PREDICTIONS OF CLIMATE CHANGE IMPACTS ON CALIFORNIA WATER RESOURCES USING CALSIM II: A TECHNICAL NOTE

WHITE PAPER

A Report From:
California Climate Change Center

Prepared By:
Sebastian Vicuña
Department of Civil and Environmental Engineering
University of California, Berkeley

DISCLAIMER

Arnold Schwarzenegger, *Governor*

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

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- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
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The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The following technical note describes the methodology used to assess the impacts of different climate change scenarios on California water resources. A water resources systems model is necessary to analyze the performance of California's water system under predicted hydrologic scenarios associated with climate change. This project used CalSim II, a model cooperatively developed by the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR). CalSim II was used previously by Brekke et al. (2004) and Vicuña et al. (submitted) to estimate the impacts of climate change on California water resources.

For this project, CalSim II was applied to hydrologic conditions developed by the Variable Infiltration Capacity (VIC) method from seven different climate change scenarios. Four of these scenarios include the outputs from the Parallel Climate Model (PCM) and the Geophysical Fluid Dynamic Laboratory (GFDL) General Circulation Models (GCM) run using the A2 and B1 SRES emissions scenarios. The three other scenarios are those considered in the study by Hayhoe et al. (2004) and Vicuña et al. (submitted) which involved a new emission scenario (A1fi) for the PCM model and two more scenarios (A1fi and B1) generated by the U.K. Hadley Centre Climate Model, version 3 (HadCM3).

The following section describes the methodological aspects of this project. The results follow, together with a brief conclusion.

2.0 Methods

The methods used to assess climate change impacts on water resources systems have been reviewed previously by Gleick (1989), Wood et al. (1997), and Dracup and Vicuña (2005). There are generally two stages of analysis. The first determines changes in unimpaired stream flow at inflow points to the managed water system, and the second uses these changes to drive a water resources systems model. This study focused only on the second stage. Data needed from the first stage was derived using the VIC model, as explained in Cayan et al. (2006) and Vicuña et al. (submitted).

To simulate the impacts of potential changes in hydroclimatology on water resource systems we employed the simulation model CalSim II. CalSim II is a network-flow programming model developed jointly by DWR and USBR to represent the joint Central Valley Project (CVP)–State Water Project (SWP) water supply delivery system. Extensive descriptions of CalSim II can be found in Munevar and Chung (1999), Brekke et al. (2004), Draper et al. (2004), and Quinn et al. (2004). Model output includes monthly reservoir releases, river flows, reservoir-stored water volumes, water deliveries, Delta export activities, and indicators of Delta water quality conditions. This study focused on water deliveries and reservoir storage for the two main supply projects: the CVP and SWP.

A baseline version of the model—called CalSim II Benchmark Studies (DWR/USBR 2002)—was built to produce monthly operations decisions for a 73-year simulation period (1922 through 1994) that reflects the historic hydrologic conditions and current level of development in the Central Valley. Water demands and system infrastructure were modified to represent a year 2020 level of development. For this work, we applied the model under implementation of the Delta Water Quality Control Plan as codified in State Water Resources Control Board Decision 1641 (D1641). The Artificial Neural Network (ANN) model was used to estimate water salinity at various locations in the Delta as a function of net Delta outflow (DWR / USBR 2002).

To run CalSim II using the perturbed hydrologic conditions of the seven different climate change scenarios, we modified the historical 73 years of reservoir inflows by multiplying every monthly datum by a perturbation ratio. These perturbations ratios were obtained by dividing monthly average runoff as simulated by VIC for the period 2070–2099, by the monthly average values for 1961–1990.[1] All other inputs to the model, such as local water supplies, water consumption among urban and agricultural users, water allocation contracts, and reservoir operations regulations were preserved following Brekke et al. (2004). The only input modified was the set of risk-tolerance curves, the Water Supply Index–Demand Index curves (WSI-DI), that determine the annual delivery allocations for both the SWP and CVP according to water supply levels (Draper et al. 2004). Because water supplies were projected to be significantly altered with climate change, new WSI-DI curves were generated for each climate change scenario using an automated procedure included in CalSim II.

