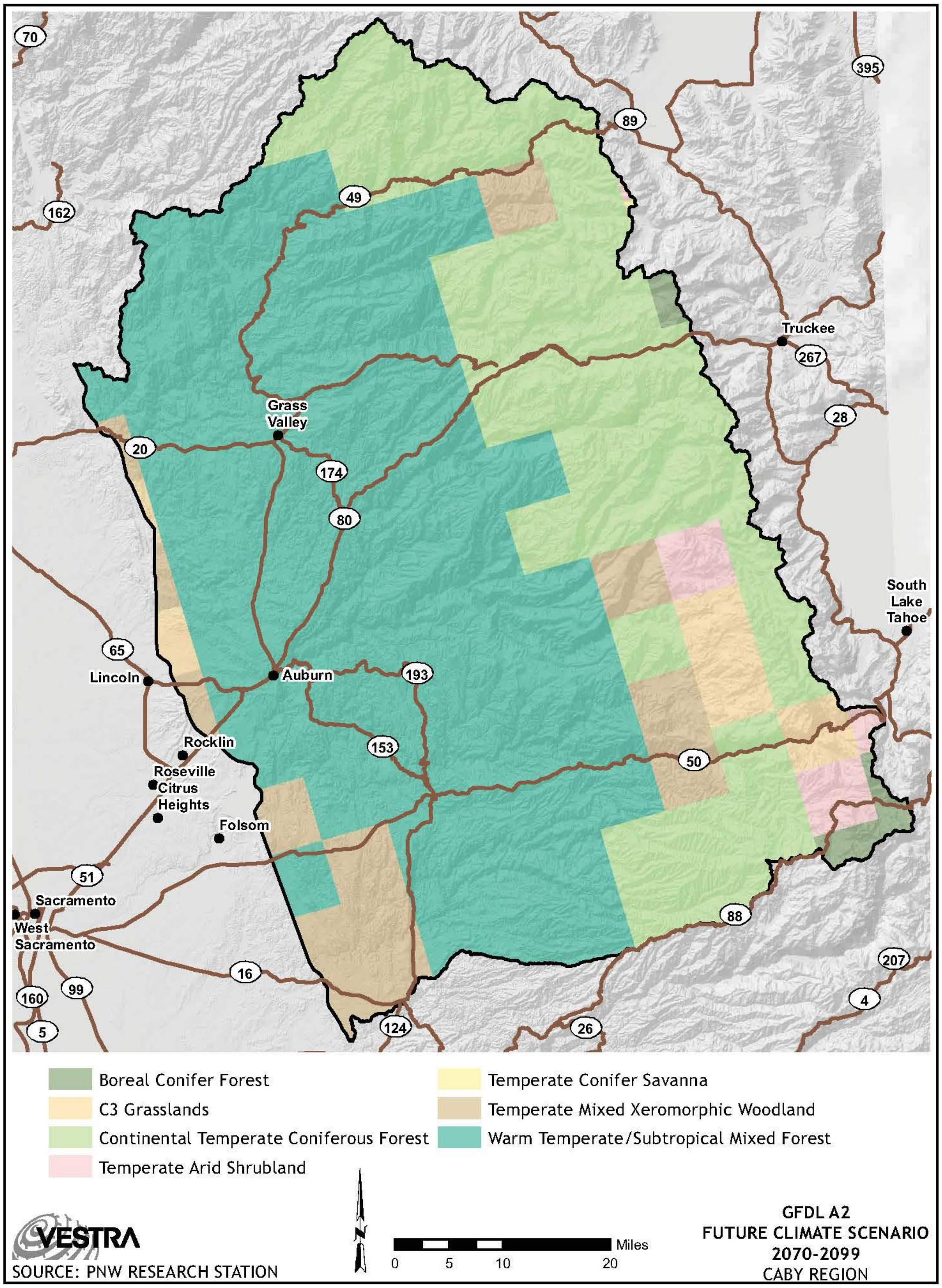
Figure 2: PCM1 A2 future climate scenario 2070-2099.



