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memorandum

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to Rob Holmlund (GHD)

from Louis White, PE

subject Climate Data Projections for Caltrans District 1 Climate Change Pilot Study

1. Introduction

This memorandum describes climate change data sets that were compiled and processed for use in the Caltrans District 1 Climate Change Pilot Study (D1CCPS). The purpose of the project is to evaluate the vulnerability of Caltrans transportation assets in District 1 to various climate change impacts and develop adaptation strategies for the most vulnerable assets. The various climate change data sets prepared for this project, and included in the GIS geodatabase, will be combined with an inventory of Caltrans assets in District 1 to evaluate the vulnerability of those assets. This analysis is based on existing information and does not include any additional modeling. Data was processed to create metrics to describe the level of exposure of the assets to a particular climate change impact relative to a threshold or trigger at specific time intervals.

The following sections describe the information that is included in the geodatabase and the metrics used to characterize exposure of each climate stressor and hazard.

The work that is described in this memorandum was conducted by James Gregory, PE, Elena Vandebroek, PE, Pablo Quiroga, Louis White, PE, and with review by Jeremy Lowe.

2. Definition of Terms and Climate Change Background

The science of climate change and modeling of future scenarios has been extensively described (IPCC, 2013). In general, global temperature is driven by concentrations of greenhouse gases (GHGs) such as carbon dioxide, methane, and water vapor which absorb energy radiating from Earth back into space. Global emissions of greenhouse gases have rapidly increased following the industrial revolution in the mid-1700s primarily due to the burning of fossil fuels such as coal, oil, and natural gas. Emissions continue to grow as nations modernize and consume greater amounts of fossil fuels. Acknowledging this pattern, many national and statewide initiatives have been advanced to curb GHG emissions as well as respond to the anticipated impacts of climate change already underway.

Present day concentrations of carbon dioxide (CO_2) in Earth's atmosphere represent the highest ever measured, which is a key driver of increasing global temperatures, precipitation patterns, and rising sea levels. The anticipated rise in temperatures is expected to continue beyond year 2100, even if the CO_2 emissions are reduced by 2050 (Figure 1). The increased global temperature acts to warm ocean temperatures, and also has been shown to increase the rate of melting of the large ice sheets near the poles. Sea level rise (SLR) results from a combination of melting of land-based ice and thermal expansion of the oceans due to increased temperatures. The magnitude of the impact of global warming on climate change is influenced by various complex interactions in the earth-ocean-atmosphere system. Many processes and feedbacks must be accounted for in order to realistically project climate changes resulting from particular GHG emission scenarios. These complications are the source of much of the debate which has occurred about the likely magnitude and timing of climate changes due to the enhanced GHG effect.

The following sections provide background and descriptions of several terms that are used in this memorandum to describe climate change data and climate modeling.

2.1. Emissions Scenarios

Projecting potential climate trends and extremes requires first establishing future scenarios of GHG emissions that will influence future climate patterns. Due to the high level of uncertainty in the evolution of these factors, a series of qualitative storylines describing the evolution of possible trajectories of heat-trapping GHG emissions were developed by the International Panel on Climate Change (IPCC) for the IPCC Fourth Assessment Report (AR4) (IPCC 2007). These were used to guide climate change modeling efforts in AR4 upon which most of the available climate impact modelling has been based. The IPCC's (2000) special report on emissions scenarios (SRES) provides six scenario groups of plausible global emissions pathways, with no assigned probabilities of occurrence. Two of these scenarios, A2 and B1, have been selected to represent medium-high and relatively low (or "best-case") emissions projections respectively (Cayan et al. 2012). These emissions scenarios are defined as follows:

- **A2**. Medium-high emissions resulting from continuous population growth coupled with internationally uneven economic and technological growth. Under this scenario, emissions increase through the 21st century and by 2100 atmospheric carbon dioxide (CO2) levels are approximately three-times greater than pre-industrial levels.

- **B1**. Lower emissions than A2, resulting from a population that peaks mid-century and declines thereafter, with improving economic conditions and technological advancements leading to more efficient utilization of resources. Under this scenario, emissions peak mid-century and then decline, leading to a net atmospheric CO2 concentration approximately double that of pre-industrial levels. This scenario is often referred to as a "best-case" scenario.

2.2. General Circulation Models (GCMs)

General circulation models (GCMs) are used for predicting climate change. They model how the atmosphere, oceans, land surface, and ice interact to create weather and climate over long periods of time (decades and centuries) over the whole globe. GCMs subdivide the Earth's surface, atmosphere, and oceans into a 3D grid of thousands of cells. Standard physical equations for the transfer of heat, water, and momentum are solved for each grid cell to predict temperature, precipitation, and winds. Many relevant processes are well represented at the scale of these grid cells, such as the large-scale westerly flow of moisture from the Pacific Ocean. Due to the spread of climate projections over the various models, data is often averaged over multiple GCMs to avoid biasing towards any one model.

To identify the GCMs that best suited to predicting climate phenomena in the State of California, Cayan et al. (2012) selected six models from AR4 based on data availability and on historic skill in representing climate patterns in California, including seasonal precipitation and temperature, annual variability of precipitation, and the El Niño/Southern Oscillation (ENSO) phenomenon. Data was obtained for six GCMs considered representative of climate trends in California. Each model has multiple runs with 16 total runs for the A2 scenario, and 17 total runs for the B1 scenario. Runs represent different initial conditions in the GCMs. The six models selected for the assessment were:

1. The NCAR Parallel Climate Model (PCM);

2. The NOAA Geophysical Fluids Dynamics Laboratory (GFDL) model, Version 2.1;

3. The NCAR Community Climate System Model (CCSM);

4. The Max Plank Institute 5th generation ECHAM model (ECHAM5/MPI OM);

5. The medium-resolution model from the Center for Climate System Research of the University of Tokyo and collaborators (MIROC 3.2); and

6. The French Centre National de Recherches Météorologiques (CNRM) models.

Data for a series of climate stressors downscaled to the 12-kilometer (7.5-mile) scale has been archived and made available for public use on the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) website (http://gdo-dcp.ucllnl.org). This data has been widely applied for evaluating climate trends in California. The CMIP3 archive presents compiled data from a joint effort between the US Department of the Interior's Bureau of Reclamation, Lawrence Livermore National Laboratory, Santa Clara University, Scripps, Climate Central, and the USGS. This archive includes downscaled geographic gridded data for temperature and precipitation for a number of GCMs and emissions scenarios as well as daily hydrologic projections of precipitation and other hydrologic stressors derived from the downscaled GCM data. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.

The CMIP3 dataset represents GCM data developed for AR4 driven by the SRES emissions trajectories. The downscaled GCM data has been used to develop additional datasets including surface water projections (USBR, 2011), and fire risk projections (Westerling, A. L., Bryant, B. P. 2008). For the Fifth Assessment Report (AR5), the IPCC has developed new emissions scenarios called Representative Concentration Pathways (RCPs). There are four RCPs which represent different amounts of anticipated radiative forcing by the end of the century. The emissions trajectories and GHG concentrations for the RCPs deviate from the previous scenarios. The RCPs have been used to develop new GCM output and a downscaled dataset for Phase 5 of the CMIP (CMIP5) has been published online by the WCRP. This dataset was not used for this report for two primary reasons

1. The most recent statewide assessment of climate change in California used CMIP3 data and emissions scenarios. To remain consistent with existing projection information for California the CMIP3 data was also used for this report.

2. The downscaled CMIP5 dataset is currently available for temperature and precipitation projections only. Secondary datasets such as hydrologic projections have yet to be developed using CMIP5 data.

As further data becomes available for CMIP5, projection information should be updated to reflect the most recent climate projection information.

2.3. Downscaling

GCMs are designed to represent climate change processes at the global scale. Models can show differences in the rate of climate change at different locations, but only on the continental scale. The size of the GCM grid cells, and thus the spatial resolution of the climate projections, is limited by the computing power necessary to solve the equations for all of the grid cells at hourly (or shorter) time steps for runs which may span 100 years or more. Thus, the climate models at the time of the latest IPCC report in 2007 produced output at spatial scales of roughly 120 to 180 miles.

Particularly in mountainous regions, such as the California coastal ranges and the Sierra Nevada, this scale is too coarse to capture the many important effects of topography on climate. For example, because the elevations of mountain ranges are averaged with the elevation of adjacent valleys, the Sierra Nevada, as represented in the GCMs, tops out at around 6,000 feet. The scale of GCM output is also too coarse to use as input for many models predicting environmental impacts, such as basin-scale hydrologic and water system models, or wildlife habitat models. Therefore, techniques to reduce the spatial scale of the GCM output (that is, downscaling) are needed for most user applications.

- **Statistical downscaling**. Statistical relationships between the regional circulation and aspects of the local climate (e.g., temperature, precipitation, wind) are used to apply GCM results to a particular place.

- A **regional climate model** (RCM) uses output from a general circulation model, but simulates processes at much higher resolution over the particular region. A RCM is very much like a GCM, except that it uses much finer resolution and covers a limited area. So a regional model may have a 10-mile grid spacing over specific regions, compared with 120 to 180 miles for a GCM.

When making use of downscaled climate projections, as with the underlying GCM output, a range of projections should be considered rather than one or two. In the case of statistical downscaling, several GCM projections are typically downscaled using the same method. Likewise with RCM downscaling, it is important to consider projections produced by multiple RCM-GCM combinations.

2.4. Uncertainty

Natural sources of uncertainty are inherent in climate processes due to fluctuating and chaotic processes, but the act of modeling using numerical algorithms and its required assumptions introduces two more main sources of uncertainty: method uncertainty and emissions uncertainty. The three types of uncertainty that appear in this memorandum are as follows:

- **Method uncertainty** is introduced from differences in model algorithms, techniques, and how the climate processes are considered. GCMs simulate climate phenomenon using a three-dimensional grid typically run with a spatial resolution of hundreds of kilometers. Smaller scale processes such as cloud interactions must be spatially averaged and this is managed differently between GCMs. Physical climate interactions such as ocean circulation, and water vapor and heat transport can be handled differently between models. The consequence of this is that GCMs may produce differing results for the same emissions pathway. For this reason, it is standard to evaluate multiple GCMs to estimate the range of potential changes in climate conditions.

- **Emissions uncertainty** is a function of the future pathways of global emissions which are, by definition, hypothetical, and based on assumptions of population growth, socioeconomic composition, and technological innovation. The emissions pathways are projections, not predictions, of possible future conditions and how those conditions relate to carbon emissions worldwide. It is standard to choose multiple emissions scenarios to estimate the range of projected climate conditions. However, measured global emissions have exceeded nearly all of the projected emissions pathways developed under AR4 (Le Quéré et al. 2010).

- **Natural variability** also influences climate trends lending another source of uncertainty. Even without external forcing from increasing greenhouse gases, climate variability will occur over space and time due to natural interactions within the climate system. This natural variability will continue in the future while external forcing will also induce variability. The two sources of variability lead to uncertainty in estimating the impact of radiative forcing on climate patterns independent of natural variations.

3. Geodatabase of Climate Information

The GIS geodatabase attached includes a series of raster files containing climate data processed from downscaled CMIP3 data. Datasets of temperature, precipitation, and runoff for 1950-2100 at a spatial resolution of 12 km by 12 km (7.5x7.5 miles) were downloaded from the CMIP3 archive for the A2 and B1 emissions scenarios. The timestamp for these online datasets is August, 2011. The datasets in the geodatabase developed for this project are horizontally referenced to the World Geodetic System of 1984 (WGS 1984). The climate datasets in the geodatabase and key parameters are summarized in Attachment 1 and described in more detail below.

3.1. Temperature

Daily maximum air temperature data was obtained from the CMIP3 archive and processed to illustrate average trends, as well as projections of extreme conditions. The annual average of daily maximum temperature for District 1 is projected to increase by approximately 4.1°F and 6.7°F for the B1 and A2 emissions scenarios, respectively, by 2100 (Figure 2). This time series represents a spatial average of temperatures across all of District 1 and is presented as a 10-year moving average to remove noise. The solid line represents an ensemble average of the results over all model runs, and the shading indicates the range in projections due to method uncertainty between models. The general trend is that the average temperatures in District 1 will increase over the coming century. Changes in the annual average of the daily maximum temperature are similar for all four counties, and close to the District 1 average (Table 1).

TABLE 1
CHANGE IN ANNUAL AVERAGE OF DAILY MAXIMUM AIR TEMPERATURE FROM HISTORIC AVERAGE (°F)

Year	2050		2100	
Emissions Scenario	A2	B1	A2	B1
District 1	3.3	3.0	6.7	4.1
Del Norte	3.2	2.8	6.7	4.0
Humboldt	3.3	2.9	6.7	4.0
Lake	3.5	3.2	6.9	4.4
Mendocino	3.4	3.0	6.7	4.2

For this study, extreme temperature is defined as the number of days per year exceeding 95° F, referred to here as "heat days." The two future conditions datasets (2050 and 2100) represent the change in number of heat days relative to a historic 30-year average (1970-2000) from the CMIP3 model data. This variable is averaged over a 30-year period (2035-2065 for 2050, and 2070-2100 for 2100) and then averaged over the GCMs.

The change in the number of projected heat days for 2050 and 2100 vary spatially throughout District 1, and tend to show a larger change for emissions scenario A2 compared to scenario B1 (Figures 3 and 4, respectively). Maps of the projected data show that inland areas have the greatest change in the number of extreme heat days, while little or no increase in the number of extreme heat days is expected in the coastal areas. Although the projections show an increase of approximately 15 to 20 extreme heat days per year by 2050, up to an additional 40 days per year are projected for inland areas. This is particularly the case in Lake County and the eastern portions of Mendocino and Humboldt Counties. A greater increase in heat days is projected for the A2 emissions scenario as compared to the B1 emissions scenario.

Method uncertainty introduced by the different model runs indicates that the number of additional heat days for the district could be significantly higher or lower (Figure 5). The number of extreme heat days presented in Figures 3 and 4 correspond to an average of all model runs, which tends to hide the model disagreement. The time series in the top panel of Figure 5 shows a running 30-year average of the additional number of heat days per year, where the solid line represents the average of all models, and the shaded areas correspond to the spread of the model projections. Note that this data is for a district average, as compared to the spatial data shown in the preceding figures. The lower panel of Figure 5 presents box plots that illustrate the distribution of model projections, where the blue box indicates the 25^{th} percentile of the model projections, the red box indicates the 75^{th} percentile, and the outer limits represent the maximum and minimum model projections.

3.2. Precipitation

Daily maximum precipitation data was obtained from the CMIP3 archive and processed to illustrate average trends, as well as projections of extreme conditions. The relative change of the total annual precipitation compared to the historic average is projected to decrease by approximately 2% to 7% for the B1 and A2 emissions scenarios, respectively, by 2100 (Table 2). The values in Table 2 represent a spatial average of precipitation across all of District 1 and was estimated using a 30-year moving average to remove noise in the signal. Figure 6 presents a time series graphic of the modeled precipitation data, where the solid line represents an ensemble average of the results over all model runs and the shading indicates the range in projections due to method uncertainty between models. The time series is presented using a 10-year moving average. The general trend of the data indicates that the changes in total annual precipitation in District 1 over the coming century are very uncertain, as shown by the wide range of model projections. However, the GCM averaged relative change in the total annual precipitation as a spatial average over each county yields similar results close to the District 1 average (Table 2).

TABLE 2
PERCENT CHANGE IN TOTAL ANNUAL PRECIPITATION FROM HISTORIC AVERAGE (%)

Year	2050		2100	
Emissions Scenario	A2	B1	A2	B1
District 1	-4.1	-0.5	-6.5	-2.0
Del Norte	-3.0	0.0	-5.6	-0.6
Humboldt	-3.9	-0.4	-6.5	-1.8
Lake	-5.1	-1.2	-6.8	-3.0
Mendocino	-4.6	-0.8	-6.8	-2.6

The District 1 average of the total annual precipitation for the ensemble average of models was compared to a selected "wet" model (PCM) and a selected "dry" model (GFDL) to illustrate the range in projections (Table 3). The results of the wet model indicate an increase in the total annual precipitation of up to approximately 9% greater than the historic average (for B1 scenario at 2100), while the dry model shows a decrease of up to approximately 15% (for A2 scenario at 2100). These results indicate that careful interpretation and selection of future climate projections need to be considered when applying to assessing the vulnerability of assets as well as the selection of an appropriate emissions scenario.

TABLE 3
PERCENT CHANGE IN TOTAL ANNUAL PRECIPITATION FOR DIFFERENT MODELS

Year	2050		2100	
Emissions Scenario	A2	B1	A2	B1
Model Average	-4.1	-0.5	-6.5	-2.0
Wet Model	-0.7	7.1	-1.3	8.6
Dry Model	-5.0	1.1	-15.1	-8.3

Note: Data represents spatial average over all of District 1

For this study, extreme precipitation was characterized by the 98th percentile daily precipitation event over 30-year periods for 2050 and 2100. The 2050 timeframe was estimated based on the period from 2035 to 2064; the 2100 timeframe was estimated based on the period from 2070 to 2099. The 98th percentile is a statistical measure of the extreme occurrence which may be exceeded 2% of the time over a given period. The 98th percentile is used as an indication of the extreme events for this study rather than the 100-year recurrence because:

- The projections of extreme precipitation are highly uncertain due to modeling, downscaling, and may not be in agreement with the historical observations of precipitation;

- The use of recurrence requires an assumption of "stationarity[1]," in which the precipitation patterns are not changing.

However, the magnitude of the relative changes of the 98th percentile values may be correlated to changes in the 100-year event as an indication of changes in extremes. For example, an increase in the 98th percentile precipitation may be indicative of an increase of the 100-year event by a similar amount.

Maps of the ensemble average of extreme precipitation generally show a decrease for the A2 scenario (Figure 7) and a slight increase for the B1 scenario (Figure 8). However, Figures 7 and 8 represent the ensemble average over all models, which tend to indicate a low degree of change although the different models tend to show a significant amount of change.

Similar maps were generated to show the range in projected changes in extreme precipitation resulting from the wet and dry models. The wet model projects a District-wide increase in extreme precipitation for both emissions scenarios A2 (Figure 9) and B1 (Figure 10). The dry model projections show a significant decrease in extreme precipitation event for the A2 emissions scenario (Figure 11). However, results from the B1 emissions scenario for the dry model show that a decrease in extreme precipitation is limited to the southern portion of District 1 by 2050, and then expanding northward by 2100 (Figure 12). A general conclusion that can be made from these figures is that the projections of extreme precipitation are greater in the B1 emissions scenario than the A2 scenario.

The projections of changes in precipitation have a large amount of uncertainty due to disagreement between the different models (Figure 13). The box and whisker plots in Figure 13 show the distribution of the model projections for extreme precipitation as a District average for 2050 and 2100. The black diamond represents the 98th percentile value for the wet model, and the gray diamond represents the 98th percentile value for the dry model. Generally, the model agreement on projecting the extreme precipitation decreases for the A2 emissions scenario, as shown by the increasing spread of values. A similar range in values is projected for the B1 scenario, except that the majority of models tend to be greater than the average A2 values. A range in the percent change, from negative to positive, is projected for both the A2 and B1 emissions scenarios. However, the spatial distribution, as illustrated in the maps in Figures 7 through 12, is an important consideration in applying the projected changes to evaluate the vulnerability of the assets.

3.3. Runoff

Similar to the precipitation, daily maximum runoff data was obtained from the CMIP3 archive and processed to illustrate average trends, as well as projections of extreme conditions. Daily runoff projections were calculated using a simple water balance model that is driven by the projections of precipitation and temperature. The relative change of the total annual runoff compared to the historic average is projected to decrease by approximately 2% to 4% for the B1 and A2 emissions scenarios, respectively, by 2100 (Figure 14). This time series represents a spatial average of runoff across all of District 1 and is presented as a 10-year moving average to remove noise. The solid line represents an ensemble average of the results over all model runs, and the shading indicates the range in projections due to method uncertainty between models, which is noticeably large. The general trend

[1] Stationarity is defined as a quality of a process in which the statistical parameters, such as the mean and standard deviation, of the process do not change with time.

indicates that the changes in total annual precipitation in District 1 over the coming century are very uncertain, as shown by the wide range of model projections. The relative change in the total annual runoff is similar for Del Norte, Humboldt and Mendocino Counties, which are close to the District 1 average, although Lake County values tend to suggest relatively greater amount of runoff (Table 2). The table also suggests that, on average, runoff decreases for the A2 emissions scenario, but increases for the B1 emissions scenario.

TABLE 4
PERCENT CHANGE IN TOTAL ANNUAL RUNOFF FROM HISTORIC AVERAGE (%)

Year	2050		2100	
Emissions Scenario	A2	B1	A2	B1
District 1	-3.1	2.6	-4.1	2.2
Del Norte	-3.1	1.9	-4.3	2.6
Humboldt	-3.1	2.4	-4.2	2.1
Lake	-3.0	4.2	-1.9	3.9
Mendocino	-3.3	3.0	-4.5	1.8

The average percent change in total annual runoff for District 1 exhibits similar characteristics to the precipitation, in that there is a wide range in projections that show increase up to 150-200% and decrease up to 150-200% (Figure 14). The uncertainty is due to the different results from the several models used in the projections. The results are greatly affected by the different emissions scenarios, which project an increase in runoff by 2100 for the B1 scenario, and a decrease by 2100 for the A2 scenario (Table 4). However, the spatial results show a decrease in the total annual runoff from the historic values when averaged over all GCMs, particularly by 2100 (Figure 15).

The District 1 average of the total annual runoff for the ensemble average of models was compared to a selected "wet" model (PCM) and a selected "dry" model (GFDL) to illustrate the range in projections (Table 5). The results of the wet model indicate an increase in the total annual precipitation of up to approximately 30% greater than the historic average (for B1 scenario at 2100), while the dry model shows a decrease of up to approximately 15% (for A2 scenario at 2100). These results indicate that careful interpretation and selection of future climate projections need to be considered when applying to assessing the vulnerability of assets as well as the selection of an appropriate emissions scenario, and that method uncertainty poses a major challenge to providing management recommendations.