3.0 Assessment Limitations

Like all such studies, our analysis is subject to several limitations. The following are the most prominent limitations of the approach used in this study:

- Instead of evaluating the continuing impacts of climate change, we used static snapshots taken at one specific period in the next century to perturb the historical time series of inflows. This is the most relevant limitation in our approach because it does not allow for changes in interannual variability. Some studies have examined changes in the frequency of extreme climatic conditions (e.g., Miller et al. 2003; Dettinger et al. 2004; Kim 2005), although uncertainties remain about the reliability of GCM projections of interannual variability.
- Another limitation in the approach taken is that, despite inclusion of spectrum of possible future climatic scenarios, our approach, including three GCMs run under three GHG emission scenarios, is still too restricted to perform a probabilistic assessment of the impacts. To do a probabilistic assessment of climate change

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[1] Due to an infeasible solution (while trying to simulate the 1976–1977 drought) CalSim II could not complete the simulation of the GFDL A2 climate scenario. As a fix to overcome this problem, we used inflow conditions corresponding to the GFDL B1 climate change scenario for the 1976–1977 water years; this produces a somewhat optimistic projection of the potential impacts under the GFDL A2 climate change scenario.

impacts would require more GCMs and more GHG emissions scenarios, following the approach taken by Dettinger (2005) and Maurer and Duffy (2005). Such an approach is outside the scope of this study.

- Finally, the approach taken does not account for impacts apart from changes to reservoir inflows that might occur under climate change. Such impacts include changes to surface-ground water interactions and changes in water demands by both agricultural and urban users. For example, it is apparent that agricultural water demand—and thus water supply reliability—will be affected by increasing temperature. Nevertheless, limitations in the water resources model prevent us from including this effect in our assessment.

4.0 Results

4.1. Impacts on Hydrology: Developing Input Data for CalSim II

Figure 1a shows the hydrologic impacts of the climate change scenarios in terms of *perturbation ratios*. A perturbation ratio is the ratio of the value of the relevant variable (e.g., average monthly streamflow on the Sacramento River over the period 2070–2099) under a certain scenario (e.g., PCM A2) to the corresponding value of the same variable in the same month under baseline (historical) conditions. Figure 1a shows the monthly perturbation ratios for selected major rivers in the Sacramento and San Joaquin basins under the seven climate change scenarios for period 2070–2099.

To get a better sense of the implications behind these perturbation ratios Figure 1b presents a comparison between the historical (1961–1990) and climate change hydrologic predictions under all climate change scenarios.[2] The results show lower summer and late-spring runoff for all river basins. Results for other seasons are less consistent, reflecting differences in winter precipitation predictions among the different GCMs. For example, those scenarios that show increased in winter precipitation also show the highest runoff perturbation ratios in winter months (e.g., PCM B1). The graphs show similar annual flow patterns for each GCM but different impact amplitudes, depending on the GHG emission scenario. The output of PCM shows a relative increase in streamflows during mid-late winter as compared to the rest of the year, with the highest relative impacts during the spring. In contrast, the GFDL and HadCM3 results show relative decreases in streamflows in nearly all months except late fall and early winter.

As part of the analysis of changes in hydrologic conditions associated with the climate change scenarios, we estimated the change in the relative proportion of years classified under different water year types (see Table 1). The methodology considered the Sacramento Four River Index (also called Sacramento 40-30-30 Index) to determine the

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[2] It is important to mention that all climate change scenarios predict different "historical" predictions, which might not necessarily be equal to the real historic conditions. Figure 1b shows an average of historical conditions for all seven climate change scenarios.