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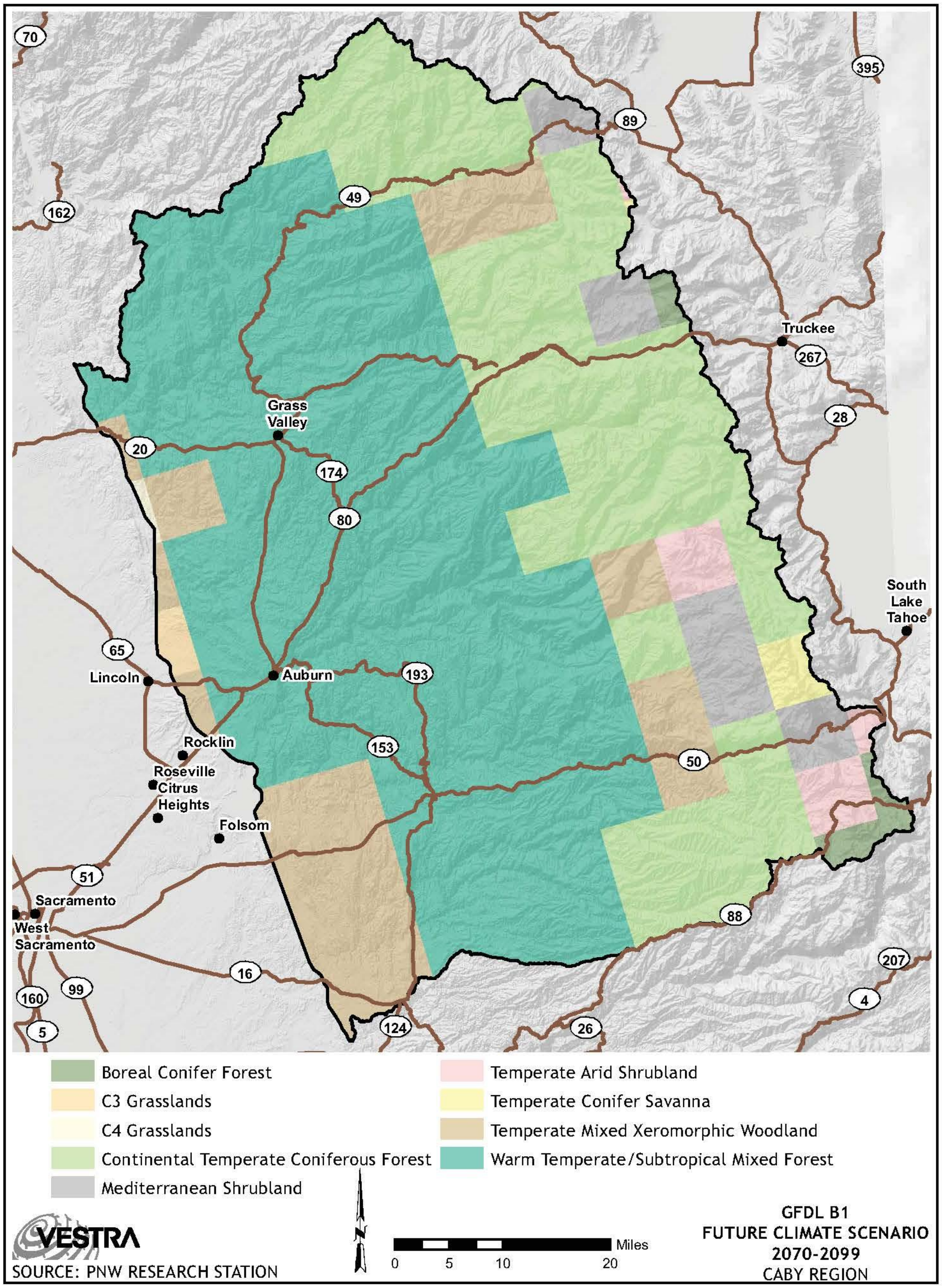

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Figure 4: GFDL B1 future climate scenario 2070-2099.

These data corroborate the information uncovered in the literature review: warmer conditions and more highly variable hydrology indicate the movement of different habitats and biomes upslope as well, as an increase in total biomass.