TABLE 5
PERCENT CHANGE IN TOTAL ANNUAL RUNOFF FOR DIFFERENT MODELS (%)

Year	2050		2100	
Emissions Scenario	A2	B1	A2	B1
Model Average	-3.1	2.6	-4.1	2.2
Wet Model	3.6	19.5	6.4	29.9
Dry Model	-3.3	5.7	-14.5	-10.4

Note: Data represents spatial average over all of District 1

For this study, extreme runoff was characterized by the 98th percentile daily runoff event over 30-year periods for 2050 and 2100, similar to how extreme precipitation is characterized and described above. The 2050 timeframe was estimated based on the period from 2035 to 2064; the 2100 timeframe was estimated based on the period from 2070 to 2099. Maps of the ensemble average of extreme runoff generally show a decrease for the A2 and B1 scenarios (Figures 15 and 16, respectively).

Similar to the analysis of extreme precipitation, maps were generated to show the range in projected changes in extreme runoff resulting from the wet and dry models. The wet model shows little changes District-wide for the A2 scenario (Figure 17), but suggests that areas in Lake County, northern portions of Mendocino County, and most of Humboldt and Del Norte Counties, may experience an increase in extreme runoff for the B1scenario (Figure 18). The dry model projections are somewhat different, and, by 2050, show a decrease to no change in extreme runoff north of Mendocino County, but a significant increase in extreme runoff throughout Lake County and most of Mendocino County for the A2 emissions scenario (Figure 19). However, by 2100, the dry model results suggest a District-wide decrease in the extreme runoff for the A2 scenario. Results from the B1 emissions scenario for the dry model show an increase in runoff by 2050, followed by a decrease by 2100 (Figure 20).

The projections of changes in runoff have a large amount of uncertainty due to disagreement between the different models (Figure 21). The box and whisker plots in Figure 21 show the distribution of the model projections for extreme runoff as a District average for 2050 and 2100. The black diamond represents the 98th percentile value for the wet model, and the gray diamond represents the 98th percentile value for the dry model. Generally, the model agreement on projecting the extreme precipitation decreases for the A2 emissions scenario, as shown by the increasing spread of values. A similar range in values is projected for the B1 scenario, overall, except that the majority of models tend to be greater than the average A2 values. A range in the percent change, from negative to positive, is projected for both the A2 and B1 emissions scenarios. However, the spatial distribution, as illustrated in the maps in Figures 15 through 20, is an important consideration in applying the projected changes to evaluate the vulnerability of the assets.

3.4. Fire Risk

3.4.1. Cal-Adapt Data

The projected fire risk data was obtained through Cal-Adapt.org. The data provided through Cal-Adapt represents projected increase in burned area as a ratio relative to existing fire risk for three GCMs for the A2 and B1 emissions scenarios averaged for 30-year time periods ending in 2020, 2050, and 2085. The three GCMs available for the Fire Risk data are:

1. The NCAR Parallel Climate Model (PCM);
2. The NOAA Geophysical Fluids Dynamics Laboratory (GFDL) model, Version 2.1;
3. The French Centre National de Recherches Météorologiques (CNRM) models.

The data provided in the geodatabase represents an average over the three GCMs for the 2050 and 2085 periods. The Cal-Adapt fire risk data projects an increase in fire risk for the whole district by 2100 (Figure 22).

3.4.2. Department of Water Resources Fire Exposure Data

A separate set of projections of wildfire exposure for early-, mid- and late-century were provided by the California Department of Water Resources (DWR). Fire exposure was estimated by DWR (2013) to evaluate vulnerability of their assets throughout the state, and was based on an extensive study of fire risk projections for California (Krawchuk and Moritz 2012). The Krawchuck and Moritz (2012) study estimated the change in probability of one or more fires occurring within a 30-year time period for three future periods (2010-2039; 2040-2069; and 2070-2099) as compared to the historic period (1971-2000). The future projections of wildfire risk were completed using two GCMs (PCM and GFDL), two emissions scenarios (A2 and B1), and two land use projections (business-as-usual and smart-growth. The final results of projected wildfire risk report the maximum modeled probability to represent a conservative estimate of future wildfire. DWR selected curves of five exposure categories from very low to very high to relate the future change in probability to existing probability of fire risk. For this study we used the exposure rating curves developed by DWR (2013).

The wildfire exposure data for mid- and late-century in District 1 is shown in Figure 23, and indicates that fire exposure increases for most areas by 2100, particularly the inland areas of Lake and Mendocino Counties.

3.5. Landslides

Projections of future landslide risk due to climate change are not available for the District 1 area. Existing information on the risk of deep-seated landslides is available from the California Geologic Survey (Wills et al. 2011). The study classifies deep-seated landslide susceptibility as a function of slope class and rock strength, with increasing susceptibility with slope and in weaker rocks. Much of District 1 is classified as high susceptibility to deep-seated landslides. We are not aware of any studies or date that indicates how the susceptibility may change due to climate change factors such as increased temperature and changes in precipitation.

Shallow landslides, including debris flows, are highly correlated to extreme rainfall events, and may be of the most interest to Caltrans in terms of hazards related to climate change. We understand that numerical and empirical models of shallow landslide susceptibility have been developed by researchers and geologists; however we are unaware of available data for District 1. Efforts to map existing and projected shallow landslide susceptibility for District 1 should be considered as a tool to aid in planning and design.

3.6. Sea Level Rise

Four datasets for sea level rise and coastal erosion were compiled for this project: coastal erosion and flood data from the Pacific Institute (2009) sea level rise study for the coast of California, data from Trinity Associates (2013) shoreline inventory, mapping, and vulnerability rating for Humboldt Bay, recent sea level rise inundation modeling and mapping by Northern Hydrology and Engineering (NHE) (2014) developed for the Humboldt Bay sea level rise vulnerability assessment project, and sea level rise inundation mapping using NOAA’s Coastal Viewer. These datasets are described further below.

3.6.1. Pacific Institute and PWA (2009)

The Pacific Institute (2009) study mapped coastal erosion and flood hazard zones along the coast of California from Santa Barbara County north to the Oregon border.

Storm Flood Zones

Storm flood zones were estimated for the California Coast for existing (year 2000) and future (2100) conditions that assume a sea level rise of 55-inches, in accordance with state guidance at the time (CCC 2011). This sea level rise projection also falls within the range recommended by the updated state guidance (CCC 2013). 2011) The storm flood mapping used a bathtub model approach mapping the 100-yr total water level[2] resulting from 55-inches SLR by 2100. This is an overestimate of the 100-year flood zone in inland areas and is generally more accurate near the coast where wave run-up is occurring. These flood zones do not consider coastal erosion or vertical land motion.

Figure 24 shows an example of the existing and future (2100) 100-year coastal flood zone near Point Arena in Mendocino County. The areas with the blue shading represent the existing flood zones, and the green areas represent flood zones for 2100 that consider sea level rise. Although the bathtub approach used in the study generally tends to provide an overestimate of the flood elevations, areas with river mouths, such as at the mouth of the Garcia River, may be more accurate due to the interactions of fluvial discharge, inlet morphodynamics, and the “perching” of the estuarine water bodies due to the littoral barrier.

Dune and cliff erosion

Dune and cliff erosion hazard areas resulting from low (0.6 meters or 24 inches by 2100) and high (1.4 meters or 55 inches by 2100) sea level rise for years 2025, 2050, and 2100 were also estimated and mapped for the California coast north of Santa Barbara. Some gaps in coverage exist in District 1: Crescent City harbor, ~11 miles of coast near the Del Norte/Humboldt County Line, and from the Mattole River to Humboldt/Mendocino County Line.

A coastal erosion hazard zone represents an area where erosion (caused by coastal processes) has the potential to occur over a certain time period. This does not mean that the entire hazard zone is eroded away; rather, any area within this zone is at risk of damage due to erosion during a major storm event. Actual location of erosion during a particular storm depends on the unique characteristics of that storm (e.g. wave direction, surge, rainfall, and coincident tide). As sea level rises, higher mean sea level will make it possible for wave run-up to reach the dune more frequently, undercutting at the dune toe and causing increased erosion. These hazard zones consider historic trends in erosion, increased erosion due to sea level rise, and potential erosion of a 100-year storm. Figure 24 presents an example of the dune and cliff hazard zone near Point Arena. The red, orange, and yellow areas represent the erosion hazard zones for 2025, 2050, and 2100, respectively. Similar zones extending up and down the coast are included in the geodatabase.

3.6.2. Humboldt Bay Sea Level Rise Adaptation Planning Project (2010-present)

The State Coastal Conservancy (SCC) is funding a multi-phased project to identify sea level rise vulnerabilities and adaptation strategies for Humboldt Bay. This effort began in 2010 after Governor Schwarzenegger issued Executive Order S-13-08, which identified the necessity to plan for sea level rise. The first phase of the project, titled the Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment, was completed in January 2013 by Trinity Associates. The 2013 report presented the results of the inventory and

[2] The total water level is the elevation that represents the vertical extent of wave runup plus storm surge. Here the 100-year total water levels were developed using existing FEMA base flood elevations. Where no FEMA flood study was available a 100-year total water level was estimates using engineering judgment.

mapping of existing shoreline conditions, assessed shoreline vulnerability to extreme high water events and sea level rise, and presented an inventory of land uses and infrastructure vulnerable to inundation from overtopping, breaching, and rising sea levels. A shoreline vulnerability rating, a quantitative measure of vulnerability was developed as an addendum to the shoreline vulnerability assessment (2013). Trinity Associates shoreline vulnerability rating and mapping is useful in locating shoreline segments that are likely to fail during extreme high water events and as sea levels approach a critical elevation threshold for shoreline structures such as dikes and railroad grade.

The second phase of the project, titled Humboldt Bay Sea Level Rise Adaptation Planning Project, is sponsored by the Coastal Ecosystems Institute of Northern California (CEINC). There are two components to this project: inundation modeling and mapping by NHE and an adaptation planning working group led by the Humboldt County Public Works and Humboldt Bay Harbor, Recreation and Conservation District, with members from the Local Coastal Program authorities, Coastal Commission and various local and state resource agencies and Wiyot Tribe. Trinity Associates is the adaptation planning consultant for this phase of the project. Preliminary inundation mapping provided by NHE are used and presented herein.

There are nearly 9,000 acres of diked former tidelands adjacent to Humboldt Bay. Inundation maps were generated for existing conditions to illustrate areas subject to flooding if shoreline structures such as earthen dikes are compromised. 100-year storm flood maps were also developed for Humboldt Bay for existing conditions and four sea level rise scenarios: 0.5 meters (1.6 ft), 1.0 meter (3.3 ft), 1.5 meters (4.9 ft), and 2.0 meters (6.6 ft). The mapping identifies areas adjacent to Humboldt Bay and the adjoining sloughs that are below the 100-year extreme water surface elevation. Figure 25 presents an example of the preliminary model results and mapping by NHE that shows inundation from 100-year extreme water level variations within different portions of the Humboldt Bay for existing conditions and for 1.5 meters of sea level rise. These maps are based on preliminary model results provided by NHE as part of the State Coastal Conservancy funded Phase II Humboldt Bay Sea Level Rise Adaptation Planning Project. The geodatabase also includes information on the following flood zones for existing and sea level rise scenarios: 100-yr, 10-yr, and mean higher high water[3] (MHHW). These elevations comprise the base tidal elevations used to assess shoreline vulnerability in the Humboldt Bay Sea Level Rise Adaptation Planning Project.

3.6.3. NOAA SLR Viewer Data

Sea level rise inundation mapping data is available online using the NOAA Coastal Services Center's Sea Level Rise and Coastal Flooding Impacts Viewer (SLR Viewer). The SLR Viewer is an online tool that is helpful in graphically presenting potential impacts of sea level rise to coasts of the United States of America. The SLR Viewer provides a simple visual tool with a user interface that illustrates the potential impacts of sea level rise on the coast. A slider bar is used to see how various levels of sea level rise will impact the area of interest. The base elevation of the data is the MHHW elevation, which is 6.52 ft NAVD[4] in the vicinity of Humboldt Bay. The SLR Viewer presents several levels of high tide inundation with 1-foot incremental increases in sea level rise. The inundated areas is presented in a map with shades of blue, where darker blue represents hydrologically connected

[3] Mean higher high water (MHHW) is a tidal datum that is calculated as an average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (approximately 19 years).

[4] NOAA NOS Station 9418767, North Spit, CA

greater depths, lighter blue represents hydrologically connected shallow areas, and green shading represents low-lying areas that are not hydrologically connected but may flood.

The data is limited in that several natural processes associated with sea level rise are not included. The data presented in the maps is based on projected water surface elevations and mapped onto a digital elevation model (DEM). The mapping represents a bathtub mapping effort for existing conditions, when in fact natural processes associated with sea level rise, including erosion, marsh migration, fluvial-tidal interactions, and lagoon dynamics, are not included in establishing the inundation limits. Furthermore, other processes including storm surge and waves could present additional flood pathways that are not considered in the mapping. The confidence of the mapping is not 100%, as with all sea level rise mapping exercises, and user should evaluate the uncertainties in the extent of mapped inundation resulting from errors in the elevation data and the tidal corrections. Other hydrologic features, such as canals, ditches and stormwater infrastructure, may not be included to completely capture the area's hydrology.

More information on the SLR Viewer is summarized in documentation that is available on the website.[5,6]

4. Summary of Sea Level Rise Guidance for Caltrans District 1

This section summarizes California state guidance on sea level rise adaptation planning and design. Federal guidance also exists (USACE 2011); however, the California guidance incorporates recent science specific to the West Coast and is tailored to California planning processes. In 2008, Executive Order S-13-08 directed state agencies to plan for sea-level rise and other climate change impacts. It also directed the California Natural Resources Agency, in coordination with other state agencies and the National Research Council (NRC) of the National Academy of Sciences, to assess sea level rise for the Pacific Coast and create official sea level rise estimates for state agencies in California, Oregon and Washington.

In March 2011[7], the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) presented interim guidance to state agencies for incorporating the risks posed by sea level rise into project and program plans (OPC 2011). The guidance was targeted towards state agencies and non-state entities implementing projects or programs funded by the state or on state property.

In May 2011, Caltrans published specific guidance on when and how to implement sea level rise guidance in transportation planning and design (Caltrans 2011). The guidance included the sea level rise projections from the interim state guidance and stated that the Caltrans guidance would be revised when the NRC study (below) was complete. The guidance has not been updated as of May 2014.

In 2012, the National Research Council (NRC) released a report titled "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future" (NRC 2012). This report provides global and regional sea level rise projections and likely ranges at four locations along the West Coast. The report splits the West Coast into two tectonic regions when incorporating vertical land motion into regional sea level rise

[5] NOAA 2012, Method Description: Detailed Methodology for Mapping Sea Level Rise Inundation, May 2012.
[6] NOAA 2014, Frequent Questions: Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer, March 2014.
[7] Prior to completion of the NRC 2012 report

estimates: North of Cape Mendocino (uplift, 1 ± 1.5 mm/year) and South of Cape Mendocino (subsidence, -1 ± 1.3 mm/year).

In March 2013, the Ocean Protection Council (OPC) staff presented an update to the interim guidance (OPC 2013). The purpose of the document remained the same but was updated to include the range of sea level rise projections NRC 2012 study. The guidance document seeks to enhance consistency across agencies as each develops its respective approach to planning for sea level rise. It will be updated regularly, to keep pace with scientific advances associated with sea level rise.

In October 2013, the California Coastal Commission released draft guidance to help local governments apply the OPC 2013 guidance in new and updated Local Coastal Programs and Coastal Development Permits (CCC 2013). The draft document is currently out for public comment, and is expected to be finalized in early summer 2014. A series of technical appendices provide examples, adaptation strategies, and detailed instructions for estimating local hazard conditions. This guidance recommends modifying the regional sea level rise projections in the vicinity of Humboldt Bay and the Eel River, where vertical land motion differs significantly from that assumed by NRC 2012 (and adopted in OPC 2013).

Caltrans District 1 includes regions north of Cape Mendocino, south of Cape Mendocino, and Humboldt Bay to the Eel River. Therefore, according to draft CCC 2013 guidance, three different sea level rise projections should be considered. Table 6 presents the range of sea level rise projections for each of these regions, as presented in OPC 2013 for North and South of Cape Mendocino and as estimated by ESA for Humboldt Bay according to CCC 2013 draft guidance[8].

TABLE 6
SEA LEVEL RISE PROJECTIONS FOR CALIFORNIA, RELATIVE TO YEAR 2000

Year	North of Cape Mendocino (OPC 2013)	South of Cape Mendocino (OPC 2013)	Vicinity of Humboldt Bay (ESA analysis, based on CCC 2013)
2030	-4 to 23 cm (-0.13 to 0.75 ft)	4 to 30 cm (0.13 to 0.98 ft)	13 to 33 cm (5 to 13 in)
2050	-3 to 48 cm (-0.1 to 1.57 ft)	12 to 61 cm (0.39 to 2.0 ft)	25 to 65 cm (9.8 to 25.7 in)
2100	10 to 143 cm (0.3 to 4.69 ft)	42 to 167 cm (1.38 to 5.48 ft)	66 to 177 cm (25.8 to 69.7 in)

5. Selection of Climate Stressors for Asset Exposure Analysis

Evaluation of the exposure of critical Caltrans transportation assets in District 1 to a range of climate stressors is a key component of the vulnerability assessment. As described in Section 2.4, many sources of uncertainty accompany the climate model outputs, including method uncertainty from climate models, implications of different emissions scenarios, and the natural and spatial variability of the projections. Therefore, this section screens the climate data to select climate stressor datasets that represent the “worst-case” scenarios in terms of asset exposure and that yield the most conservative results.

8 Vertical land motion at North Spit was estimated by NOAA 2013 (-3.42 mm/yr ± 0.54 mm/yr). This estimate (including the uncertainty) was added to the regional sea level projections for Newport, OR (the nearest regional projection, assume vertical land motion removed) in NRC 2012 to give an estimate of relative sea level rise at North Spit.

5.1. Temperature

Evaluating the exposure of assets to temperature should consider the climate scenarios that project the greatest increase in the number of extreme heat days. The results shown by the box plot in Figure 5 suggest that the A2 emissions scenario yields the most conservative results with the greatest change in number of extreme heat days per year.

5.2. Precipitation

Although the projections of extreme precipitation show a wide range in relative change, the exposure analysis will focus on the dataset that shows the greatest increase in extreme daily rainfall event. The focus on the "wet" conditions will allow the exposure analysis to consider the potential impacts of flooding that may result from increased heavy precipitation events. Out of the three sets of model results, the "wet" model (PCM) run for the B1 emissions scenario yields the greatest change in the extreme daily rainfall. The wet model is represented by the black diamond in the box plot in Figure 13, and is consistent with projecting more wet conditions.

5.3. Runoff

Similar to the extreme precipitation, extreme runoff projections varied greatly across models and emissions scenarios. The greatest change in extreme daily runoff results from the "wet" model with the B1 emissions scenario. The wet model is represented by the black diamond in the box plot in Figure 21. Note that although the results vary considerably spatially, and that some specific areas may show large changes for a particular model or emissions scenario, the analysis is focused on the entirety of District 1 suggesting that the "wet" model with B1 emissions scenario best represents the extreme runoff condition.

5.4. Wildfire

Evaluation of the exposure of transportation assets to wildfire should be accomplished using the DWR (2013) dataset, which was previously screened by DWR to consider the "worst-case" conditions resulting from the A2 and B1 emissions scenarios. Furthermore, DWR already rated the exposure of the original fire risk projections made by Krawchuk and Moritz (2012) in a semi-quantitative scale that can easily be applied to this vulnerability assessment.

5.5. Sea Level Rise

Exposure of assets to sea level rise should be completed using separate datasets for areas along the open coast of District 1 and for the interior of Humboldt Bay. This is partly due to the availability of the data. For example, the Pacific Institute study covers most of the shoreline of District 1, while the Humboldt Bay Sea Level Rise Adaptation Planning Project is focused only on the shores of Humboldt Bay. These represent the best available data for this assessment. For more frequent events (i.e. daily to annual occurrences) we understand that data from the NOAA SLR Viewer will be used to assess the exposure of assets to flooding.

5.5.1. Open Coast

The Pacific Institute study data should be applied along stretches of the open coast in all available areas besides within Humboldt Bay. The conditions along the open coast are subject to large waves and elevated tides which result in flooding and erosion. Erosion hazard maps show the areas that may be impacted by increased erosion from sea level rise at years 2050 and 2100. These zones can be applied to the exposure analysis to determine if an asset is impacted or not. Similarly, existing and future (year 2100) flood zones that represent the approximate 100-year flood elevation can be used to assess the exposure of the assets to potential coastal flooding. Intermediate conditions at year 2050 can be inferred from results of the existing and future extreme conditions.

5.5.2. Humboldt Bay

Flooding within Humboldt Bay should use the data developed by the Humboldt Bay Sea Level Rise Adaptation Planning Project that show areas of inundation resulting from different amounts of sea level rise. Specifically, extreme flooding in Humboldt Bay should consider the different projections of inundation of the simulated 100-year recurrence flood projections.

Because the inundation mapping was conducted for discrete amounts of sea level rise, and the exposure will be conducted for the planning horizons of 2050 and 2100, the following datasets should be used:

- Year 2050: Use the 0.5 meter projection with the 100-year recurrence water level to infer the extreme water level at 2050;
- Year 2100: Use the 1 and 1.5 meter projections of the 100-year recurrence water level to develop a range in the anticipated extreme water level at 2100.

This dataset represents the best available flood mapping that considers increased water surface elevation resulting from sea level rise. Assessing the range of potential sea level rise for 2100 is important because of the non-uniform rates of vertical land motion that are observed in Humboldt Bay, and suggest that areas along the southern shore of Humboldt Bay may be experiencing greater rates of relative sea level rise than in the north (Cascadia GeoSciences 2013). Site specific and design-level analyses may need to use sanctioned rates and estimates of sea level rise in accordance with the National Geodetic Survey and National Ocean Service.