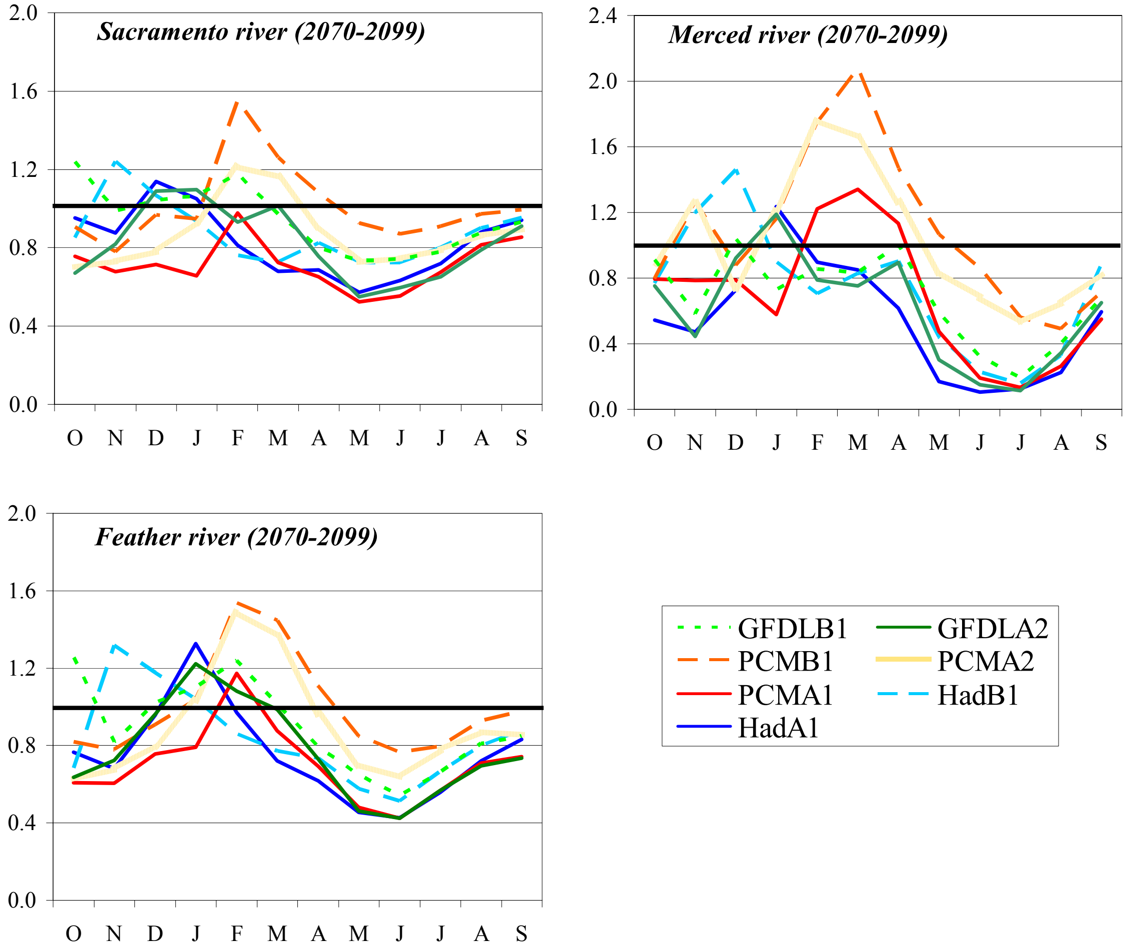

Figure 1a. Perturbation change ratio in monthly streamflow in selected rivers in the Sacramento and San Joaquin Basins under GFDL, PCM, and HadCM3 climate change scenarios