Fire and Fuels Vulnerabilities

Increased wildfire risk and severity are vulnerabilities throughout the Sierra Nevada (Westerling, 2008). Catastrophic wildfire in particular is projected to become more frequent and more severe in the coming decades. All analyses completed for fire occurrence and severity into the future predict more fires and greater severity (Bryant, 2009; Fried, 2004; Lenihan, 2006; McKenzie, 2004; Westerling, 2008). These are the same data used for the Cal Adapt fire risk modeling. Increased fire occurrence and severity will secondarily affect other areas of vulnerability, as noted below.

Increased Fire Risk

- Higher air temperatures in general will speed up spring melt, lengthening the fire season and drying vegetation out more quickly, creating greater fire risk (McKenzie, 2004; Miller, 1999; Running, 2006; Taylor, 2009)
- Increases are expected throughout the century in the number of fires and proportion of those that are high severity for both high- and low-emissions scenarios (Bryant, 2009; Westerling, 2008)
- On inter-annual and shorter time scales, climate variability affects the flammability of live and dead forest vegetation (Westerling, 2006)

Greater Fuel Loads

- Years with widespread fires, historically, are often preceded by wet years (Taylor, 2005) – these wet years feed greater vegetation growth, especially in the understory
- Invasive species, which often populate disturbed areas quickly, may have a competitive advantage over native species; this often results in a higher, more readily flammable fuel load (Brooks, 2004)
- Drought years may increase the fuel loads because of a greater occurrence of insects and disease that kill trees and in turn contribute to fuel loads

Secondary Effects of Increased Fire Activity

Changes in Vegetation Community Makeup:

- Fire may be more important and have more effect on vegetation change that primary climate change outcome, which can be positive or negative (Flannigan, 2000)
- Increased fire severity will both amplify and accelerate the ecological impacts of climatic change (Flannigan, 2000)
- Because trees can survive from decades to centuries and take years to become established, climate-change impacts are expressed in forests, in part, through alterations in disturbance regimes (Dale 2001)

- Increases in species dependent upon early-successional habitat (due to greater disturbance by forest fires) will have greater success (McKenzie, 2004)
- Invasive species are often more shallow-rooted and quick-lived, which can be a contributing factor to mass wasting events and excessive sedimentation in general (TetraTech EC, Inc., 2007)
- Drought years may increase the vulnerability of the tree population to insects and disease, and the lower occurrence of extended freezing periods in the winter will allow greater insect survivability
- "[Lennihan et al]… estimated that under all climate change scenarios, forests and other types of vegetation will migrate to higher elevations as warmer temperatures make those areas more suitable for survival. For example, with higher temperatures, the area of alpine and subalpine forests will be reduced as evergreen forests and shrublands migrate to higher altitudes. They estimated that if it gets wetter, forests would expand in northern California and grasslands would expand in southern California. If it gets drier, areas of grasslands would increase across the state. Both wetter and drier scenarios resulted in increases in carbon storage (biomass) in California vegetation of between 3% and 6%. Wetter conditions generally allow for more biomass. Under drier conditions, grasslands, which store a relatively high amount of carbon below ground, expand.
- Lenihan et al. found that the frequency and the size of fires would increase under most scenarios; however, the change is not significant until the latter part of the century. The drier scenarios result in more frequent fires and more area consumed by fires. The wetter scenarios result in fires of greater intensity than those in the dry scenarios because more fuel (vegetation) would grow.
- The vegetation changes projected with MC1 model indicate a generally higher threat (decrease in habitat) to boreal conifer forest, largely found at the highest elevations.

Effects on Animal Species

- Stream temperature has shown to be moderately affected by heat radiation from fires—this may affect fish and other aquatic biota. Fish are particularly vulnerable to climate change because of their inability to monitor their own body temperature, as well as having movements that are constrained to streams: linear networks that are easily fragmented (Isaak, 2010)
- Climate-induced changes in fire behavior and frequency will species distribution, migration, and extinction (Flannigan, 2000)
- Animals and plants dependent upon boreal forests will likely become more imperiled because the warming trend will force them higher in elevation where habitat may be less suitable.