5.5.3. NOAA SLR Viewer Data

We understand the SLR Viewer data will be used to assess frequent tidal inundation for existing and future conditions with sea level rise. Table 7 summarizes the recommended data mapping layers to be applied in evaluation of the asset exposure. The table presents three planning horizons: existing conditions at 2010; future conditions at 2050; and future conditions at 2100. For each of the three planning horizons we identify two inundation frequencies that can be used for the evaluation: daily high tide and annual high tide. Here, we assume that the MHHW elevation can be representative of the daily high tide without storm surge and without the effects of waves and wave runup. The annual high tide elevation was assumed to include an additional 2 feet of storm surge above the MHHW elevation, but does not include the effects of waves. We selected an annual storm surge of 2 feet as a conservative estimate based on review of tidal records at Point Arena, North Spit in Humboldt Bay, and at Crescent City.

TABLE 7
RECOMMENDED DATA LAYERS FOR EVALUATING INUNDATION FREQUENCY

Year	Frequency of Inundation	Assumptions	Mapping Layer
2010 (Existing)	Daily High Tide	MHHW	CA_EKA_slr_0ft
2010 (Existing)	Annual High Tide	MHHW + 2 feet of storm surge	CA_EKA_slr_2ft
2050	Daily High Tide	MHHW + 2 feet SLR	CA_EKA_slr_2ft
2050	Annual High Tide	MHHW + 2 feet SLR + 2 feet storm surge	CA_EKA_slr_4ft
2100	Daily High Tide	MHHW + 4 feet SLR	CA_EKA_slr_4ft
2100	Annual High Tide	MHHW + 4 feet SLR + 2 feet storm surge	CA_EKA_slr_6ft

Note: Assumes no wave action; assumes storm surge limited to 2 feet;

Applying the data layers listed in Table 7 to the asset exposure analysis will help to inform the level of impact that may occur for a range of inundation magnitudes. The level of impact to an asset will be a function of the level or frequency of inundation that occurs. For example, an asset that experiences shallow flooding approximately once per year may have a moderate impact, or in a “temporary closure” category of impacts. However, an asset that is flooded on a daily to monthly frequency likely implies a higher degree of impact, such as the “temporary closure” or “complete failure” categories.

Use of the NOAA SLR Viewer data is considered acceptable in the absence of other available data that considers other important factors, such as waves and erosion. The geomorphic changes to the shore associated with sea level rise play an important role in erosion hazard determination and flood routing, which have major implications on assessing vulnerability. In evaluating the vulnerability of the assets, the data should be used in combination with the separate sea level rise and erosion data sets provided. Additional assumptions were made by ESA regarding the degree of storm surge associated with a flood event with an approximately annual recurrence, but is based on tidal records in the vicinity of District 1. Further, the NOAA data does not include waves when it is known waves play an important role in coastal flooding along the exposed and open coast in California. Other interactions between fluvial and tidal processes, including the water surface elevation of coastal lagoons, should be considered a special case and may need additional site specific evaluation. We recommend associating the annual high tide inundation with the “reduced capacity” category of impacts and the daily high tide inundation with the “temporary closure” or “complete failure” impact categories.

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7. Figures

Figure 1. Residual Climate Effects Continue Beyond 2100

Figure 2. Change in Annual Average of Daily Maximum Temperature from Historic Average A2 and B1 Emissions Scenarios

Figure 3. Extreme Temperatures: Days Above 95°F for Scenario A2, All Models

Figure 4. Extreme Temperatures: Days Above 95°F for Scenario B1, All Models

Figure 5. Change in Extreme Temperature over Time for Multiple GCMs – District 1 Average

Figure 6. Percent Change of Total Annual Precipitation from Historic Average for A2 and B1 Emissions Scenarios

Figure 7. 98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, All Models

Figure 8. 98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, All Models

Figure 9. 98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, Wet Model

Figure 10. 98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, Wet Model

Figure 11. 98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, Dry Model

Figure 12. 98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, Dry Model

Figure 13. Change in Extreme Precipitation over Time for Multiple GCMs – District 1 Average

Figure 14. Percent Change in Total Annual Runoff from Historic Average for A2 and B1 Emissions Scenarios

Figure 15. 98th Percentile Runoff: Average Values and Relative Change for Scenario A2, All Models

Figure 16. 98th Percentile Runoff: Average Values and Relative Change for Scenario B1, All Models

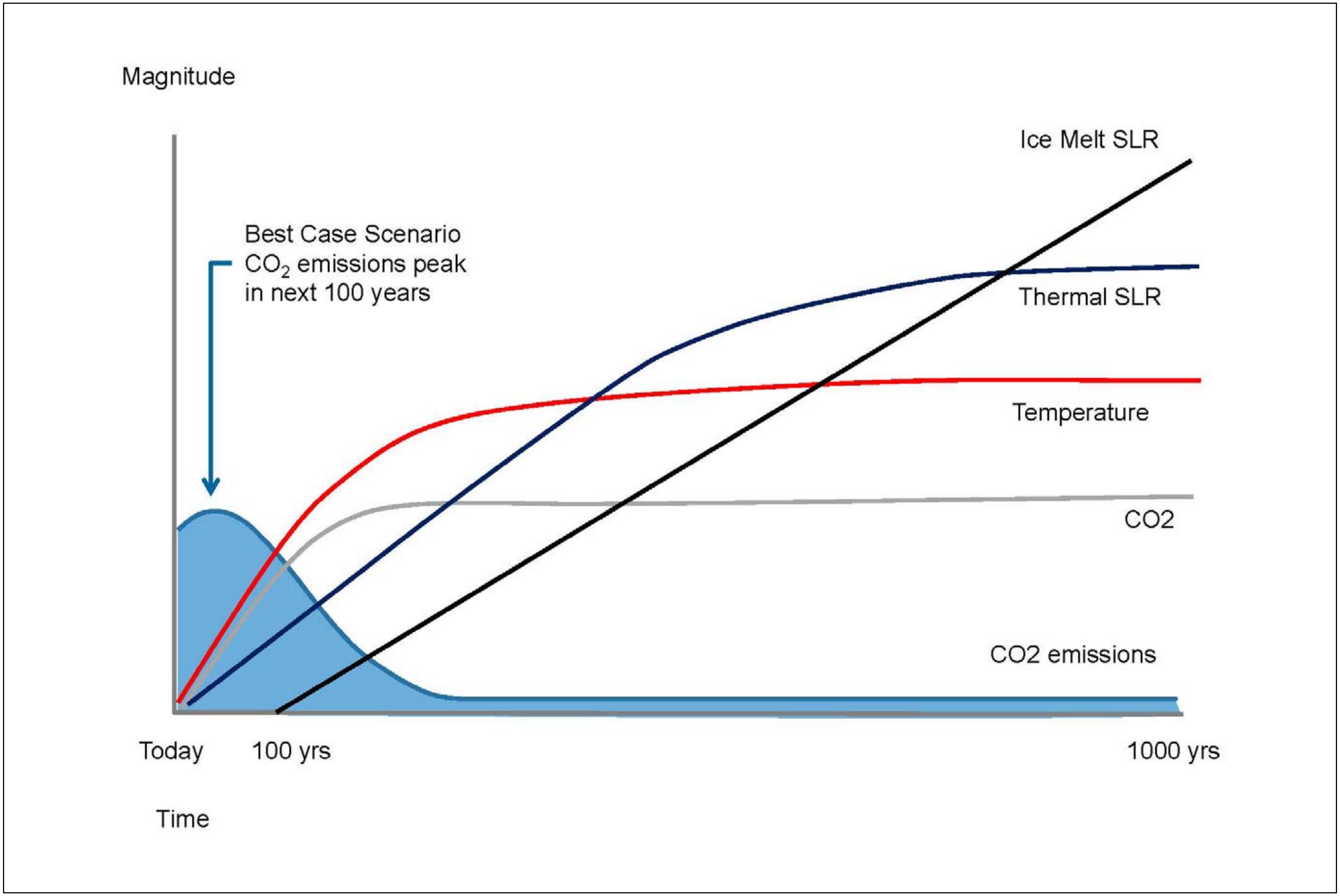
Figure 17. 98th Percentile Runoff: Average Values and Relative Change for Scenario A2, Wet Model

Figure 18. 98th Percentile Runoff: Average Values and Relative Change for Scenario B1, Wet Model

Figure 19. 98th Percentile Runoff: Average Values and Relative Change for Scenario A2, Dry Model

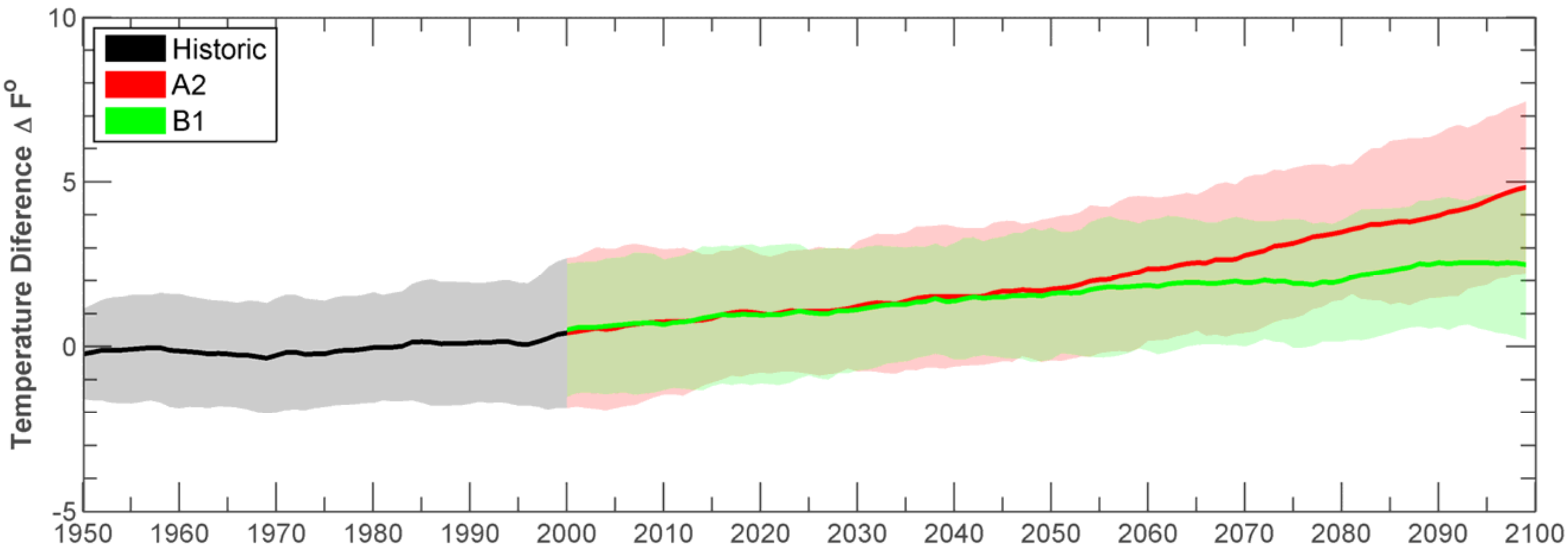
Figure 20. 98th Percentile Runoff: Average Values and Relative Change for Scenario B1, Dry Model

Figure 21. Change in Extreme Runoff over Time for Multiple GCMs – District 1 Average



SOURCE: After IPCC 2007

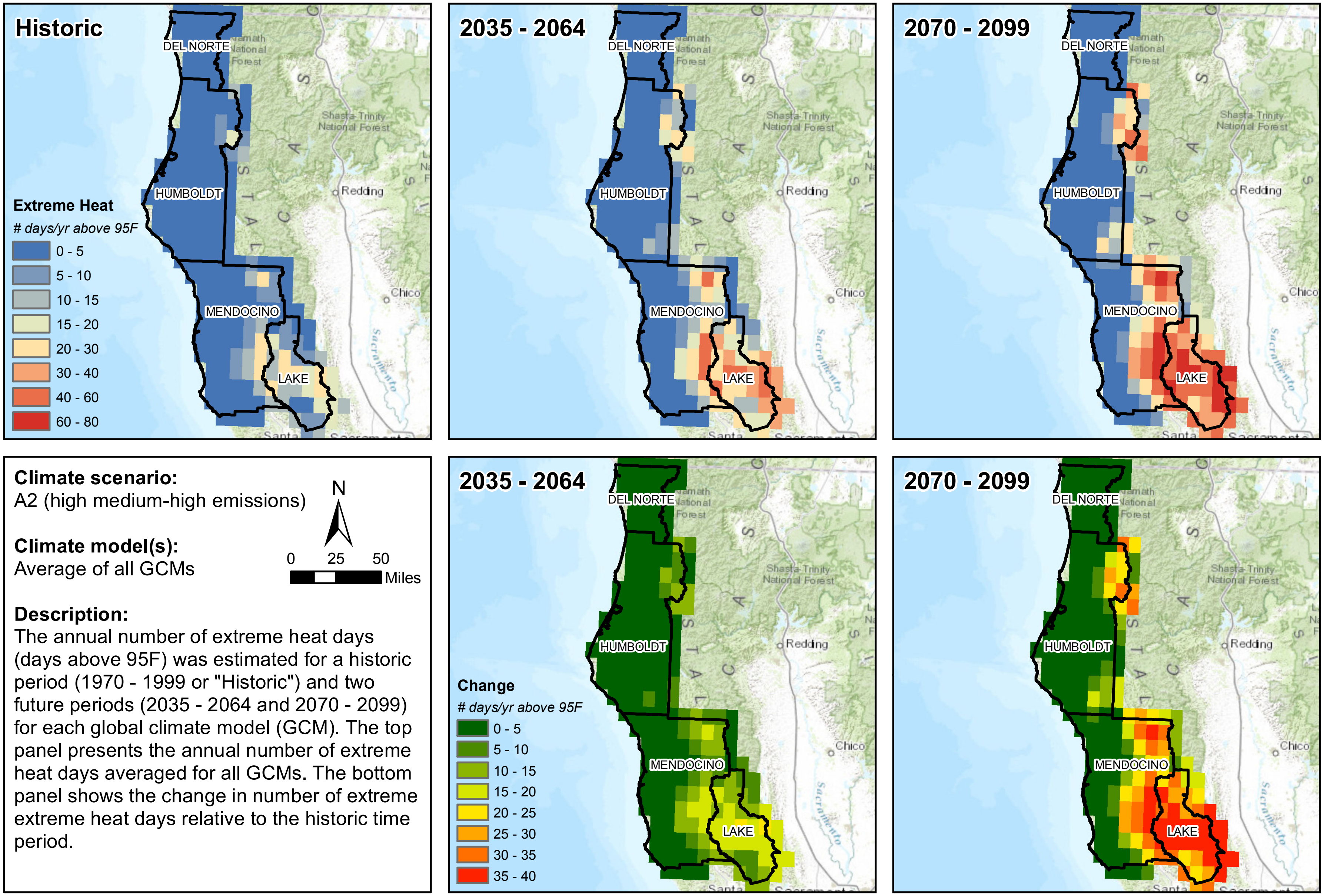
Figure 1
Residual Climate Effects Continue Beyond 2100



SOURCE: CMIP3

NOTES: 10-year moving average; spatially averaged over District 1;
solid lines are ensemble average;
shading represents range of individual GCMs

Figure 2
Change in Annual Average of Daily Maximum Temperature from Historic Average for A2 and B1 Emissions Scenarios



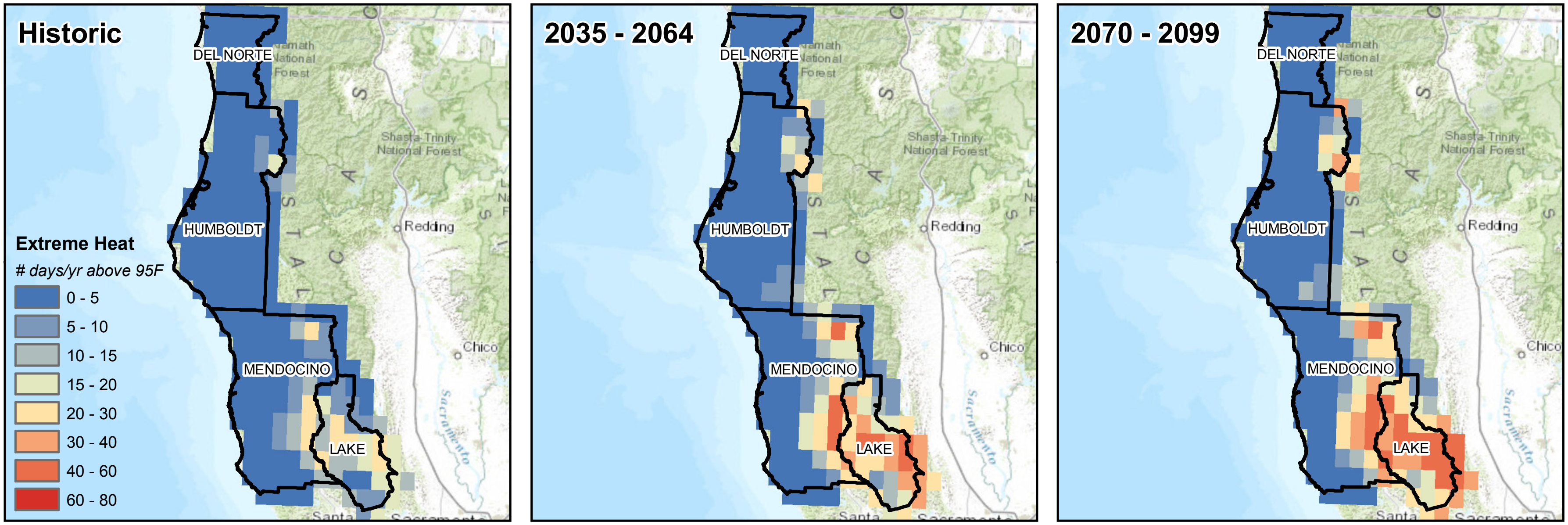
G:\130588_HCAOG-ClimateChange\MXDs\Figures\Temperature_Above95F_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Caltrans District 1 Climate Change Pilot Study . 130588.00

Figure 3

Extreme Temperatures: Days Above 95F for Scenario A2, All Models

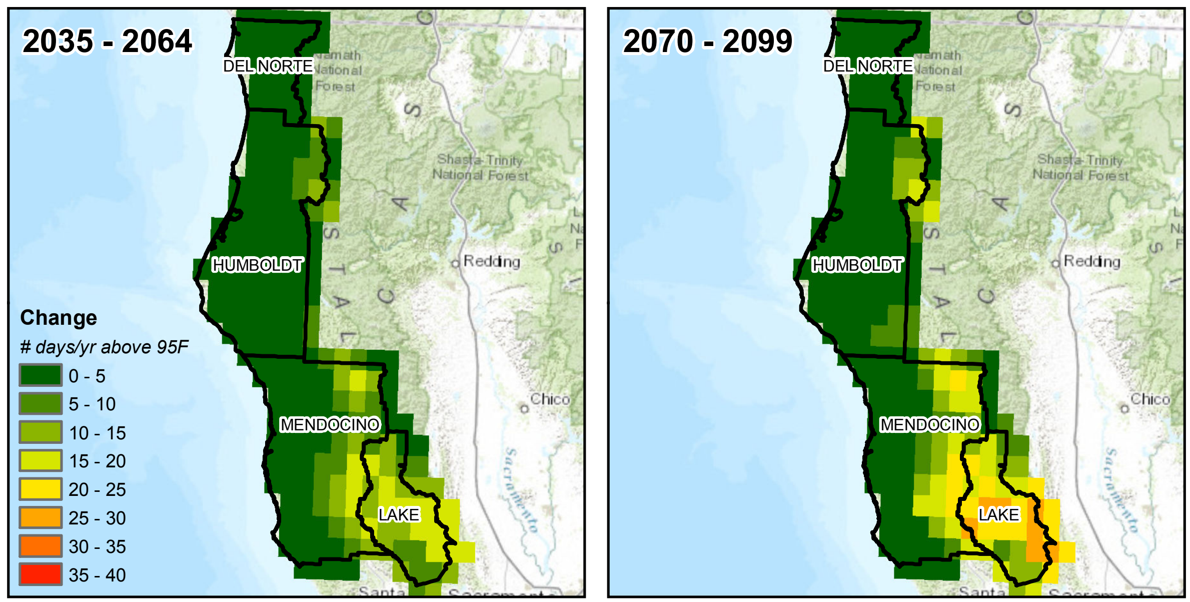


Climate scenario:
B1 (low emissions)

Climate model(s):
Average of all GCMs

N
0 25 50 Miles

Description:
The annual number of extreme heat days (days above 95F) was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for each global climate model (GCM). The top panel presents the annual number of extreme heat days averaged for all GCMs. The bottom panel shows the change in number of extreme extreme heat days relative to the historic time period.