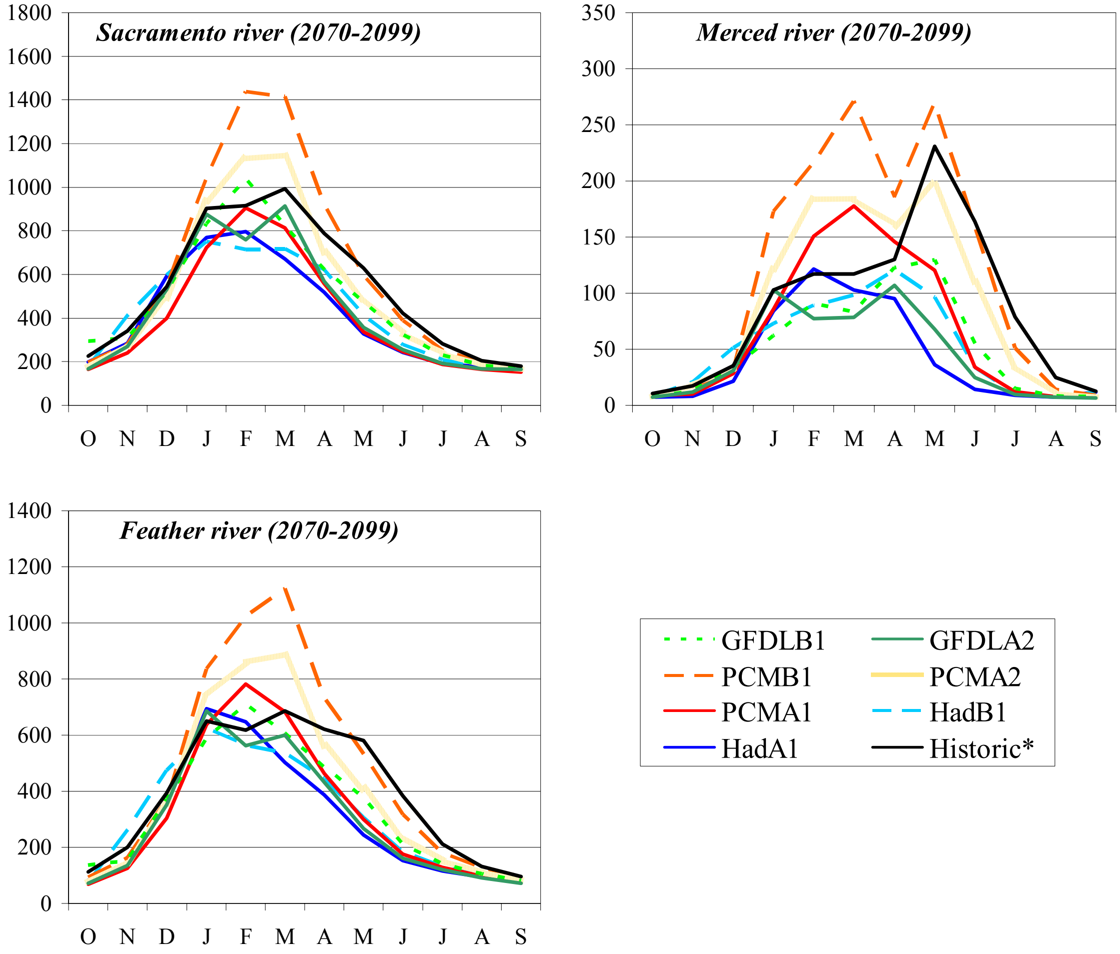

Figure 1b. Average monthly streamflow in selected rivers in the Sacramento and San Joaquin Basins under GFDL, PCM, and HadCM3 predicted historic (1961–1990) and climate change (2070–2099) scenarios

Table 1. Relative proportion of years classified as wet, above normal, below normal, dry and critical based on the Sacramento 40-30-30 Index for the historic and climate change predicted conditions.