Fire Creates a New Species Equilibrium – Changes in the Forest Makeup

- Positive: could lead to increased adaptability when it comes to plant migration
- Negative: could lead to increased presence of invasive species
- Warmer, drier summers will produce more frequent, more extensive fires in first (early-successional) ecosystems, likely reducing both the extent and connectivity of late-successional refugia (established forest) (McKenzie, 2004)
- Severe fires can cause changes in the trophic structure, causing animals to prey on different trophic levels. In fish, this has led to increased mercury contamination (Kelly, 2006)
- Wildfire activity will accelerate the change in species' distributions because mortality from wildfire removes the existing vegetation and exposes the most climate-sensitive life stages (germination and sprouting) to the new climate (Fried, 2004)

Changes in Nutrient Cycling, Pollutant Transfer, and Carbon Balance

- Fire has been found to increase mercury, as well as nitrates, in forest water bodies; this could be attributed to sediment methylization of mercury bound to organic matter and in runoff (Kelly, 2006)
- Greater occurrence of fires feeds a negative feedback loop, putting greater amounts of carbon and particulates into the atmosphere (Westerling, 2006)
- If forests are used as a carbon sink (or for carbon offsets), it is possible that this would compete with objectives of forest harvest and/or fuels management (Hudiburg, 2009)
- Low-frequency, high-severity fire regime may result in more carbon storage than a high-frequency, low-severity regime—this is due largely to fractional combustion, a more inefficient method of burning, resulting in greater particulate matter (Campbell, 2011)

Social Costs of Increased Fire

- The expense of increases in fire occurrence and severity will need to be paid for—either at the front end through landscape-level forest/fuels management, or at the back end through extremely costly fire-fighting activities
- The amount of burned property (in total area and in monetary value) in Northern CA increases substantially under global climate models' high-emissions scenarios due to greater fire risk. This is highly evident in Placer County (Westerling, 2008)
- Secondary effects of increased fire, such as loss of recreational amenities, area closures, and excessive smoke, can have serious financial effects for regional business interests and local economies.
- CABY is characterized by two types of communities: incorporated cities along major transportation corridors that have pressurized fire flow capability and permanent fire departments, and small, rural, surrounded by forest service or oak grasslands, frequently isolated population centers with limited fire flow volunteer fire departments and limited ingress/egress. The incorporated communities have sufficient infrastructure and capacity to fight fires within their urban limits. Rural communities typically have very limited resources to fight fires within their service area. In both cases, catastrophic Wildland fires have the potential to surround, encroached into, or overwhelm local communities.

Adaptation Strategies for Fire and Fuels

National Forests throughout the country are working to assess the risks and adaptation strategies associated with climate change. Within the CABY Region, the Tahoe National Forest (TNF) is discussing climate change responses on a focused staff level. As a result of the Forest's proactive stance, TNF has taken climate variation into account in management activities, and has started the discussion among staff regarding potential changes in strategic planning areas. Advances in integrated planning processes may facilitate the incorporation of climate-related treatments into on-the-ground management activity; all forms of proactive management are already decreasing the number of situations where TNF must take crisis-reaction responses. Some of examples of these activities include:

- <u>Fuel reduction projects</u>: Strategies implemented to reduce fuels and minimize chances of catastrophic fires are increasing the adaptability and resilience of the TNF.

- Revegetation and silvicultural choices: In stand improvement projects and revegetation efforts, choices are being considered to favor or plant different species and species mixes. For instance, where appropriate and based on anticipated changes, white fir could be favored over red fir, pines would be preferentially harvested at high elevations over fir, and species would be shifted upslope within seed transfer guides.
- Managing for process: TNF staff is also using available opportunities to manage for process rather than structure or composition in proposed projects; for example, those involving succession after fires, where novel mixes of species and spacing may reflect natural dynamic processes of adaptation.