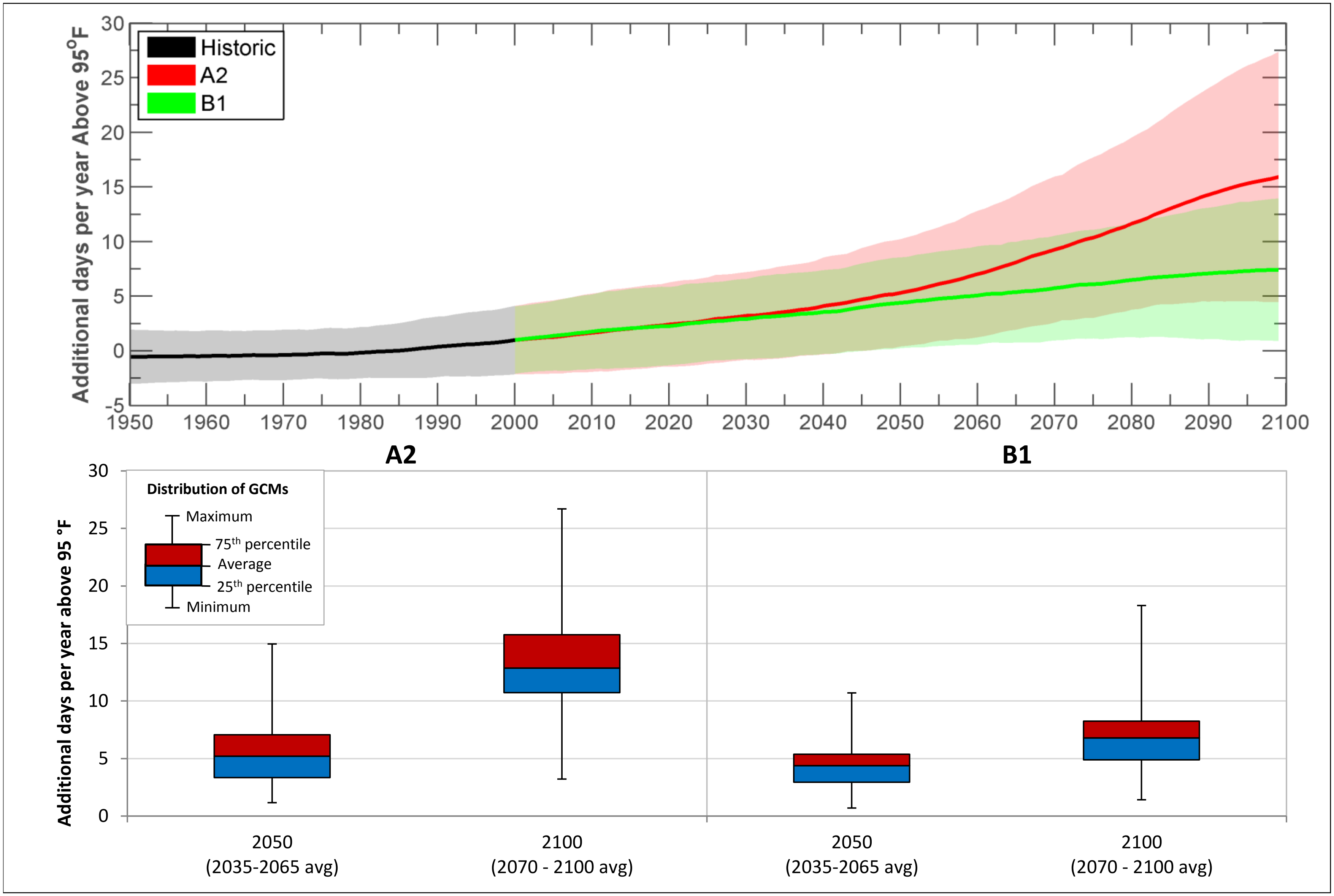


G:\130588_HCAOG-ClimateChange\MXDs\Figures\Temperature_Above95F_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

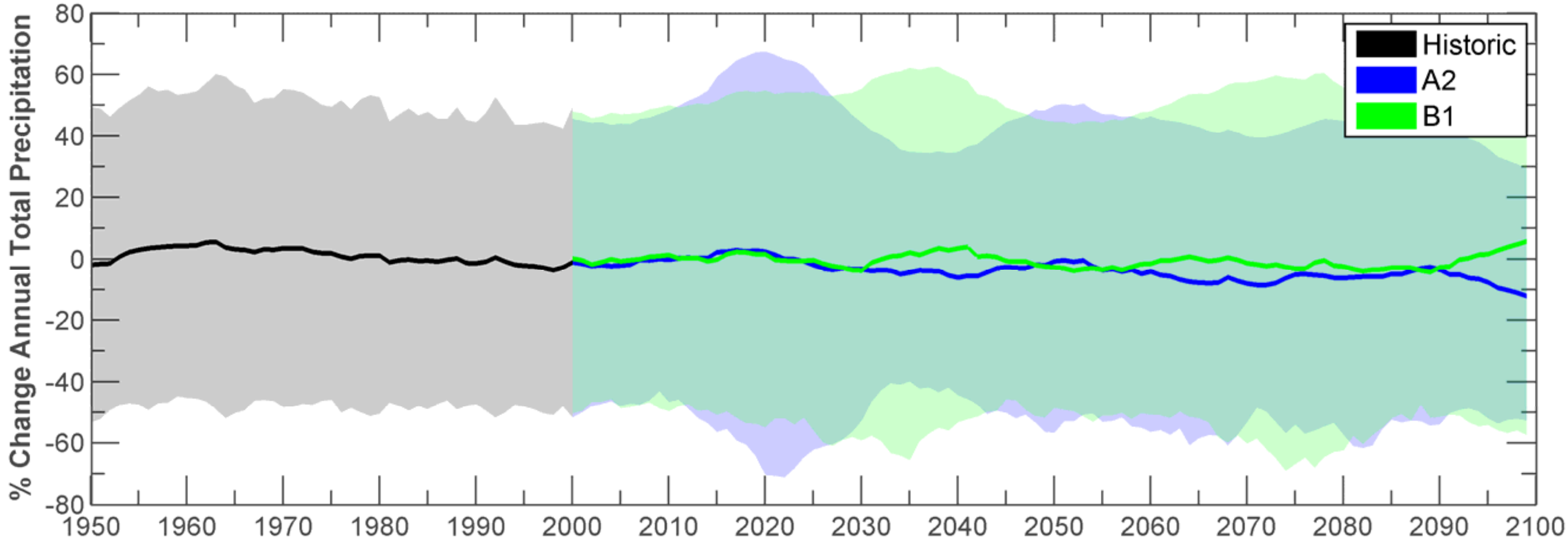
Caltrans District 1 Climate Change Pilot Study . 130588.00

Figure 4
Extreme Temperatures: Days Above 95F for Scenario B1, All Models



SOURCE: WCRP CMIP3 downscaled data
NOTE: The top plot shows a time series of the change in number of days per year exceeding 95 °F relative to a historic average (1970-2000). The range of GCMs is shown for historic (grey), A2 (red), and B1 (green) conditions. Solid lines represent an average of the GCMs. The lines are smoothed using a moving 30-year average. The bottom plot shows the range of GCMs for A2 and B1 emissions for 30-year averages for 2050 and 2100.

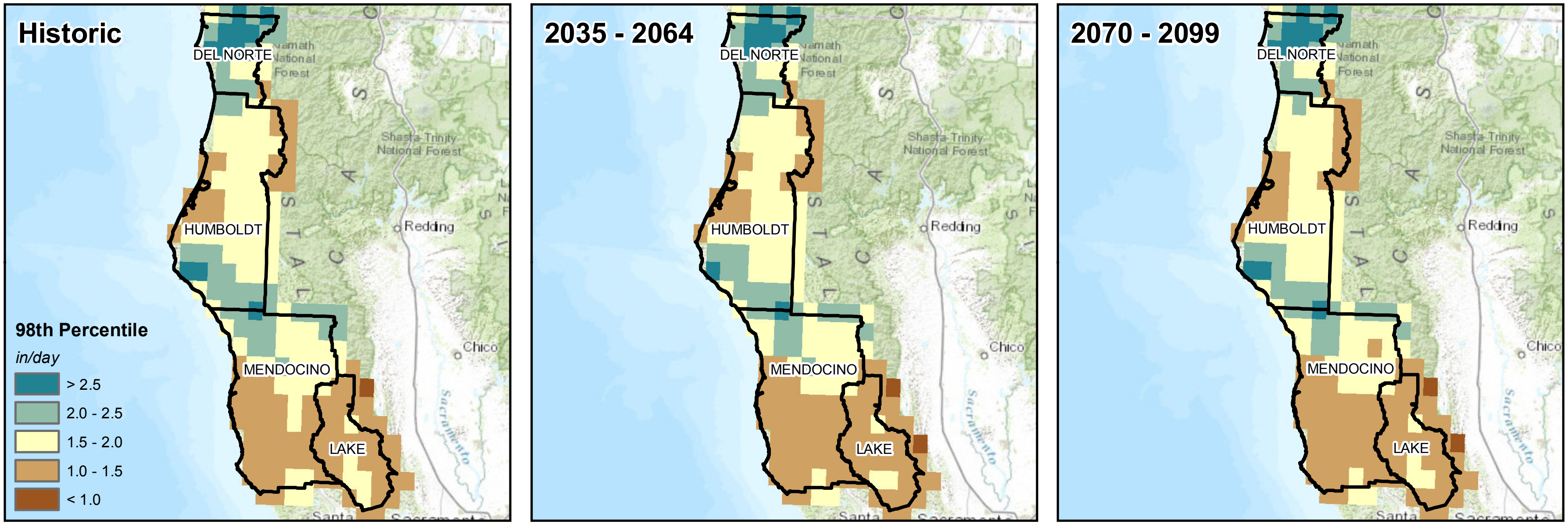
Figure 5
Change in Extreme Temperature Over Time for Multiple GCMs - District 1 Average



SOURCE: CMIP3

NOTES: 10-year moving average; spatially averaged over District 1;
solid lines are ensemble average;
shading represents range of individual GCMs

Figure 6
Percent Change of Total Annual Precipitation from Historic Average
for A2 and B1 Emissions Scenarios

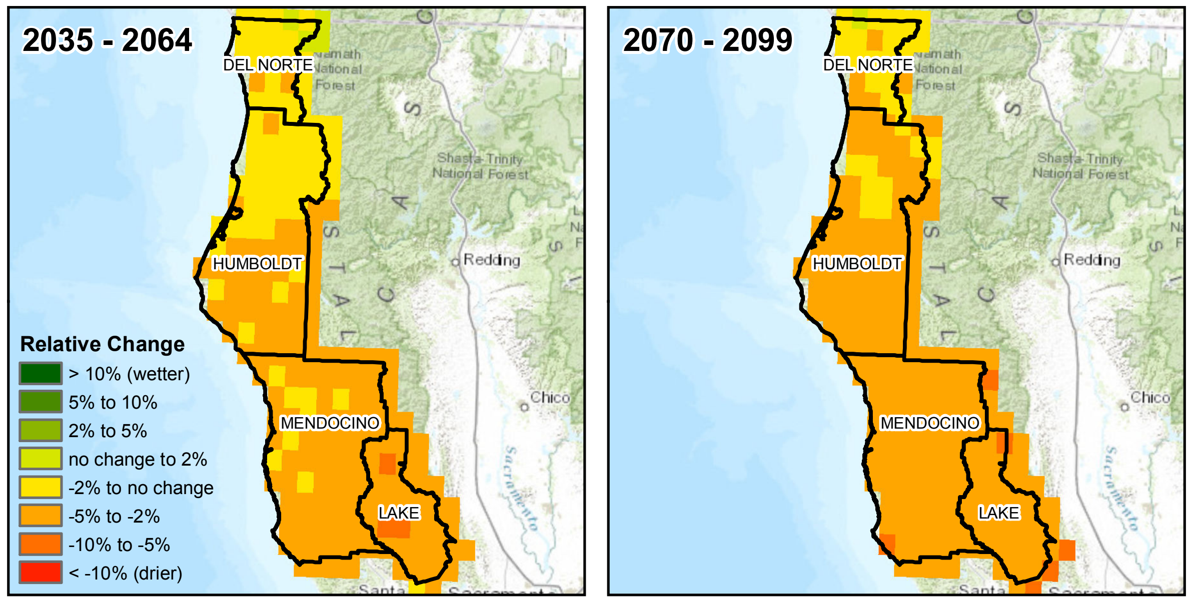


Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Average of all GCMs

N
0 25 50 Miles

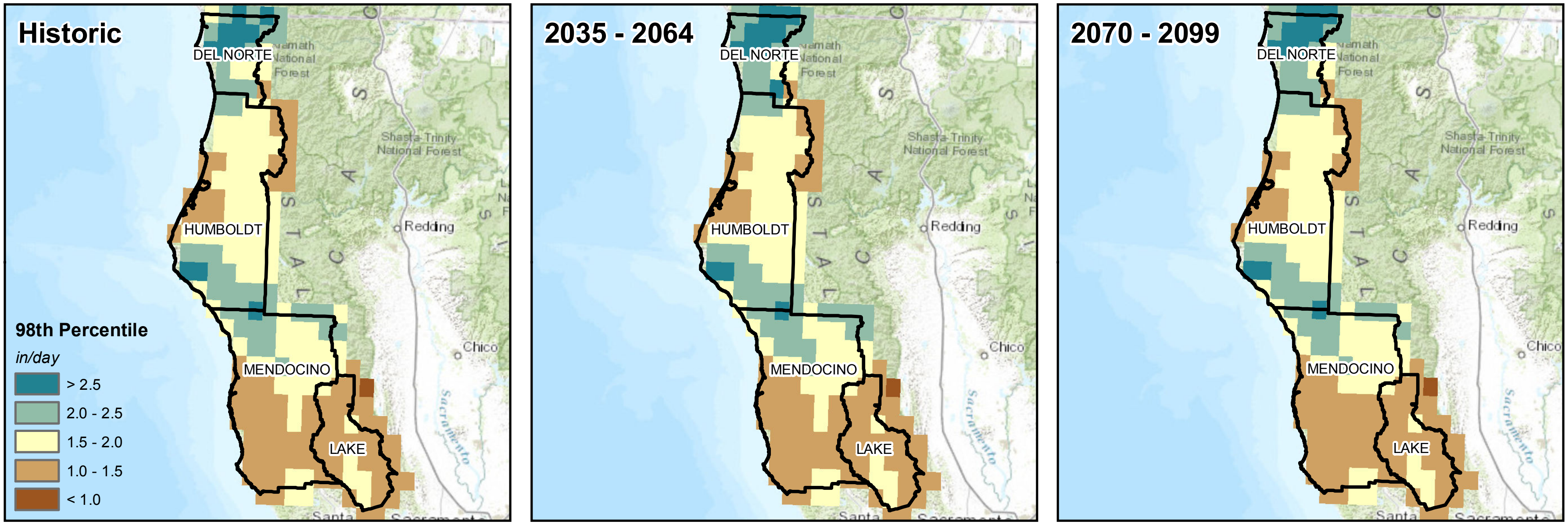
Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for each global climate model (GCM). The top panel presents the 98th percentile precipitation averaged for all GCMs. The bottom panel shows the percent change relative to the historic time period.



G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 7
98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, All Models

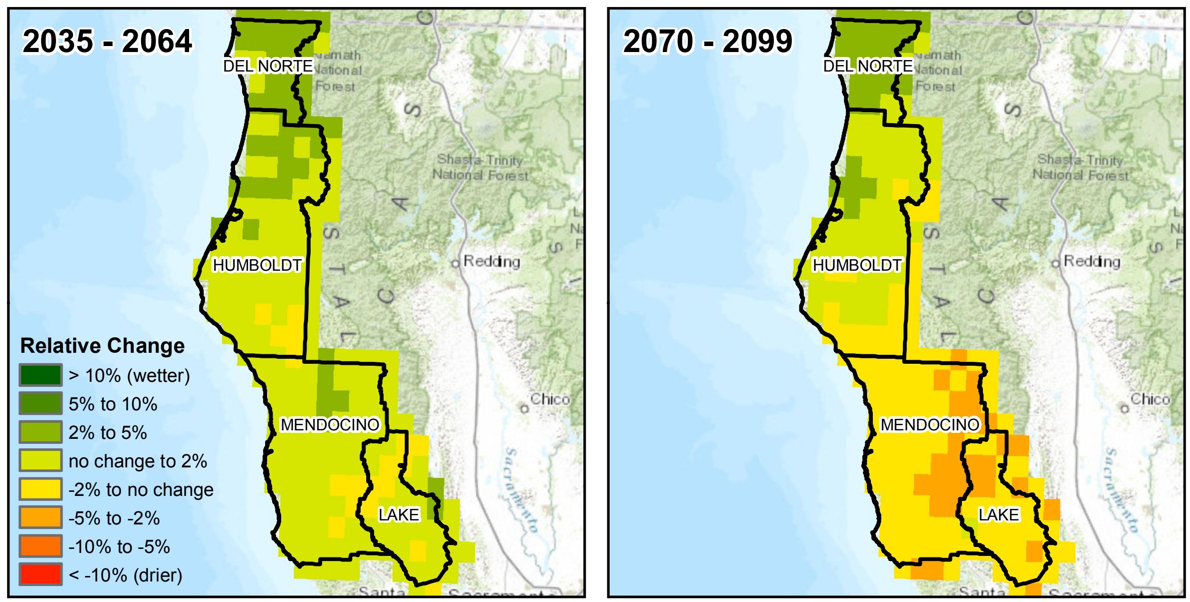


Climate scenario:
B1 (low emissions)

Climate model(s):
Average of all GCMs

N
0 25 50
Miles

Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for each global climate model (GCM). The top panel presents the 98th percentile precipitation averaged for all GCMs. The bottom panel shows the percent change relative to the historic time period.

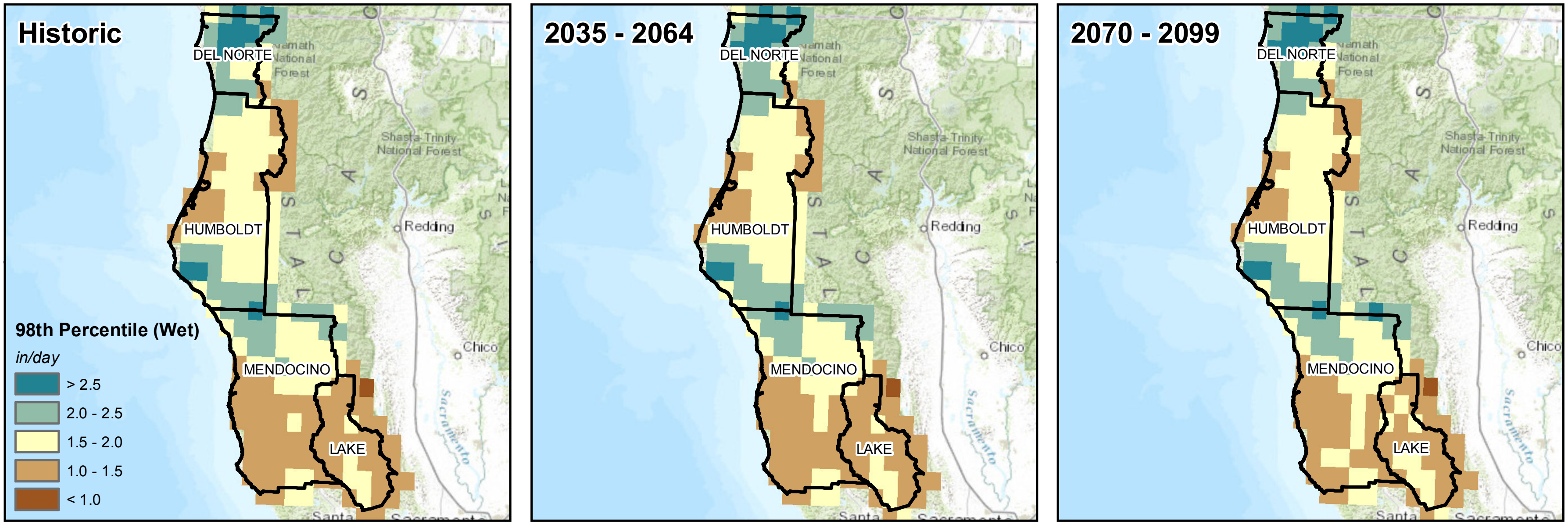


G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

Caltrans District 1 Climate Change Pilot Study . 130588.00

Figure 8
98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, All Models

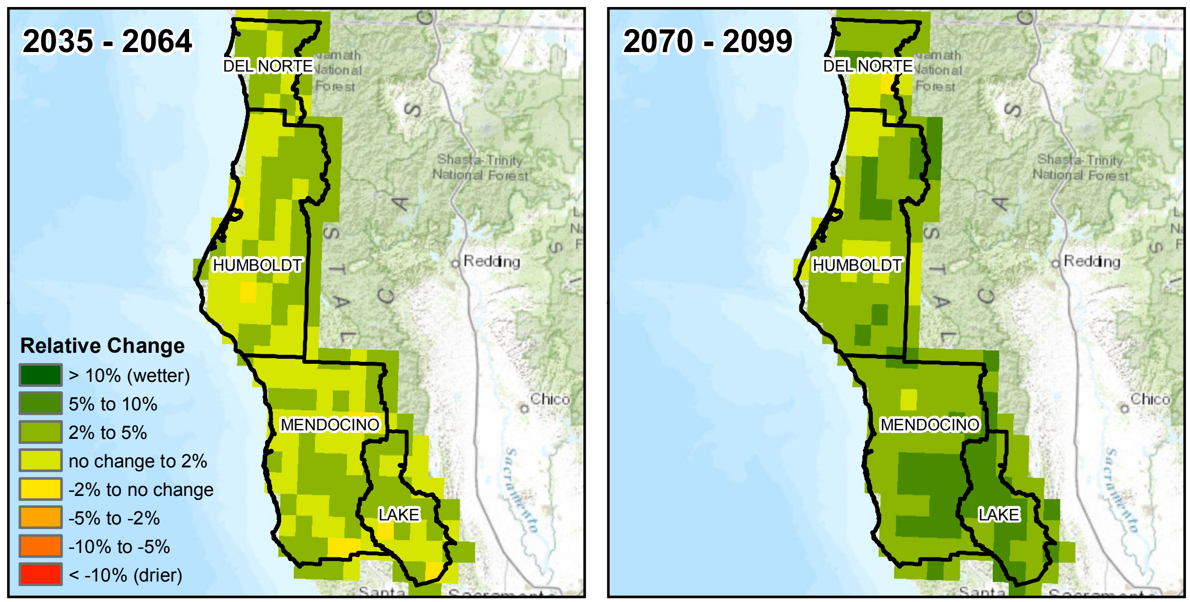


Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Wet GCM (PCM)

N
0 25 50
Miles

Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a wet global climate model (GCM). The top panel presents the 98th percentile precipitation for the wet GCM. The bottom panel shows the percent change relative to the historic time period.