	Wet	Above Normal	Below Normal	Dry	Critical
Hist	34%	14%	12%	22%	18%
PCMB1	40%	11%	19%	14%	16%
PCMA2	33%	11%	16%	18%	22%
PCMA1fi	8%	8%	16%	11%	56%
GFDLB1	26%	12%	12%	14%	36%
GFDLA2	7%	15%	8%	19%	51%
HadB1	18%	10%	16%	7%	49%
HadA1fi	14%	12%	12%	12%	49%

Average of 73 years (1922-1994)

water year type. This index classifies water years in five categories: Wet, Above Normal, Below Normal, Dry, and Critical.[3] Because the River Index pays greater attention to the aggregate stream flow than the timing of flow, it is more influenced by changes in precipitation than temperature. The projections for the less dry model (PCM) suggest that toward the end of the century, under the higher-emissions scenario, up to 50% of the years (when hydrologic conditions for 2085 are considered) could be critically dry years as compared to 18% in the historical period. Under the lower-emissions scenario in the less-dry model, little or no change in the frequency of critically dry years is expected. In contrast, in the drier models (HadCM3 and GFDL), the projections suggest that even under the lower-emissions scenarios the frequency of critically dry years could be up to twice as often as historical conditions.

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[3] The Sacramento River Index was developed by the State Water Resources Control Board for regulatory purposes, and requires the forecasting by May of each year of the current year's April–July unimpaired runoff in the Sacramento Valley. When a retrospective analysis is conducted using the historical hydrology, as it is here, the actual April–July runoff is known, but the prospective forecast is not, and therefore the index cannot be calculated in exactly the same way. The research here uses the Brekke et al. (2004) retrospective approximation for calculating the index. Future work would test different approaches to define the water year index, which might involve different weights given to different months in the water year to reflect changes in timing of inflows.

An additional analysis estimates possible future changes in hydrologic conditions in terms of drought persistence. To represent drought conditions we used only the 40-30-30 Sacramento Four River Index; a drought is considered to occur in a given year if the index for that year falls below the dry threshold. We calculated for each year an accumulated deficit representing the positive difference between the "dry" threshold and the 40-30-30 Index. Deficits are accumulated in consecutive dry years, but whenever the index is above the "dry" threshold, the deficit is reset to 0. Figure 2 shows the accumulated deficits for the historic period and for the seven climate change conditions included in this analysis. The results show that drought conditions will be better than under the historic case for the PCM B1 and A2 scenarios, but worse for all the other scenarios under which both the magnitude and duration of droughts might be exacerbated.

4.2. Water Resources System Impacts

There are several variables that could be used as performance indicators to assess the climate change impacts on California water resources systems These include reservoir storage levels, water supply deliveries, and variables measuring environmental conditions in the Delta and elsewhere. Here we use the first two indicators—reservoir storage and water supply deliveries—and consider only the two major government water supply projects: the CVP and SWP (results for other users or other variables are available from the author on request). Figures 3 through 12 show the exceedance probabilities of carryover reservoir storage, and north of Delta and south of Delta CVP and SWP deliveries under all seven different climate change scenarios. The exceedance probability curves indicate the probability that a given water supply delivery level will be achieved or exceeded.

As is expected, the results in terms of water resources impacts follow the same pattern already discussed for the impacts on hydrology (i.e., scenarios with wetter conditions will lead to benefits in terms of water resources and scenarios with drier conditions to negative impacts). There is only one scenario (PCM B1) that shows relative small positive impacts for the California water resource systems. All other scenarios show dramatically negative impacts to reservoir storage and water supply deliveries. Clearly, the impacts are higher for scenarios under higher GHG emissions for the three GCMs.

Comparing the impacts on water delivery for north of the Delta to south of the Delta we see that the impacts tend to be greater south of the Delta. This difference is due in part to the effect of environmental regulations, which limit exports to the south of the Delta and weaken the reliability of water deliveries to south water-rights holders.