The TAC also included the following adaptation strategies gleaned from its data and information analysis:

Decrease the fuel load (selective harvest vs. prescribed fire)

- **Strategic forest treatment has an effective, positive impact on forest fire effects (Strom, 2007): It increases resiliency to longer fire seasons and bark beetle outbreaks (Flannigan, 2000)**
- **Implement fuels management/reduction in watersheds where a high vulnerability exists to critical water sources**
    - **Where possible, mix selective harvest and prescribed fire to best mimic natural forest management (Schwilk, 2009)**
    - **Selective harvest can also enhance hydrology (Bales, 2011)**
- Moving beyond stand level treatments to landscape-level strategies using a mix of methods should improve overall fuels management effectiveness (Stephens, 2009)

Forest management and runoff enhancement

- Forest management practices affect soil absorption rates. Maintaining a forest at full ecological function recharges groundwater and provides for more resiliencies region-wideImproving and decommissioning roads and installing culverts prepares watershed for more extreme weather events
- Selective harvest can aid in both fuel load management and enhanced hydrology (Bales, 2011)
- Allow more naturally-triggered burns to be managed in the wildland areas
- Do very strategic and selective fuels management to protect areas vulnerable to a larger and less controllable wildfires
    - These smaller forest fires may force changes in species makeup, which could be beneficial if species are able to adapt quickly enough (Flannigan, 2000)
    - Protecting late-successional habitats is important for species dependent upon those areas (McKenzie, 2004)
- Forests and streams are tightly linked through the transfer of materials and energy that influence habitat structure (large wood and sediment), food webs and trophic dynamics (nutrients and organic carbon supply), water quality and temperature (riparian shade), and other ecological processes and functions (Rieman, 2010)
    - Enhancing and widening riparian corridors and preventing habitat fragmentation maximizes connectivity, promotes biodiversity, and improves water quality

Changes to migration corridors, species makeup, and carbon balance from management activities

- Fire is a catalyst for vegetation change (Flannigan, 2000)

- Forest fires may force a change in species makeup, which could be beneficial if species movement is able to adapt quickly enough (Flannigan, 2000)
    - Aggressively removing non-native invasive plant species (NNIPS) strengthens forest defenses as higher CO2 levels and potentially longer growing seasons favor faster-growing NNIPS
- Maintaining fish access to higher-elevation, cooler streams and rivers is an essential component of maintaining populations (Isaak, 2010)
- Species dependent upon late-succession habitat may founder with greater and more severe fire occurrence (McKenzie, 2004)

Coordination between/within management agencies

- The National Association of State Foresters recommend that climate change be included in the national fire plan (NASF, 2007)
- **Coordinate between management agencies and levels to better address clear management goals (Reiman, 2010). Steps to more successfully integrate the management of forests, fires, watersheds, and native fishes into regional and project-scale planning should include communication among disciplinary scientists with a clear definition of management goals**

Collaboration on the identification of quantifiable objectives

- The translation of goals to objectives within the contexts and constraints of the target system is important; the integration of terrestrial and aquatic objectives on a physical level is essential to identify opportunities for synergistic and successful solutions (Rieman, 2010)
- Work with forest managers to offer a forum that can find ways to manage the forests collaboratively, such s landscape-level fuels management (rather than stand-specific); this results in a greater overall fuels management effectiveness (Stephens, 2009)

Replanting the forest with fire-tolerant species

- Planting selected tree species and genotypes with relatively high oleoresin could limit insect outbreaks, thereby preserving the forest's resistance to fire and extreme weather events such as windstorms (Dale, 2001)
    - Oleoresin is strongly influenced by internal tree water balance (Mason, 1971), so it's likely that additional research is needed
- Work with private forest management entities to target replanting areas with species which are fire-tolerant and –resistant (Dale, 2001; Mason, 1971)
- Trees with thicker bark may be able to withstand the additional pressures of higher-severity fires and increases levels of insect infestations

Controlling invasive species

- The US Forest Service and other entities are researching bark beetle management (much of this research is happening in laboratories in California, by the Pacific Southwest Research Station); some actions could include the replanting of trees with greater resistance to beetle infestations.

Biomass utilization

- **Continue to explore environmentally-acceptable and economically-feasible ways of producing and utilizing power from biomass**