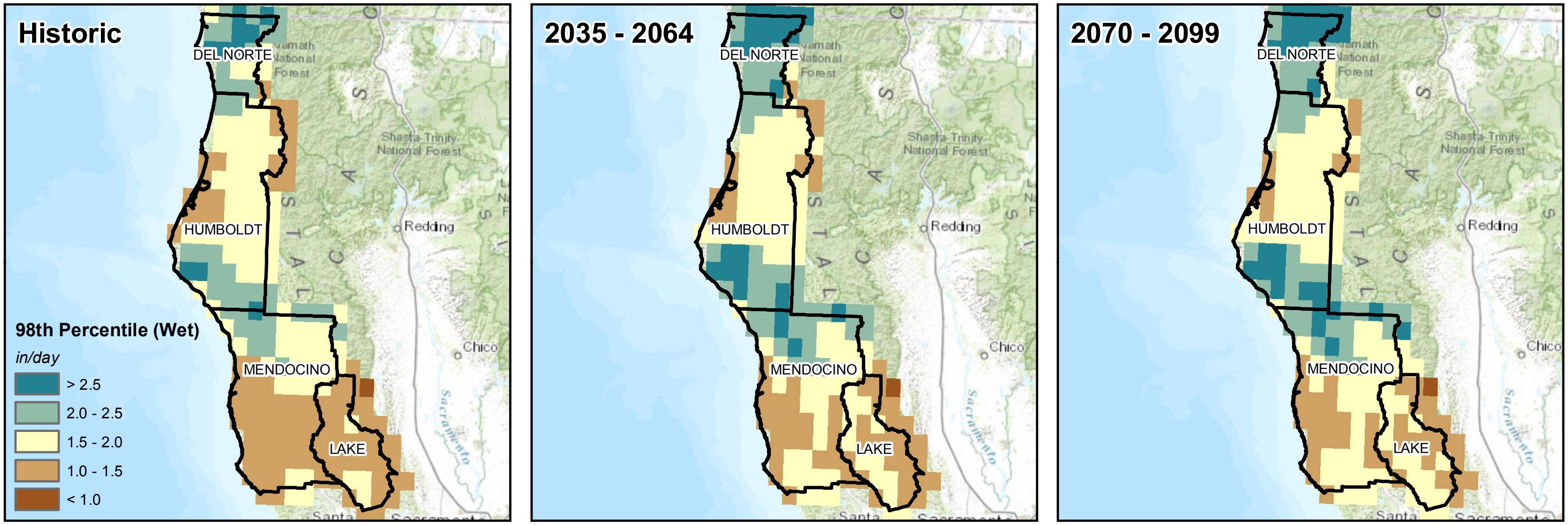


G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

Caltrans District 1 Climate Change Pilot Study . 130588.00

Figure 9
98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, Wet Model

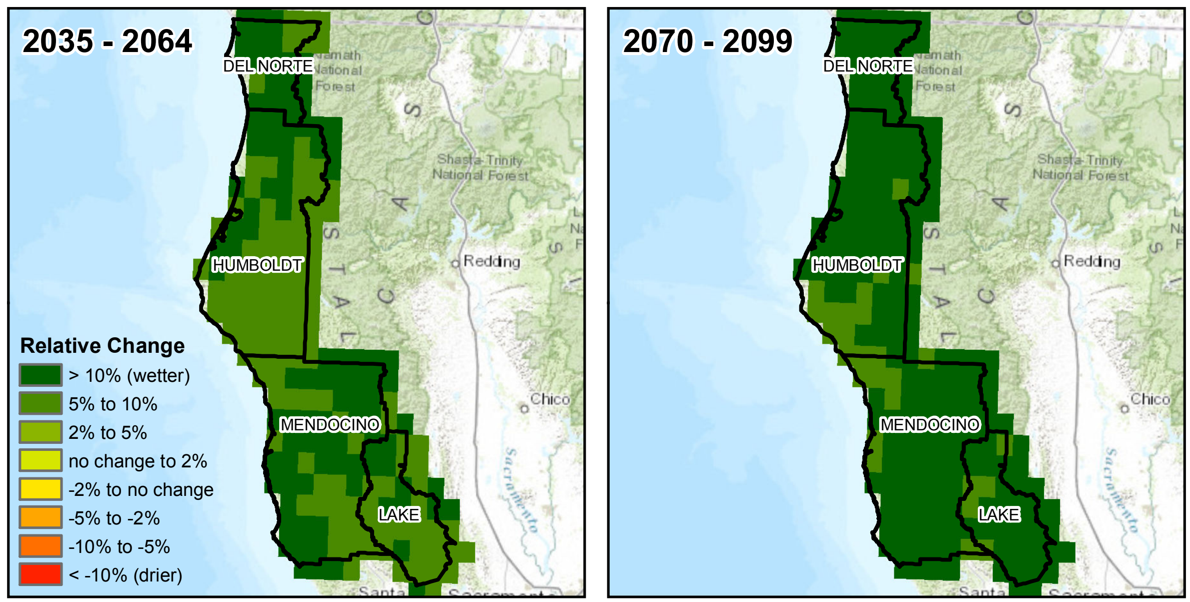


Climate scenario:
B1 (low emissions)

Climate model(s):
Wet GCM (PCM)

N
0 25 50 Miles

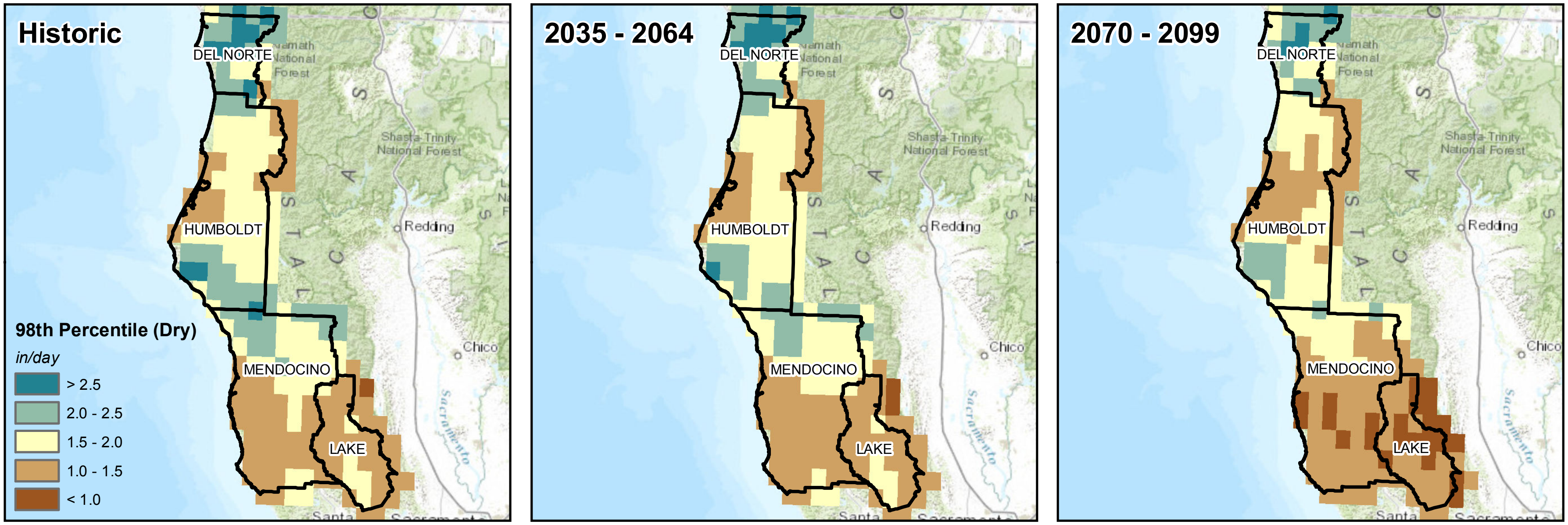
Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a wet global climate model (GCM). The top panel presents the 98th percentile precipitation for the wet GCM. The bottom panel shows the percent change relative to the historic time period.



G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 10
98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, Wet Model

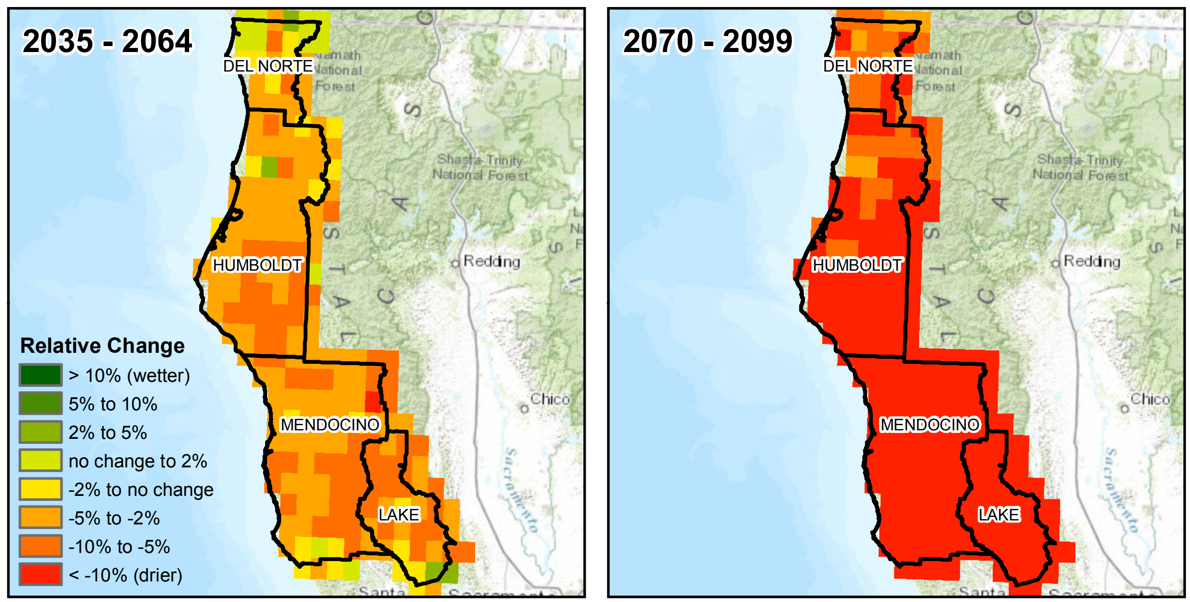


Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Dry GCM (GFDL)

N
0 25 50
Miles

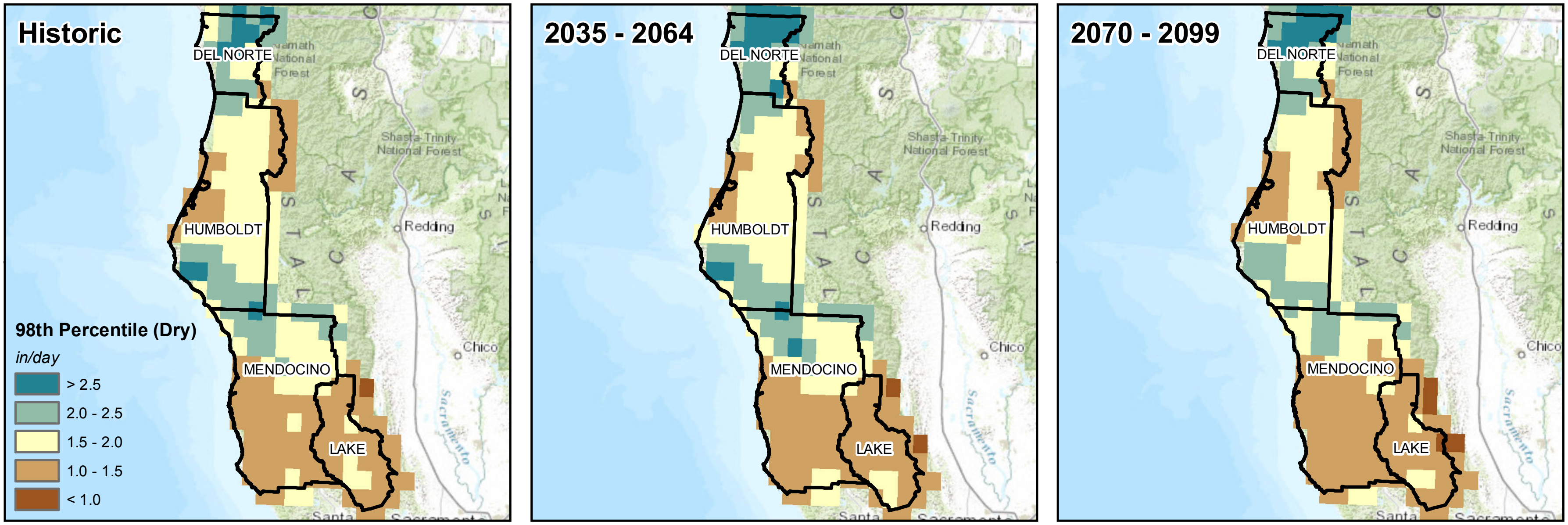
Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a dry global climate model (GCM). The top panel presents the 98th percentile precipitation for the dry GCM. The bottom panel shows the percent change relative to the historic time period.



G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

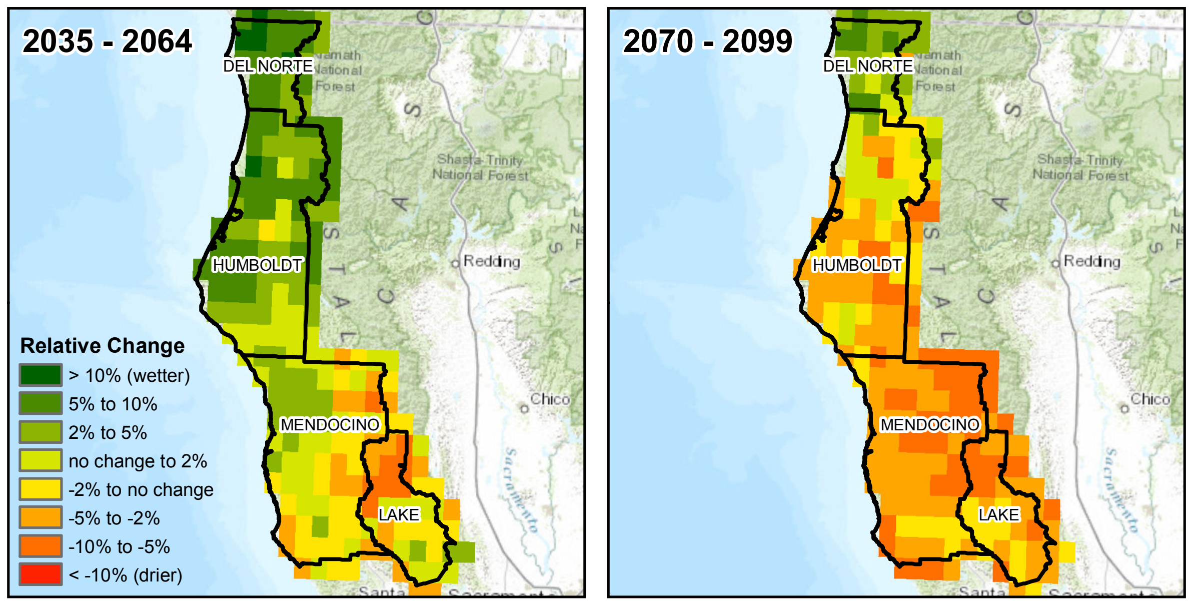
Figure 11
98th Percentile Precipitation: Average Values and Relative Change for Scenario A2, Dry Model



Climate scenario:
B1 (low emissions)

Climate model(s):
Dry GCM (GFDL)

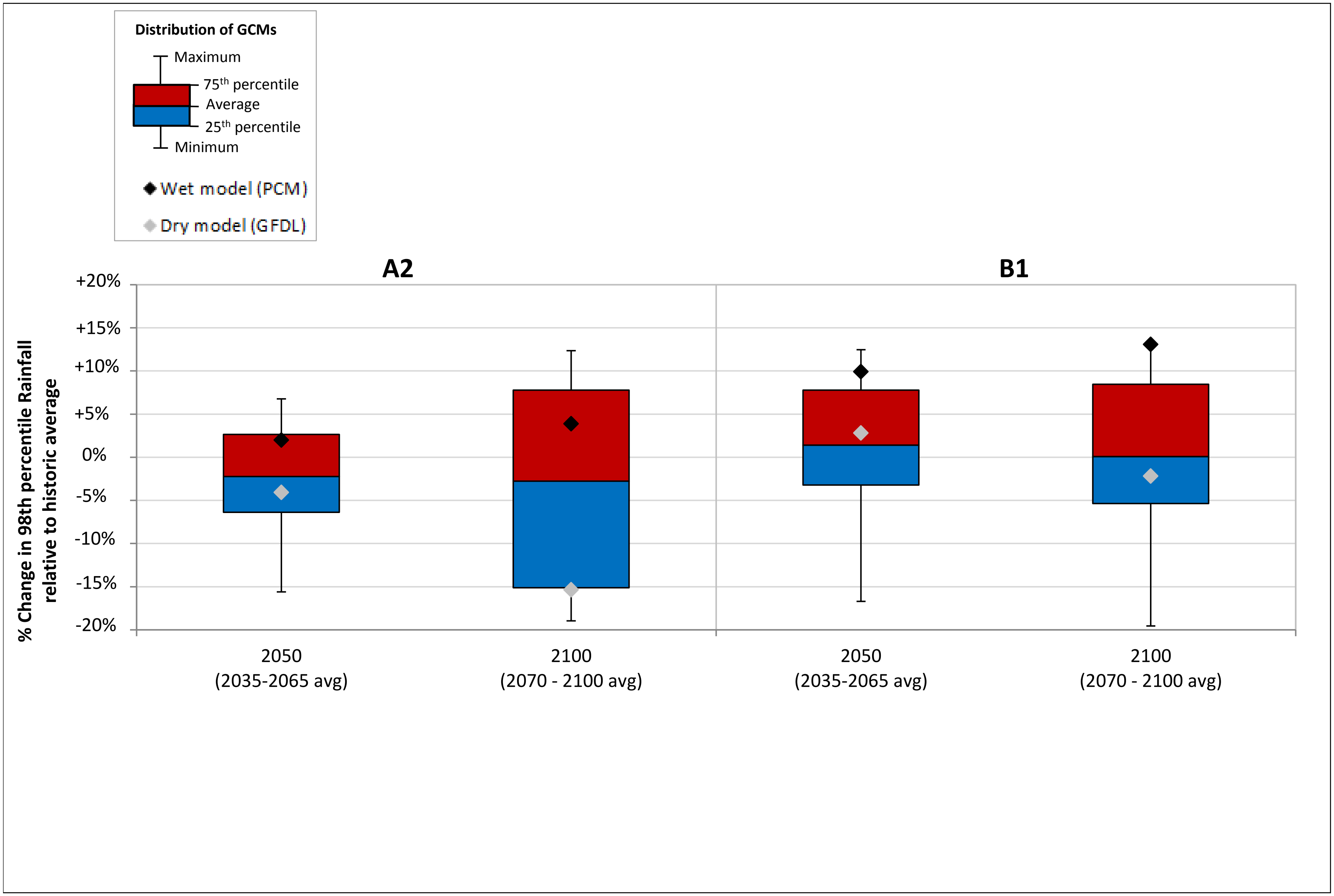
Description:
The 98th percentile precipitation was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a dry global climate model (GCM). The top panel presents the 98th percentile precipitation for the dry GCM. The bottom panel shows the percent change relative to the historic time period.



G:\130588_HCAOG-ClimateChange\MXDs\Figures\Precip_98Percentile_11Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 12
98th Percentile Precipitation: Average Values and Relative Change for Scenario B1, Dry Model

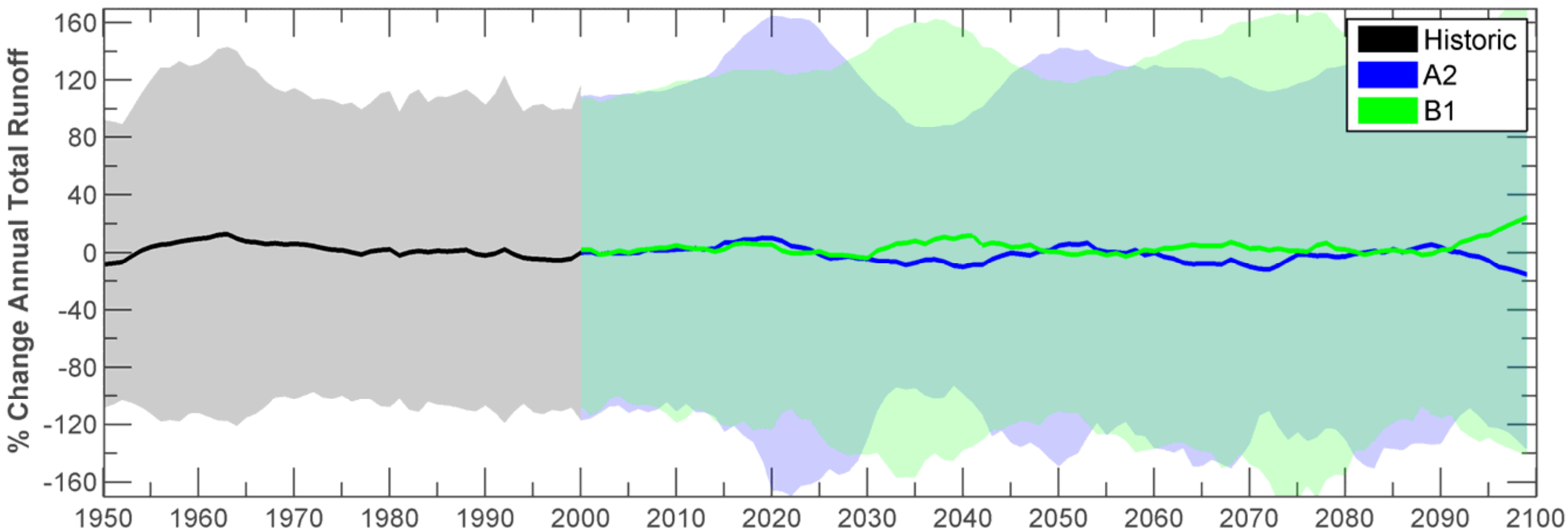


SOURCE: WCRP CMIP3 downscaled data

Caltrans District 1 Climate Change Pilot Study . 130588.00

Figure 13

Change in Extreme Precipitation Over Time for Multiple GCMs - District 1 Average

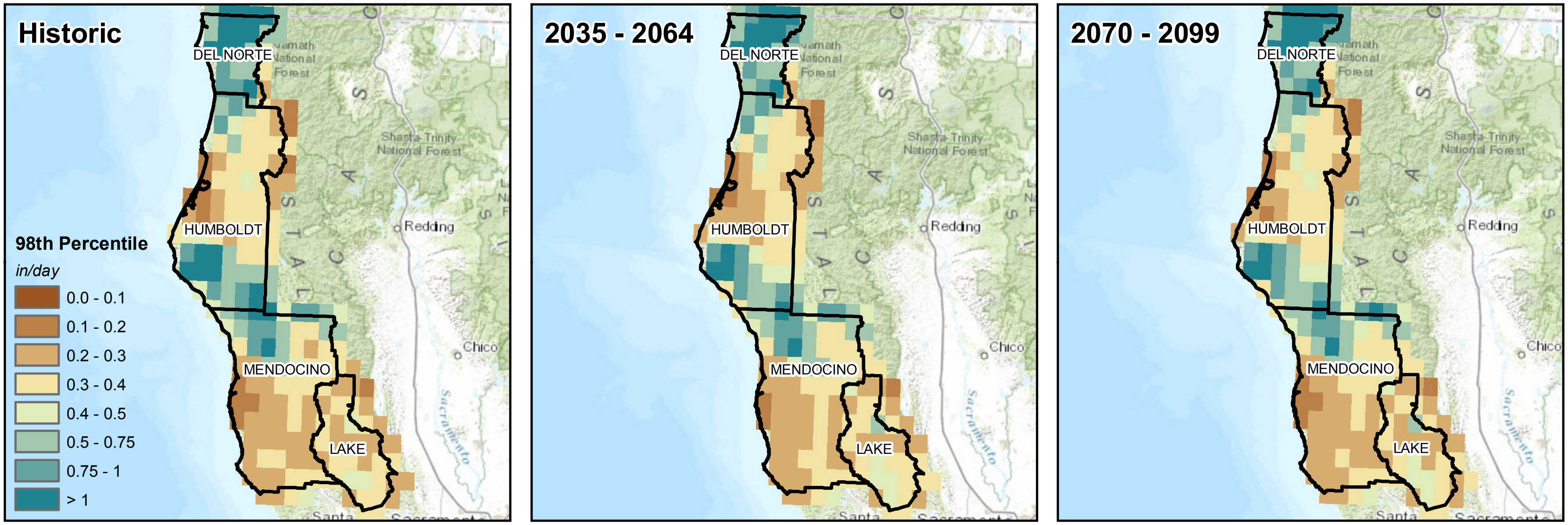


SOURCE: CMIP3

NOTES: 10-year moving average; spatially averaged over District 1;
solid lines are ensemble average;
shading represents range of individual GCMs