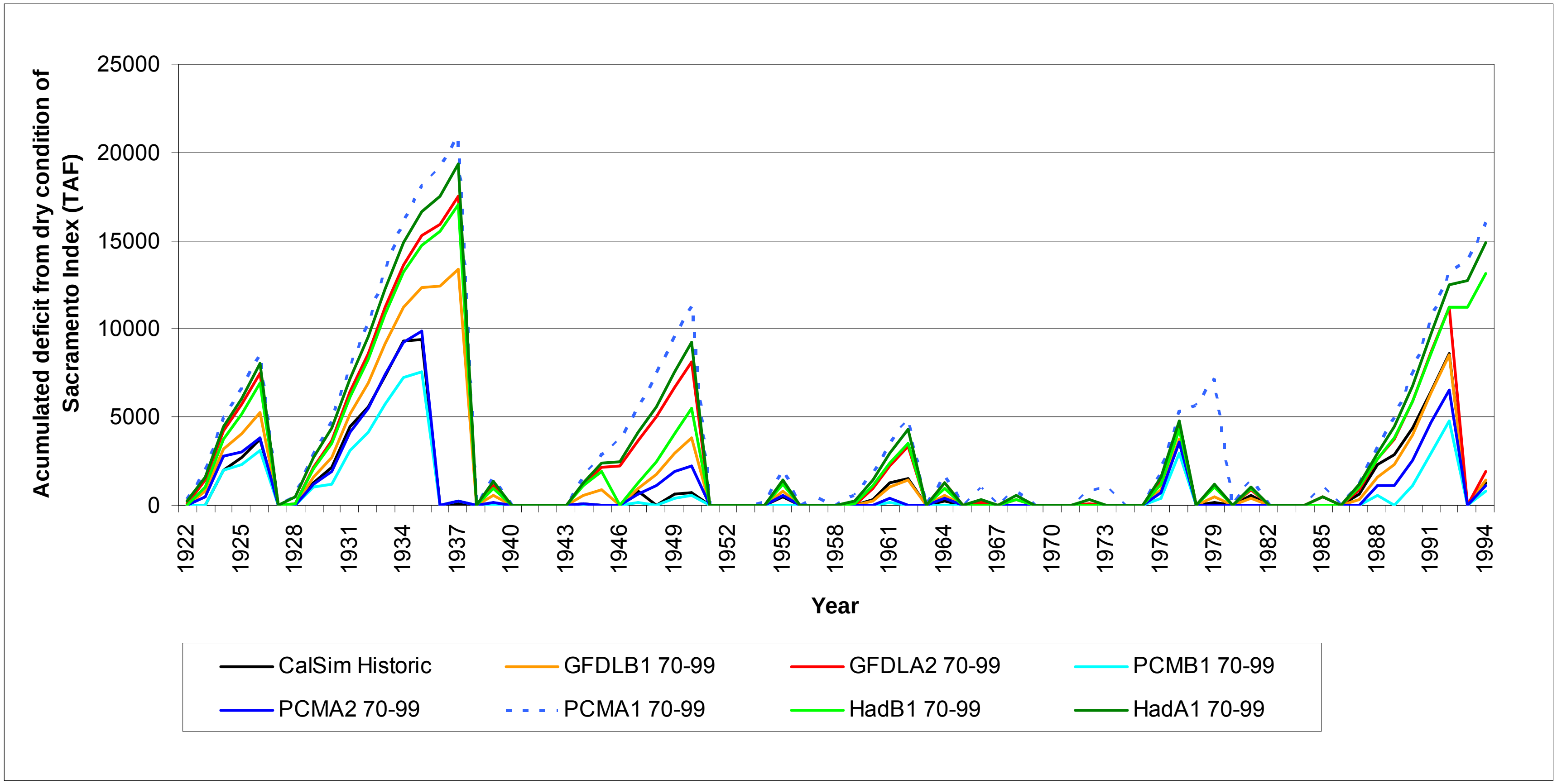