Figure 14

Percent Change in Total Annual Runoff from Historic Average for A2 and B1 Emissions Scenarios

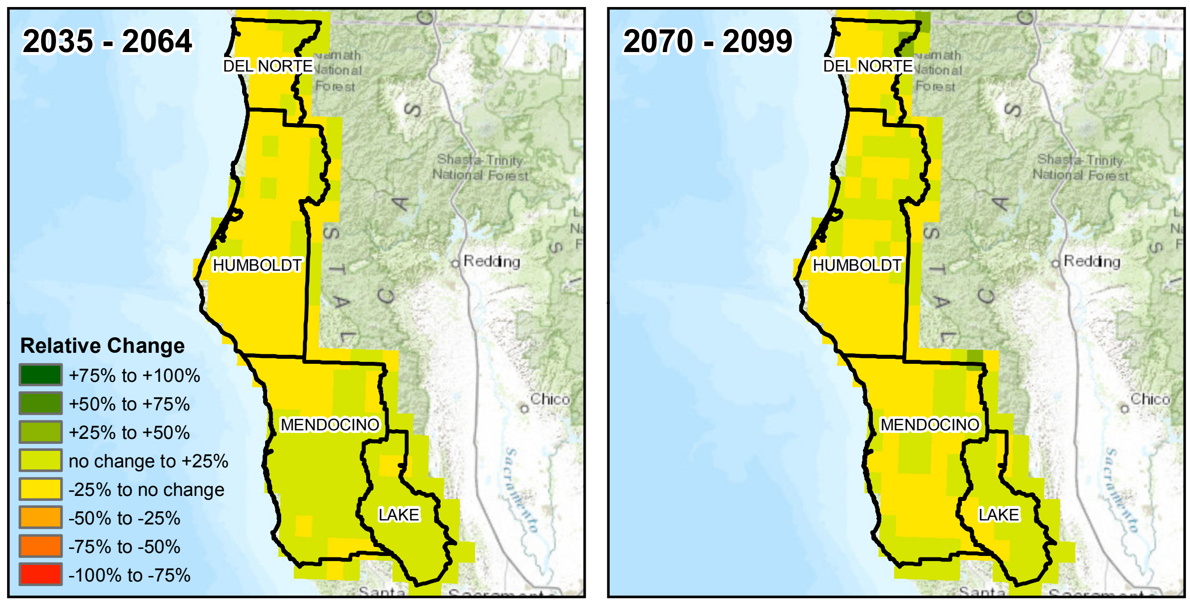


Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Average of all GCMs

N
0 25 50 Miles

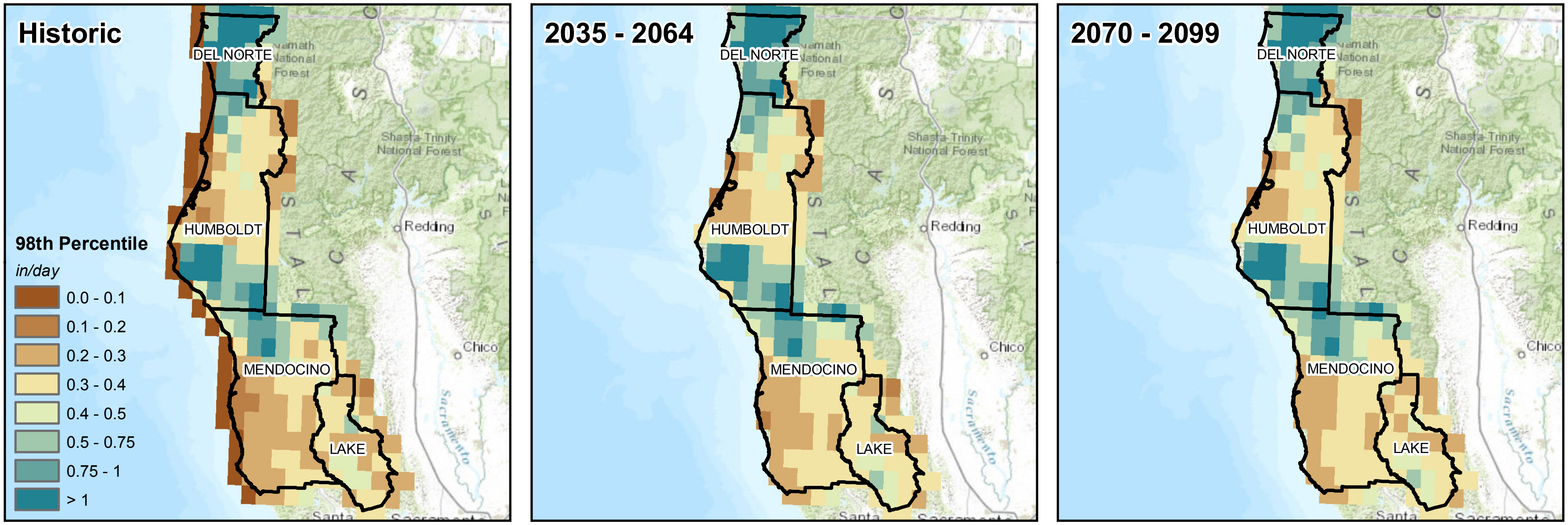
Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for each global climate model (GCM). The top panel presents the 98th percentile runoff averaged for all GCMs. The bottom panel shows the percent change relative to the historic time period.



S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 15
98th Percentile Runoff: Average Values and Relative Change for Scenario A2, All Models

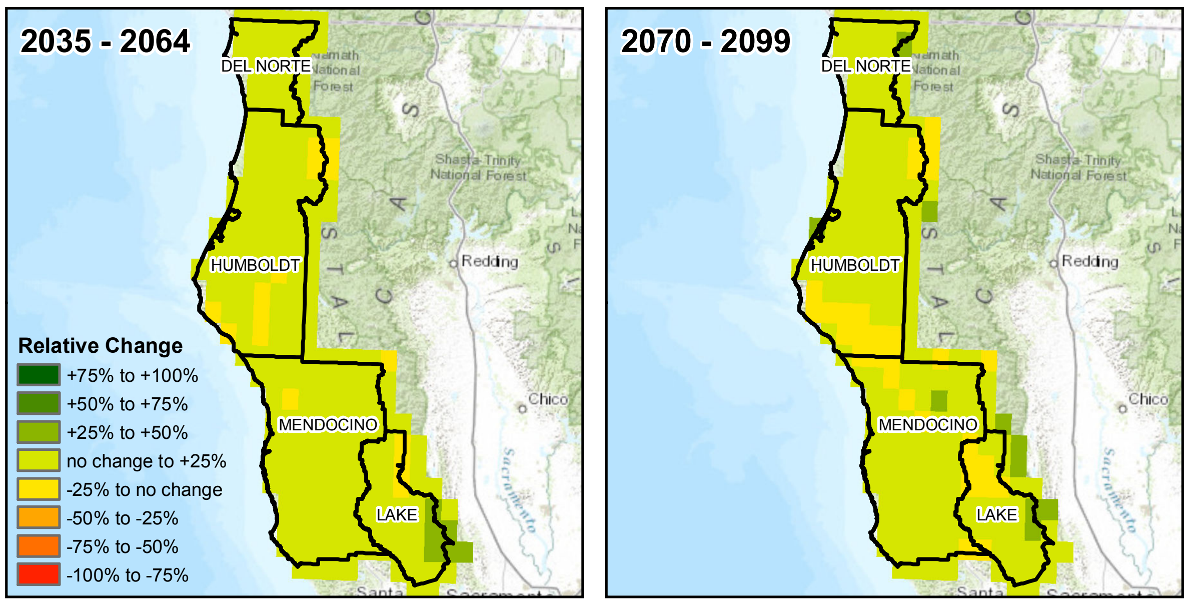


Climate scenario:
B1 (low emissions)

Climate model(s):
Average of all GCMs

N
0 25 50 Miles

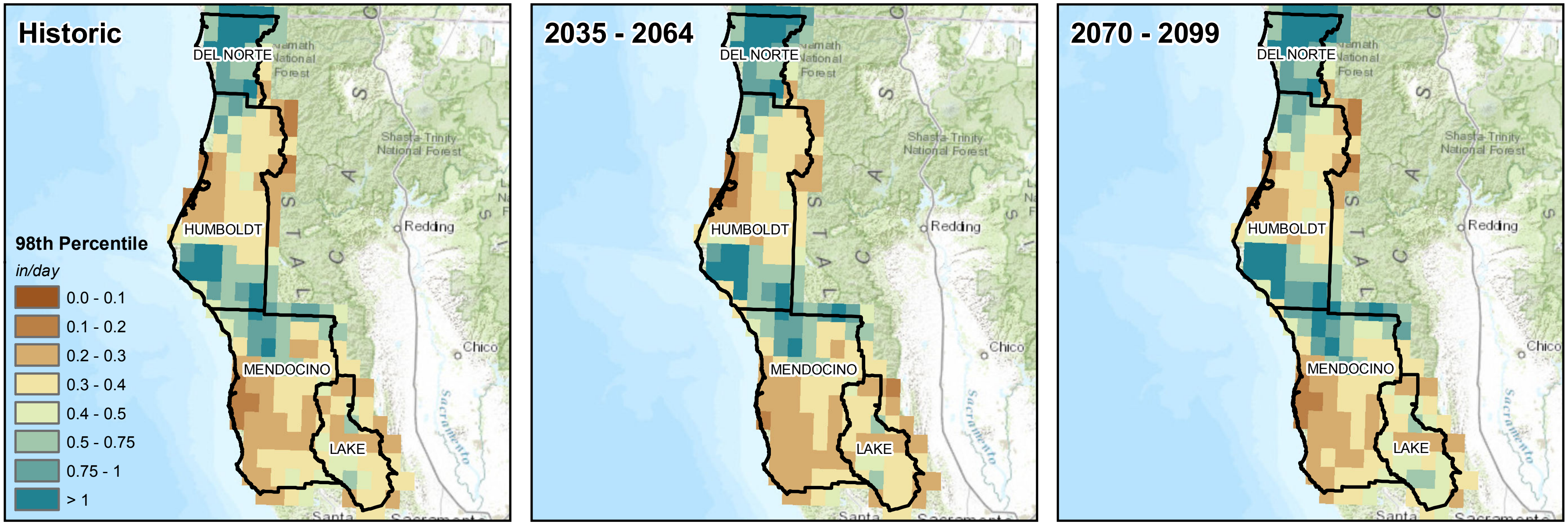
Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for each global climate model (GCM). The top panel presents the 98th percentile runoff averaged for all GCMs. The bottom panel shows the percent change relative to the historic time period.



S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 16
98th Percentile Runoff: Average Values and Relative Change for Scenario B1, All Models

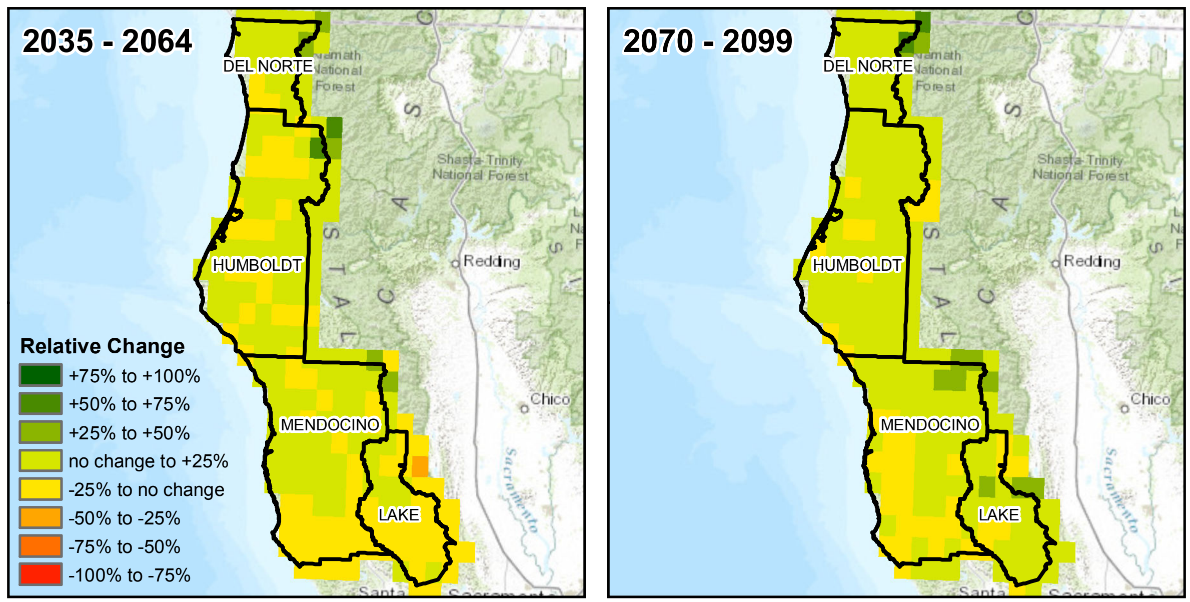


Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Wet GCM (PCM)

N
0 25 50
Miles

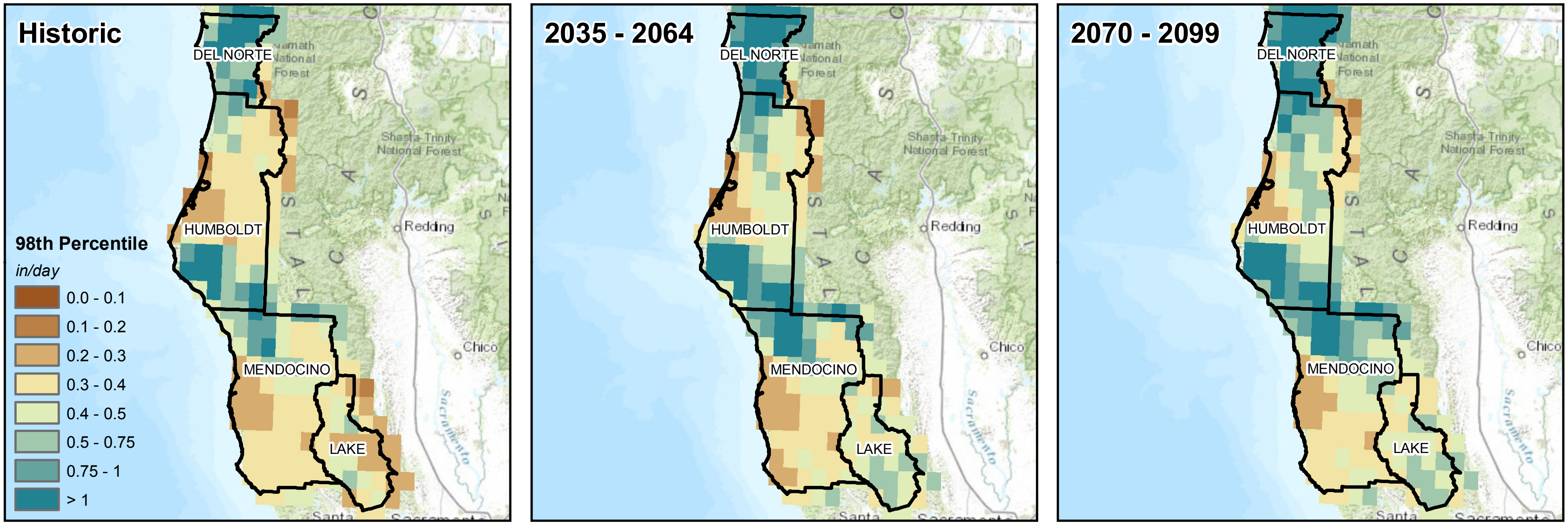
Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a wet global climate model (GCM). The top panel presents the 98th percentile runoff for the wet GCM. The bottom panel shows the percent change relative to the historic time period.



S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 17
98th Percentile Runoff: Average Values and Relative Change for Scenario A2, Wet Model

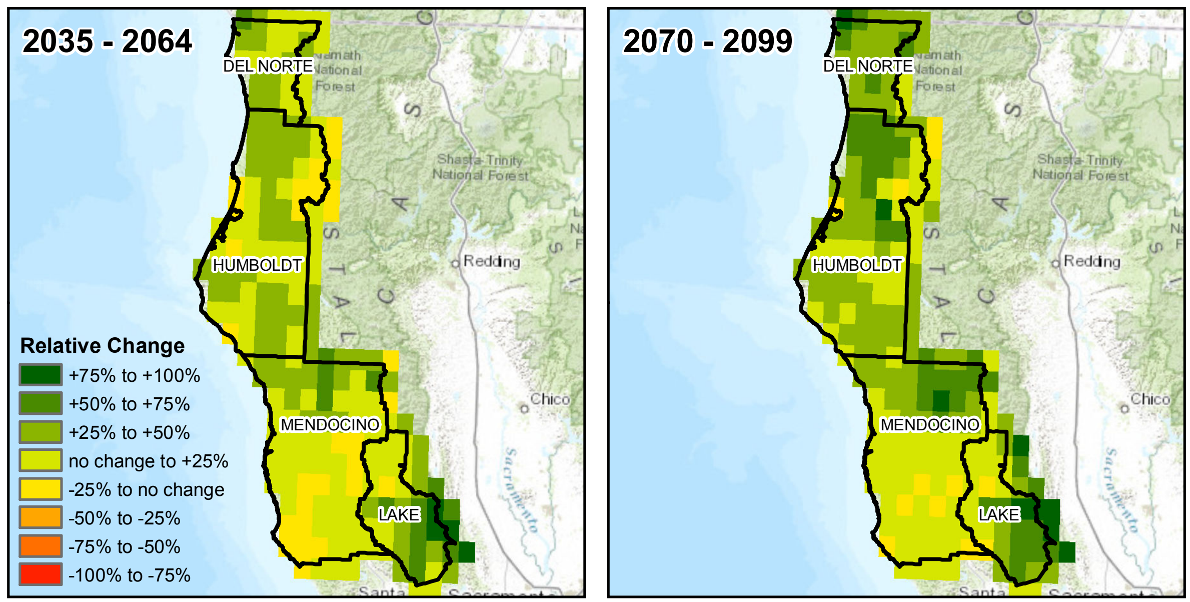


Climate scenario:
B1 (low emissions)

Climate model(s):
Wet GCM (PCM)

N
0 25 50
Miles

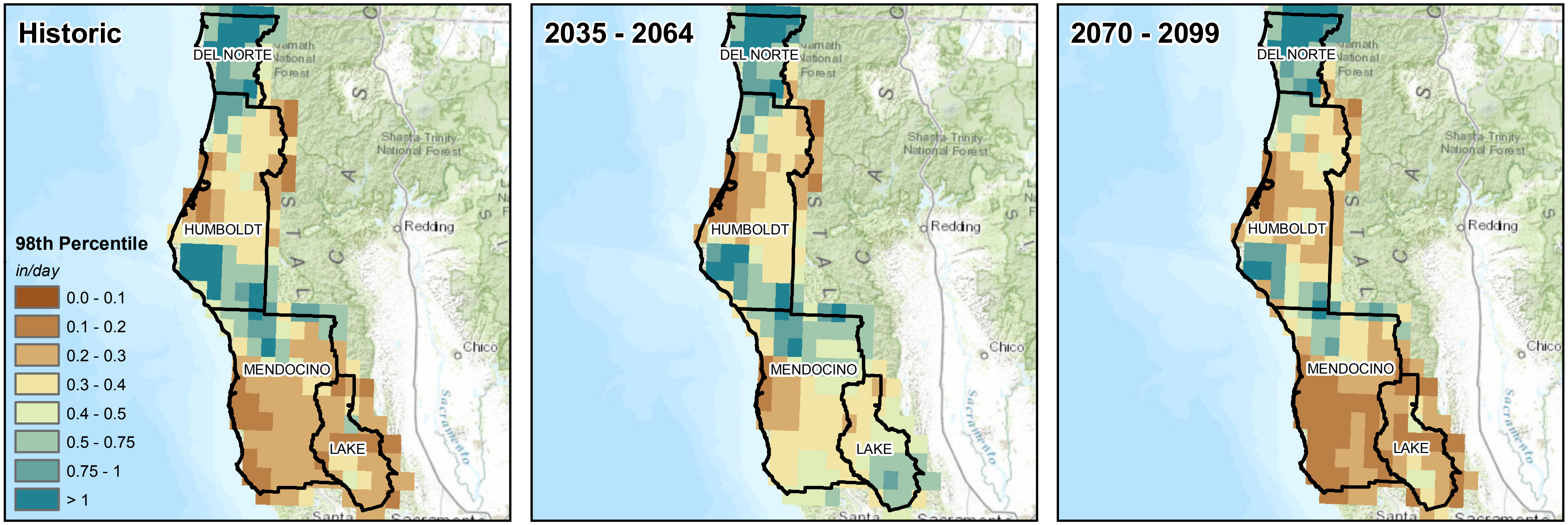
Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a wet global climate model (GCM). The top panel presents the 98th percentile runoff for the wet GCM. The bottom panel shows the percent change relative to the historic time period.



S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 18
98th Percentile Runoff: Average Values and Relative Change for Scenario B1, Wet Model



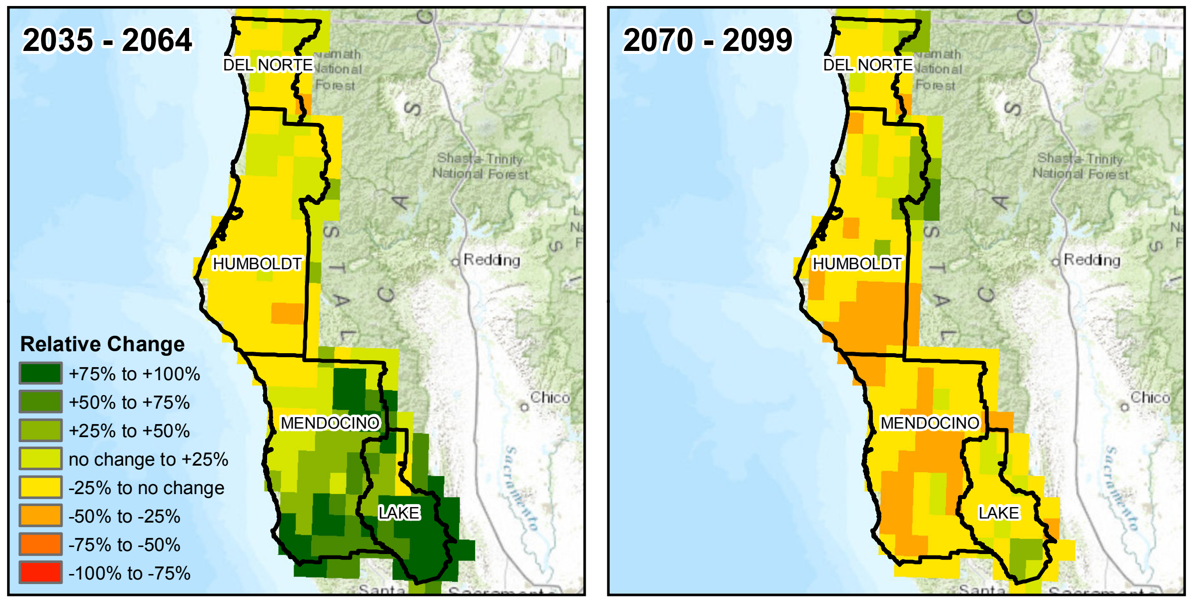
Climate scenario:
A2 (high medium-high emissions)

Climate model(s):
Dry GCM (GFDL)

N

0 25 50 Miles

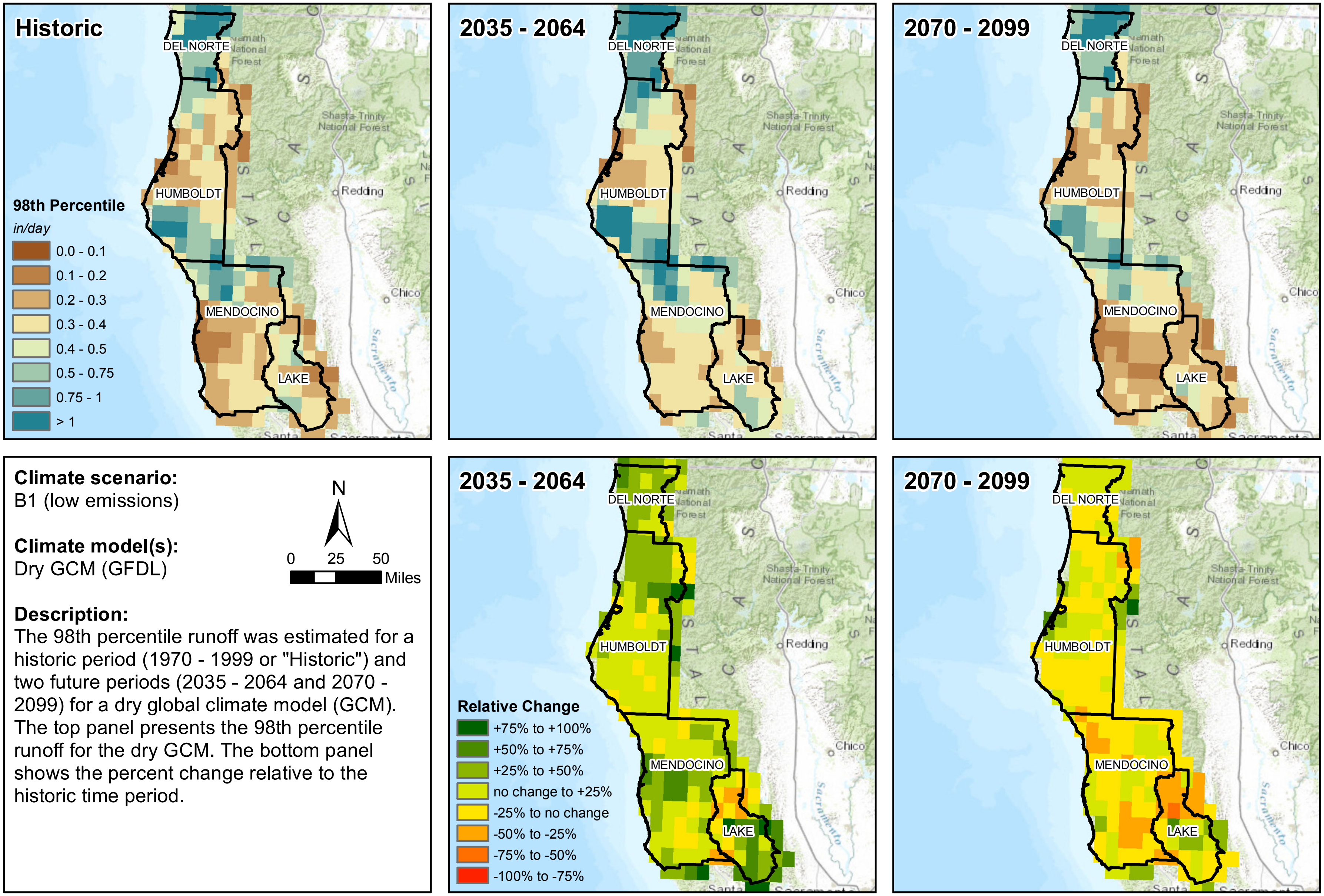
Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a dry global climate model (GCM). The top panel presents the 98th percentile runoff for the dry GCM. The bottom panel shows the percent change relative to the historic time period.



S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 19
98th Percentile Runoff: Average Values and Relative Change for Scenario A2, Dry Model



Climate scenario:
B1 (low emissions)

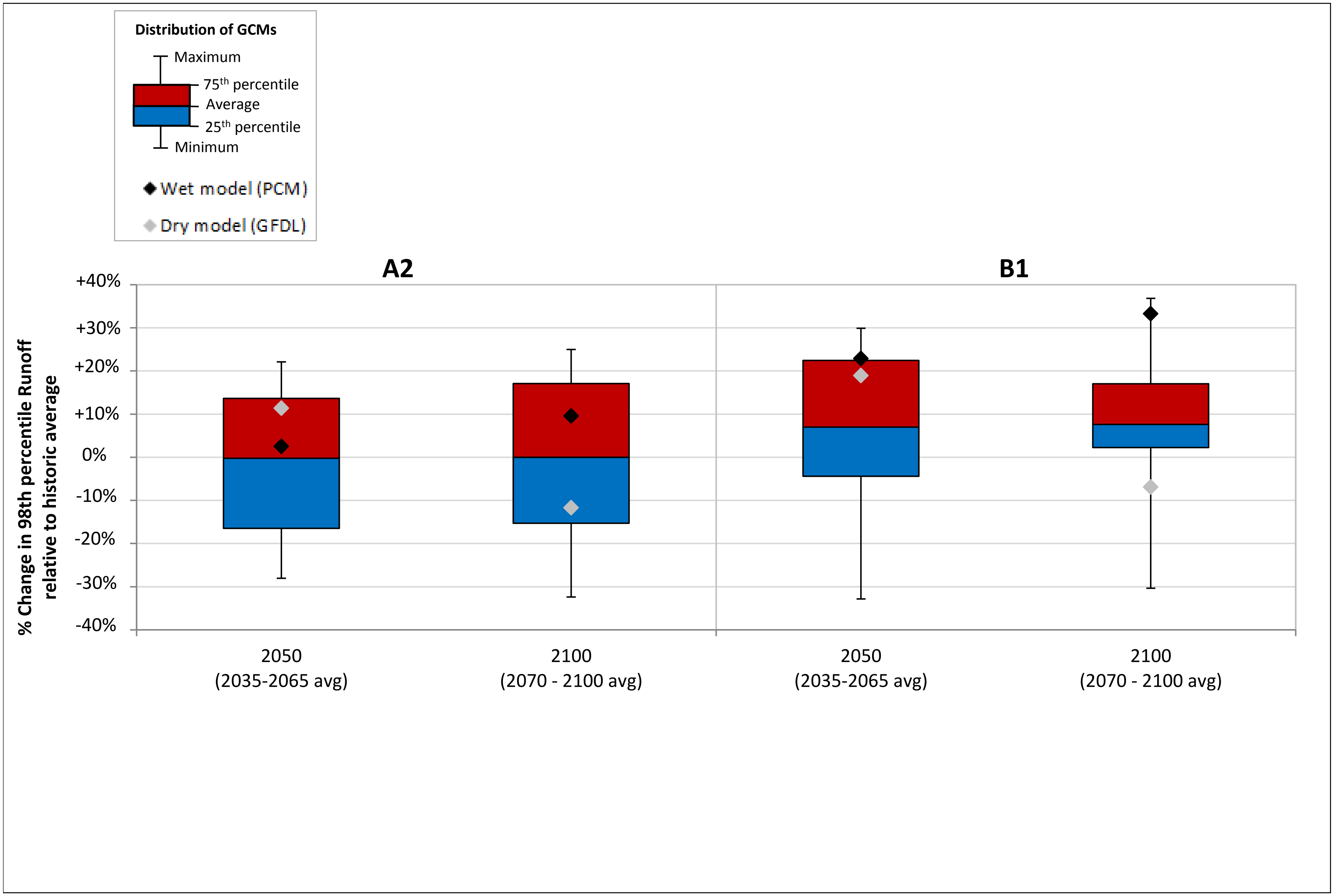
Climate model(s):
Dry GCM (GFDL)

Description:
The 98th percentile runoff was estimated for a historic period (1970 - 1999 or "Historic") and two future periods (2035 - 2064 and 2070 - 2099) for a dry global climate model (GCM). The top panel presents the 98th percentile runoff for the dry GCM. The bottom panel shows the percent change relative to the historic time period.

S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Runoff_98Percentile_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 20
98th Percentile Runoff: Average Values and Relative Change for Scenario B1, Dry Model



SOURCE: WCRP CMIP3 downscaled data

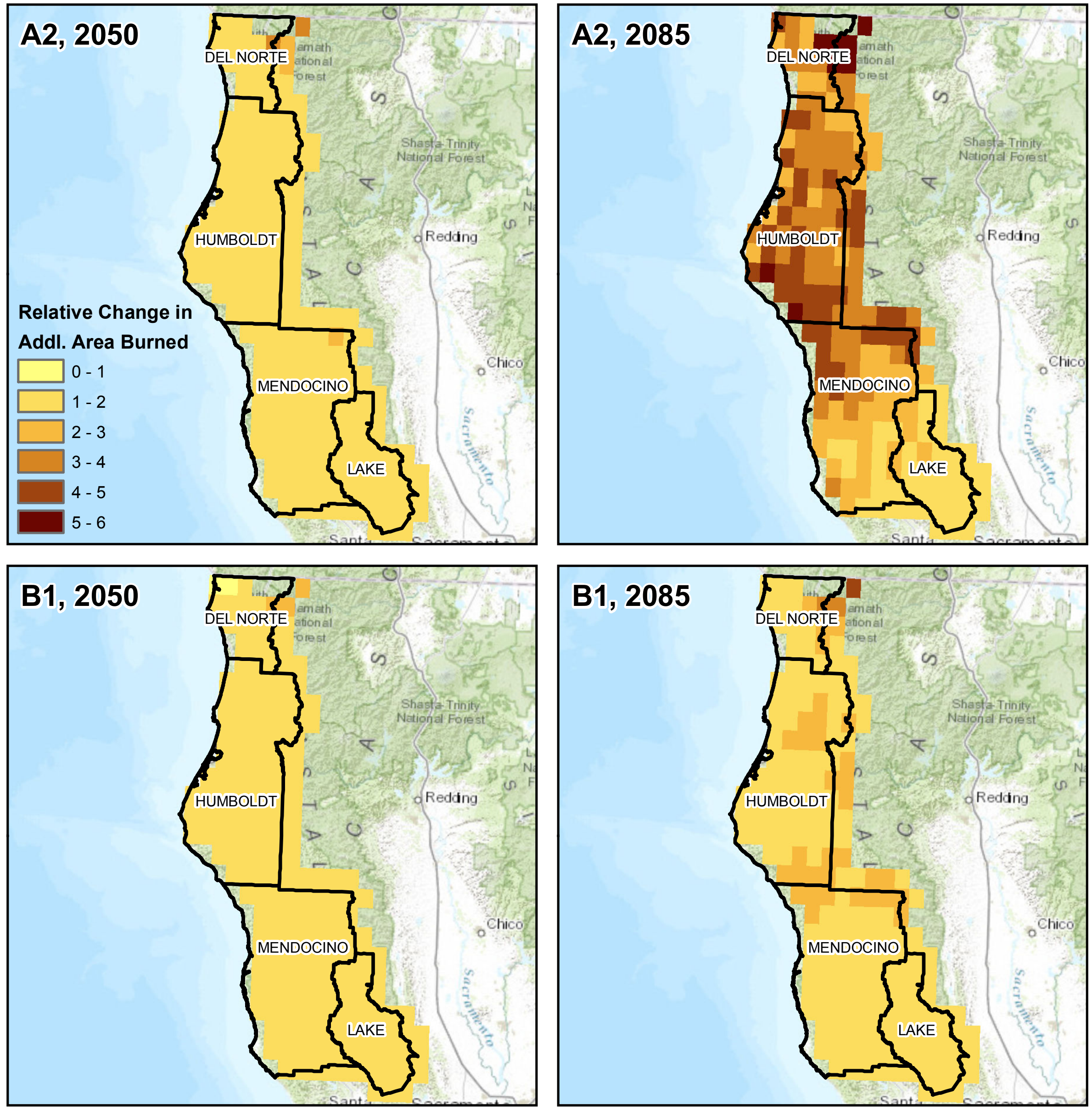
Figure 21
Change in Extreme Runoff Over Time for Multiple GCMs - District 1 Average

Climate scenario:
top panel: A2 (high medium-high emissions)
bottom panel: B1 (low emissions)

Climate model(s):
Average of three models

Description:
These maps show the relative change in burned area compared to existing fire risk, based on the average of three global climate model (GCM) projections.

N
0 25 50 Miles

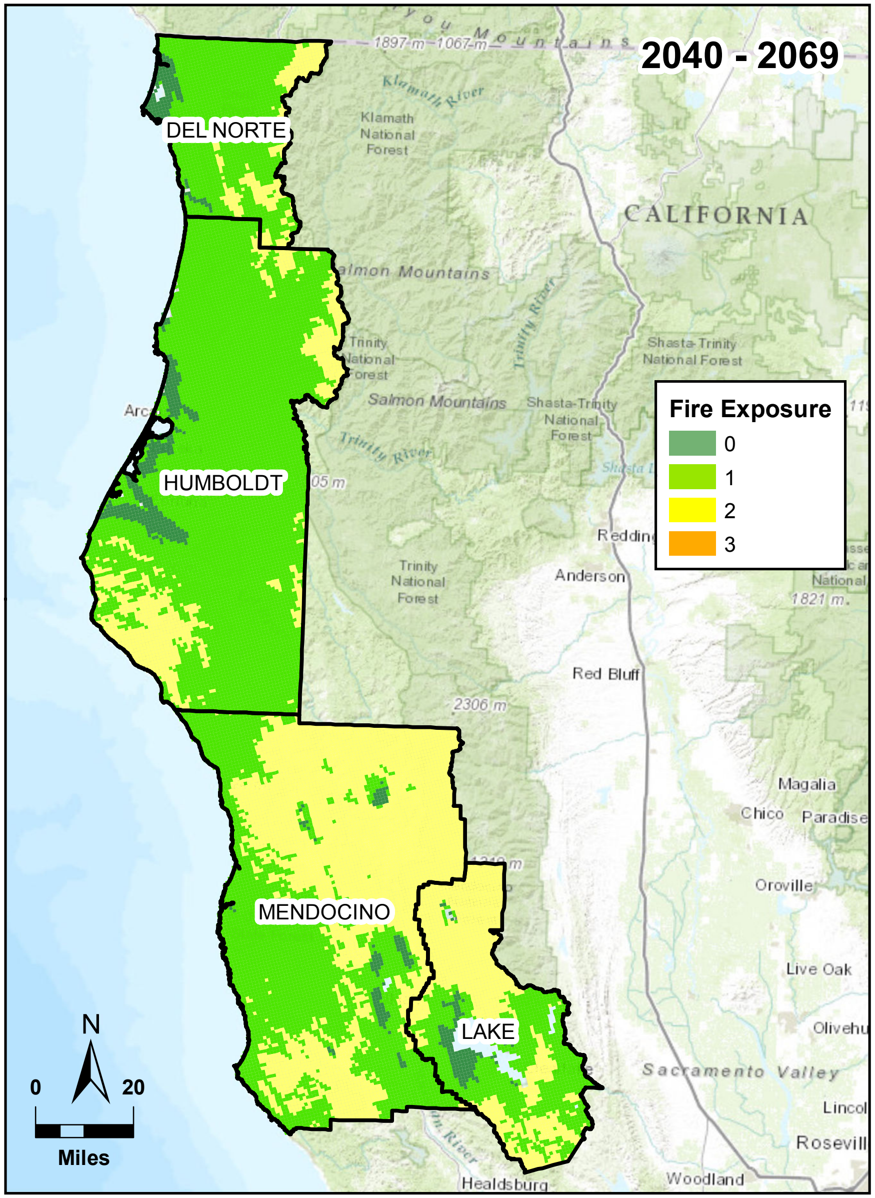


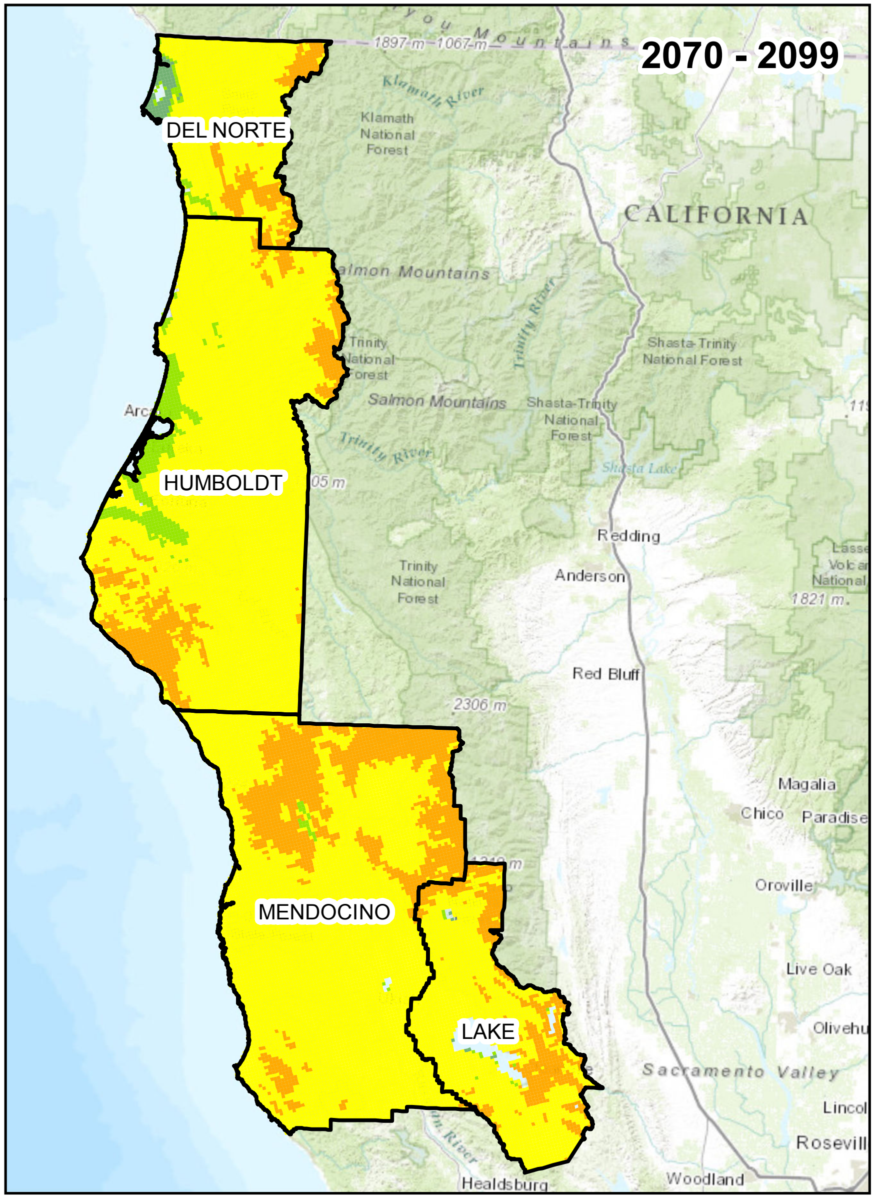
Note:
Fire risk data was downloaded from the CalAdapt website (http://cal-adapt.org/fire/). Only relative change (i.e. 3-fold increase in burned area) was available for download. These results were modeled solely on climate projections and do not take landscape and fuel sorces into account.