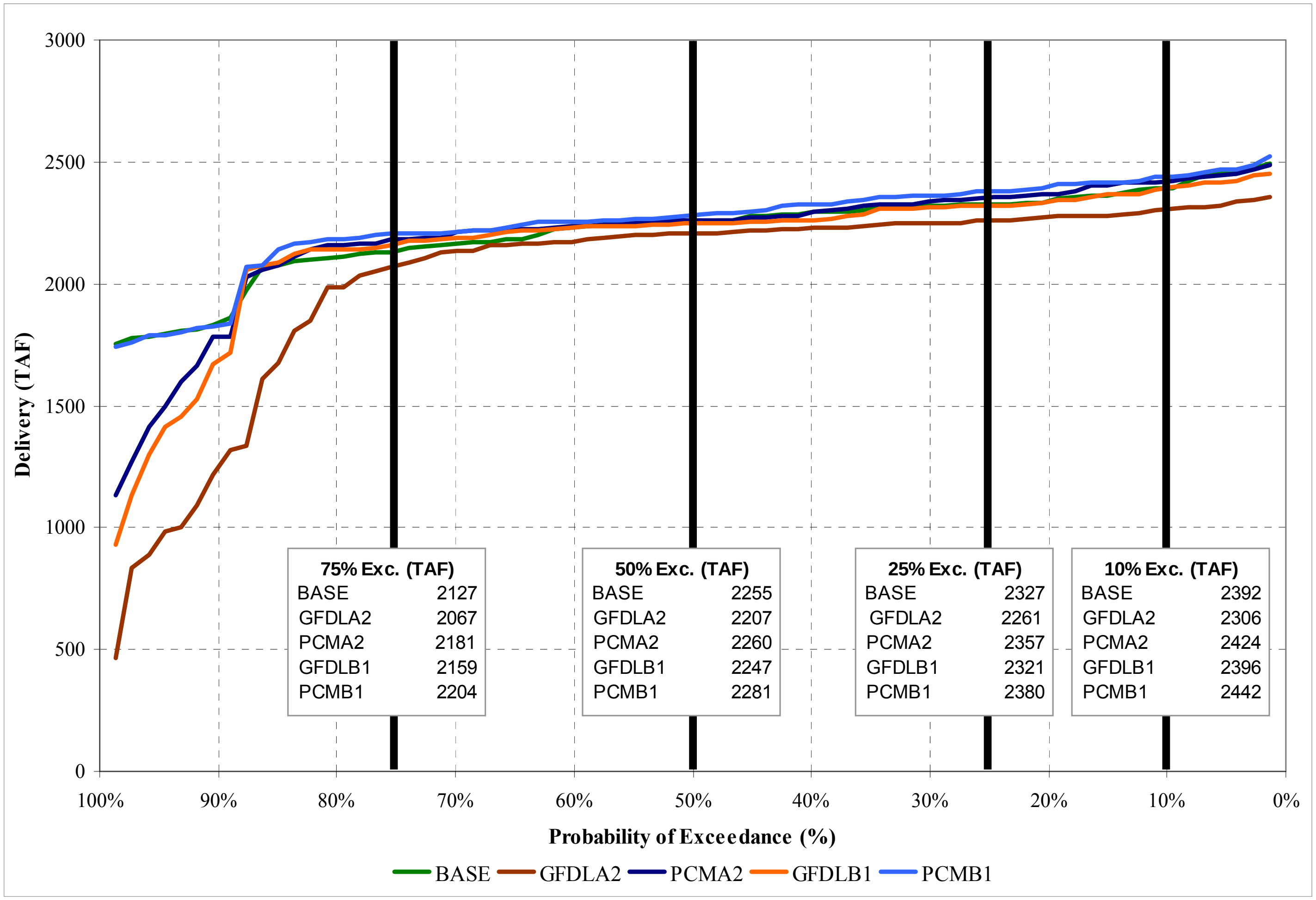