S:\GIS\130588_HCAOG-ClimateChange\MXDs\Figures\Fire Risk_16Jun2014.mxd

SOURCE: Cal Adapt, 2014

Figure 22
Fire Risk: Increase in Area Burned

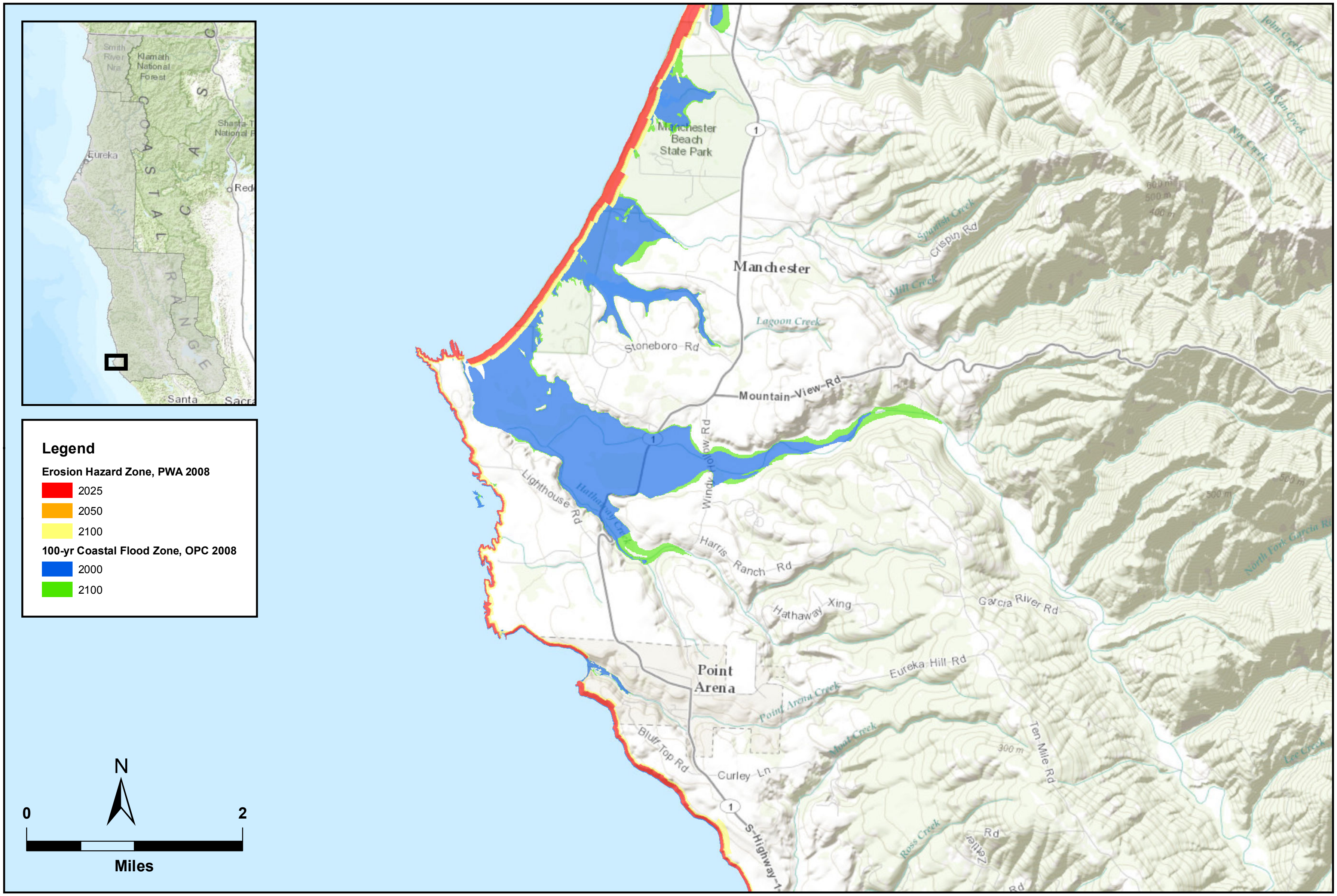




G:\130588_HCAOG-ClimateChange\MXDs\Figures\Fire Exposure_23May2014.mxd

SOURCE: DWR 2014

Figure 23
Fire Exposure Level (DWR 2014)



SOURCE: PWA 2008 and Pacific Institute 2009

Figure 24
Example of Coastal Hazard Zones at Point Arena

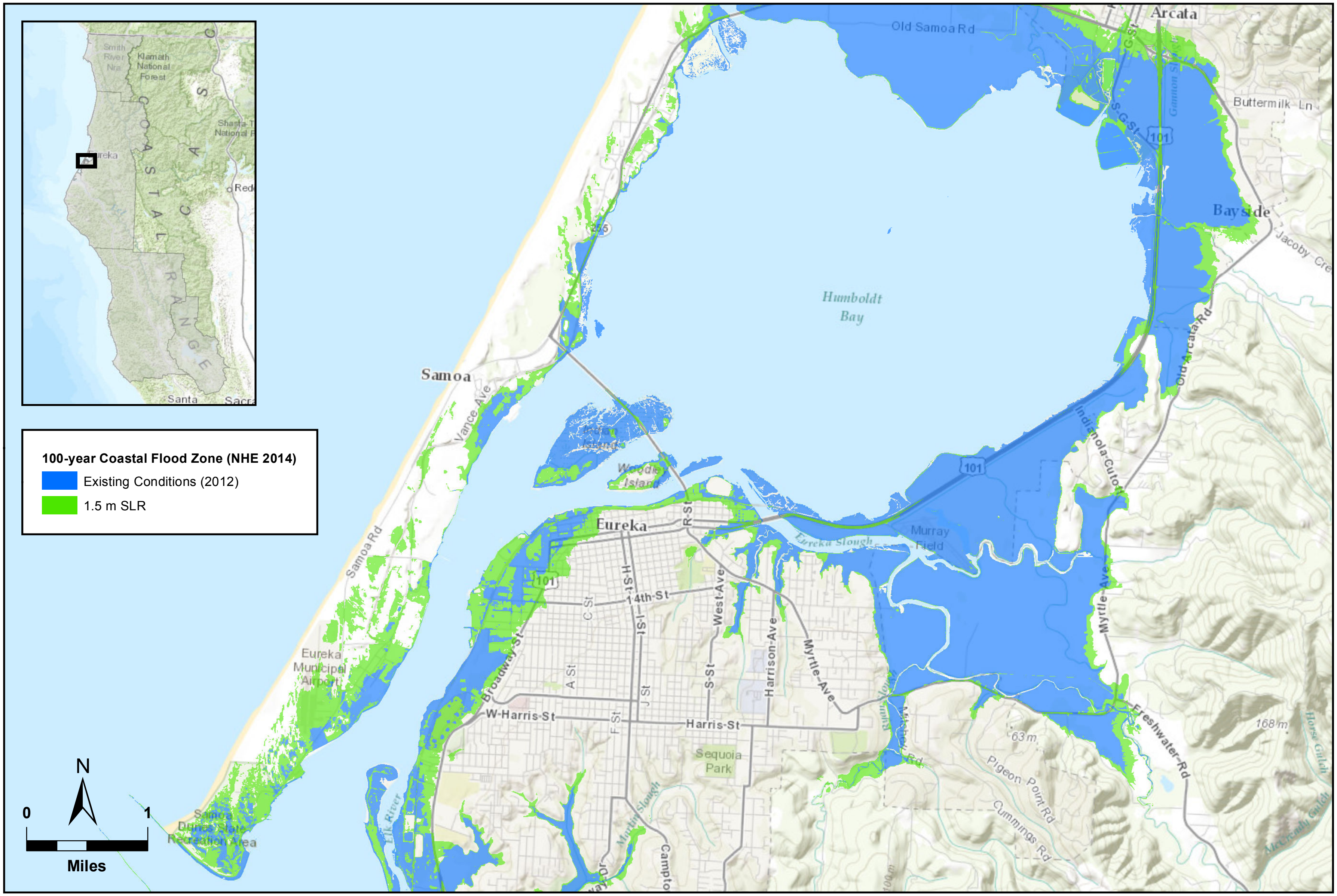


Figure 25
Example of Coastal Flood Zones in Humboldt Bay (NHE 2014)

SOURCE: NHE 2014. Flood zones also available for 0.5m, 1.0m, 1.5m, and 2.0m of sea level rise for MHHW, the 10-yr storm, and the 100-yr storm

Attachment 1. Summary of Climate Information and Datasets included in Geodatabase

Variable	Climate/Storm Conditions	Metric	Time period (s)	Sea Level Rise	Emissions scenario	Climate Model	Filename (FeatureClass/Filename)	Original Data Source	Data Resolution
Temperature	Extreme	Number of days per year with T>95° F	2000	-	A2	Average of 6 models	TempDays95_ModelAvg_A2_Historic	WCRP CMIP3 downscaled data[1]	12km x 12km
			2050				TempDays95_ModelAvg_A2_2050		
			2100				TempDays95_ModelAvg_A2_2100		
			2000		B1		TempDays95_ModelAvg_B1_Historic		
			2050				TempDays95_ModelAvg_B1_2050		
			2100				TempDays95_ModelAvg_B1_2100		
		Change in extreme heat days relative to historic average	2050		A2		TempDays95_ModelAvg_A2_2050		
			2100				TempDays95_ModelAvg_A2_2100		
			2050		B1		TempDays95_ModelAvg_B1_2050		
			2100				TempDays95_ModelAvg_B1_2100		
Precipitation	Extreme	98th Percentile Total Inches/Day	2000		A2	Average of 6 models	Precip98Percentile_ModelAvg_A2_Historic		
			2050				Precip98Percentile_ModelAvg_A2_2050		
			2100				Precip98Percentile_ModelAvg_A2_2100		
			2000		B1		Precip98Percentile_ModelAvg_B1_Historic		
			2050				Precip98Percentile_ModelAvg_B1_2050		
			2100				Precip98Percentile_ModelAvg_B1_2100		
			2000		A2	NCAR PCM1 (wet model)	Precip98Percentile_PCMwet_A2_Historic		
			2050				Precip98Percentile_PCMwet_A2_2050		
			2100				Precip98Percentile_PCMwet_A2_2100		
			2000		B1		Precip98Percentile_PCMwet_B1_Historic		
			2050				Precip98Percentile_PCMwet_B1_2050		
			2100				Precip98Percentile_PCMwet_B1_2100		
			2000		A2	NOAA GFDL (dry model)	Precip98Percentile_GFDLdry_A2_Historic		
			2050				Precip98Percentile_GFDLdry_A2_2050		
			2100				Precip98Percentile_GFDLdry_A2_2100		
			2000		B1		Precip98Percentile_GFDLdry_B1_Historic		
			2050				Precip98Percentile_GFDLdry_B1_2050		
			2100				Precip98Percentile_GFDLdry_B1_2100		
		Percent change in 98th percentile daily rainfall relative to hitoric average	2050		A2	Average of 6 models	Precip98PercentileChange_ModelAvg_A2_2050		
			2100				Precip98PercentileChange_ModelAvg_A2_2100		
			2050		B1		Precip98PercentileChange_ModelAvg_B1_2050		
			2100				Precip98PercentileChange_ModelAvg_B1_2100		
			2050		A2	NCAR PCM1 (wet model)	Precip98PercentileChange_PCMwet_A2_2050		
			2100				Precip98PercentileChange_PCMwet_A2_2100		
			2050		B1		Precip98PercentileChange_PCMwet_B1_2050		
			2100				Precip98PercentileChange_PCMwet_B1_2100		
			2050		A2	NOAA GFDL (dry model)	Precip98PercentileChange_GFDLdry_A2_2050		
			2100				Precip98PercentileChange_GFDLdry_A2_2100		
			2050		B1		Precip98PercentileChange_GFDLdry_B1_2050		
			2100				Precip98PercentileChange_GFDLdry_B1_2100		

Attachment 1. Summary of Climate Information and Datasets included in Geodatabase

Variable	Climate/Storm Conditions	Metric	Time period (s)	Sea Level Rise	Emissions scenario	Climate Model	Filename (FeatureClass/Filename)	Original Data Source	Data Resolution
Runoff	Extreme	98th Percentile Total Inches/Day	2000	-	A2	Average of 6 models	Runoff98Percentile_ModelAvg_A2_Historic	WCRP CMIP3 downscaled data[1]	12km x 12km
			2050				Runoff98Percentile_ModelAvg_A2_2050		
			2100				Runoff98Percentile_ModelAvg_A2_2100		
			2000		B1		Runoff98Percentile_ModelAvg_B1_Historic		
			2050				Runoff98Percentile_ModelAvg_B1_2050		
			2100				Runoff98Percentile_ModelAvg_B1_2100		
			2000		A2	NCAR PCM1 (wet model)	Runoff98Percentile_PCMwet_A2_Historic		
			2050				Runoff98Percentile_PCMwet_A2_2050		
			2100				Runoff98Percentile_PCMwet_A2_2100		
			2000		B1		Runoff98Percentile_PCMwet_B1_Historic		
			2050				Runoff98Percentile_PCMwet_B1_2050		
			2100				Runoff98Percentile_PCMwet_B1_2100		
			2000		A2	NOAA GFDL (dry model)	Runoff98Percentile_GFDLdry_A2_Historic		
			2050				Runoff98Percentile_GFDLdry_A2_2050		
			2100				Runoff98Percentile_GFDLdry_A2_2100		
			2000		B1		Runoff98Percentile_GFDLdry_B1_Historic		
			2050				Runoff98Percentile_GFDLdry_B1_2050		
			2100				Runoff98Percentile_GFDLdry_B1_2100		
		Percent change in 98th percentile daily runoff relative to historic average	2050		A2	Average of 6 models	Runoff98PercentileChange_ModelAvg_A2_2050		
			2100				Runoff98PercentileChange_ModelAvg_A2_2100		
			2050		B1		Runoff98PercentileChange_ModelAvg_B1_2050		
			2100				Runoff98PercentileChange_ModelAvg_B1_2100		
			2050		A2	NCAR PCM1 (wet model)	Runoff98PercentileChange_PCMwet_A2_2050		
			2100				Runoff98PercentileChange_PCMwet_A2_2100		
			2050		B1		Runoff98PercentileChange_PCMwet_B1_2050		
			2100				Runoff98PercentileChange_PCMwet_B1_2100		
			2050		A2	NOAA GFDL (dry model)	Runoff98PercentileChange_GFDLdry_A2_2050		
			2100				Runoff98PercentileChange_GFDLdry_A2_2100		
			2050		B1		Runoff98PercentileChange_GFDLdry_B1_2050		
			2100				Runoff98PercentileChange_GFDLdry_B1_2100		
Fire Risk	Average	Relative Change in Burned Area compared to existing fire risk	2050		A2	Average of 3 models	FireRisk_AddtlAreaBurned_ModelAvg_A2_2050	Cal-Adapt[2]	
					B1		FireRisk_AddtlAreaBurned_ModelAvg_B1_2050		
			2085		A2		FireRisk_AddtlAreaBurned_ModelAvg_A2_2085		
					B1		FireRisk_AddtlAreaBurned_ModelAvg_B1_2085		
Wildfire Exposure (DWR)		Exposure rating - Very low to Very High	2010 - 2039, 2040 - 2069, 2070 - 2099		A2, B1		FireExposure_DWR	DWR[3]	Developed from 1km x 1km fire risk data

Attachment 1. Summary of Climate Information and Datasets included in Geodatabase

Variable	Climate/Storm Conditions	Metric	Time period (s)	Sea Level Rise	Emissions scenario	Climate Model	Filename (FeatureClass/Filename)	Original Data Source	Data Resolution
Inundation - Humboldt Bay	MHW_SHORELINE	Existing MHW Shoreline	2012	0 m	-	-	Inundation_HumboldtBay/YEAR2012_MHW_SHORELINE_140326	Jeff Anderson/NHE[4]	Varies
	100YR	Existing Extreme 100-year WSE	2012	0 m	-	-	Inundation_HumboldtBay/YEAR2012_100YR_140326		
	10YR	Existing Extreme 10-year WSE	2012	0 m	-	-	Inundation_HumboldtBay/YEAR2012_10YR_140326		
	MHHW	Existing MHHW Shoreline	2012	0 m	-	-	Inundation_HumboldtBay/YEAR2012_MHHW_140326		
	100YR	~2050 Extreme 100-year WSE	N/A	0.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w0p5MSLR_100YR_140326		
	10YR	~2050 Extreme 10-year WSE	N/A	0.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w0p5MSLR_10YR_140326		
	MHHW	~2050 MHHW shoreline	N/A	0.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w0p5MSLR_MHHW_140326		
	100YR	2100 Extreme 100-year WSE - low SLR scenario	N/A	1 m	-	-	Inundation_HumboldtBay/YEAR2000_w1MSLR_100YR_140326		
	10YR	2100 Extreme 10-year WSE - low SLR scenario	N/A	1 m	-	-	Inundation_HumboldtBay/YEAR2000_w1MSLR_10YR_140326		
	MHHW	2100 MHHW Shoreline - low SLR scenario	N/A	1 m	-	-	Inundation_HumboldtBay/YEAR2000_w1MSLR_MHHW_140326		
	100YR	2100 Extreme 100-year WSE - mid SLR scenario	N/A	1.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w1p5MSLR_100YR_140326		
	10YR	2100 Extreme 10-year WSE - mid SLR scenario	N/A	1.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w1p5MSLR_10YR_140326		
	MHHW	2100 MHHW Shoreline - mid SLR scenario	N/A	1.5 m	-	-	Inundation_HumboldtBay/YEAR2000_w1p5MSLR_MHHW_140326		
	100YR	2100 Extreme 100-year WSE - high SLR scenario	N/A	2 m	-	-	Inundation_HumboldtBay/YEAR2000_w2MSLR_100YR_140326		
	10YR	2100 Extreme 10-year WSE - high SLR scenario	N/A	2 m	-	-	Inundation_HumboldtBay/YEAR2000_w2MSLR_10YR_140326		
	MHHW	2100 MHHW Shoreline - mid high scenario	N/A	2 m	-	-	Inundation_HumboldtBay/YEAR2000_w2MSLR_MHHW_140326		
Inundation - Open Coast	100YR	Existing 100-year total water level (extreme storm surge + waves)	2000	0 m	-	-	Inundation_AllDistrict1/YEAR2000_w0MSLR_100YR	Pacific Institute/PWA[5,6]	Developed using transects spaced at 500m intervals
	100YR	Future 100-year total water level (extreme storm surge + waves) at 2100	2100	1.4 m	-	-	Inundation_100YR_AllDistrict1/YEAR2000_w1p4MSLR_100YR		
	100YR Base Flood Elevation		2000	0 m		-	Inundation_100YR_AllDistrict1/Coastal_BFE		
Dune Erosion Hazard Zone - Open Coast	-	high end erosion at 2025	2025	1.4 m by 2100	-	-	ErosionHazardZones/DHZ_high_2025_final		
	-	high end erosion at 2050	2050	1.4 m by 2100	-	-	ErosionHazardZones/DHZ_high_2050_final		
	-	high end erosion at 2100	2100	1.4 m by 2100	-	-	ErosionHazardZones/DHZ_high_2100_final		
	-	low end erosion at 2025	2025	0.6 m by 2100	-	-	ErosionHazardZones/DHZ_low_2025_final		
	-	low end erosion at 2050	2050	0.6 m by 2100	-	-	ErosionHazardZones/DHZ_low_2050_final		
	-	low end erosion at 2100	2100	0.6 m by 2100	-	-	ErosionHazardZones/DHZ_low_2100_final		
Cliff Erosion Hazard Zone - Open Coast	-	high end erosion at 2025	2025	1.4 m by 2100	-	-	ErosionHazardZones/CHZ_high_2025_final		
	-	high end erosion at 2050	2050	1.4 m by 2100	-	-	ErosionHazardZones/CHZ_high_2050_final		
	-	high end erosion at 2100	2100	1.4 m by 2100	-	-	ErosionHazardZones/CHZ_high_2100_final		
	-	low end erosion at 2025	2025	0.6 m by 2100	-	-	ErosionHazardZones/CHZ_low_2025_final		
	-	low end erosion at 2050	2050	0.6 m by 2100	-	-	ErosionHazardZones/CHZ_low_2050_final		
	-	low end erosion at 2100	2100	0.6 m by 2100	-	-	ErosionHazardZones/CHZ_low_2100_final		
Landslide Susceptibility	-	Relative susceptibility - low to high	Existing	-	-	-	LandslideSusceptibility_north	CGS[7]	10m x 10m
	-	Relative susceptibility - low to high		-	-	-	LandslideSusceptibility_south		

1 World Climate Research Programme Coupled Model Intercomparison Project Phase 3 http://gdo-dcp.ucllnl.org/
2 Cal-Adapt.org compilation of fire risk data from UC Merced Climate Applications Lab http://cal-adapt.org/fire/
3 DWR, 2013. Draft Fire Exposure Assessment Methdology and GIS Mapping Products
4 Northern Hydrology Engineering, 2014. Humboldt Bay Sea Level Rise Adaptation Planning Project, Preliminary Sea-Level Rise Inundation Mapping Products
5 Pacific Institute, 2009. The Impacts of Sea-Level Rise on the California Coast
6 PWA, 2009. California Coastal Erosion Response to Sea Level Rise - Analysis and Mapping
7 California Geological Survey, 2011. Susceptibility to Deep-Seated Landslides in California. Map Sheet 58