Figure 2. Changes in drought conditions for all climate scenarios



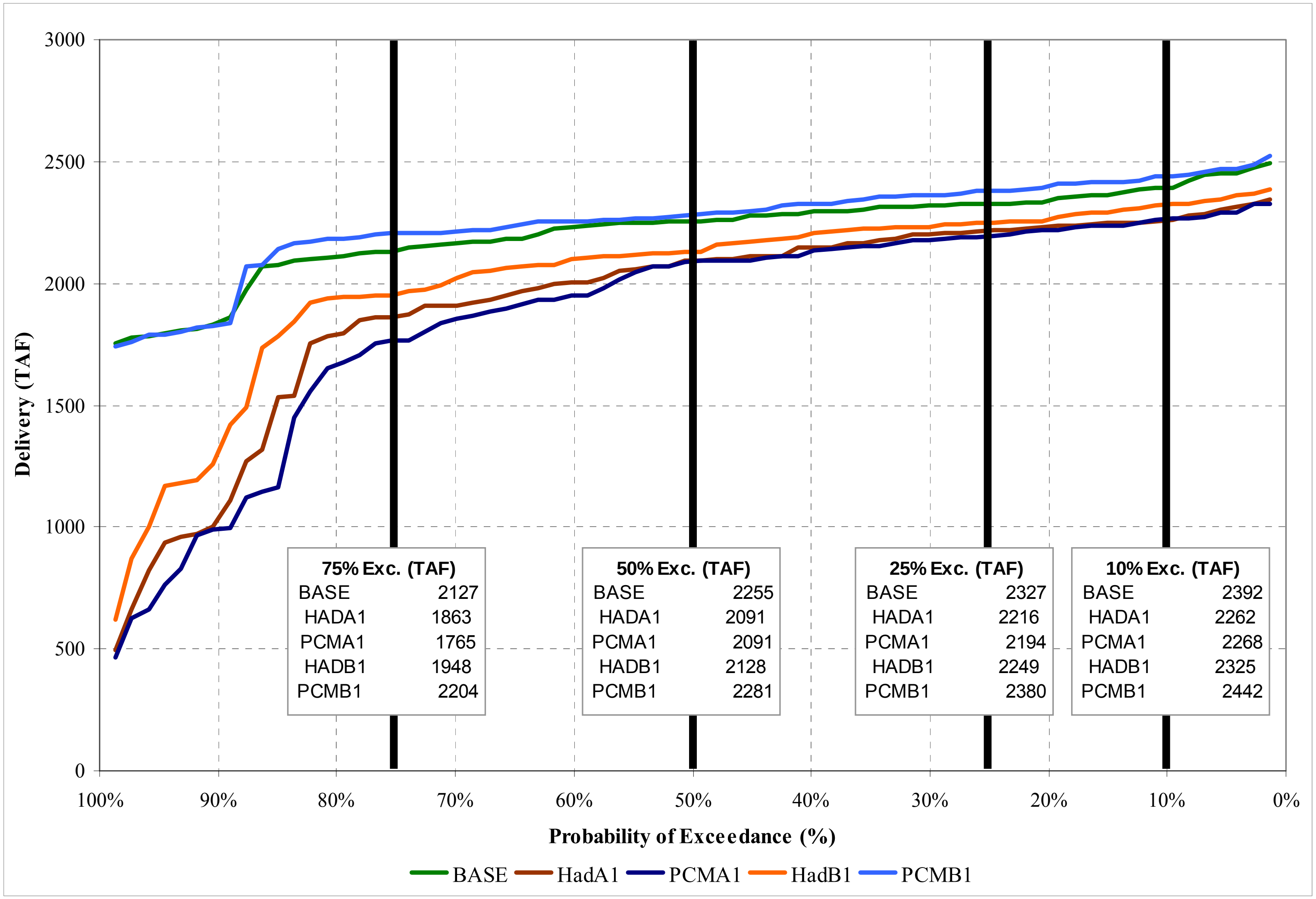
75% Exc. (TAF)	
BASE	2127
GFDLA2	2067
PCMA2	2181
GFDLB1	2159
PCMB1	2204

50% Exc. (TAF)	
BASE	2255
GFDLA2	2207
PCMA2	2260
GFDLB1	2247
PCMB1	2281

25% Exc. (TAF)	
BASE	2327
GFDLA2	2261
PCMA2	2357
GFDLB1	2321
PCMB1	2380

10% Exc. (TAF)	
BASE	2392
GFDLA2	2306
PCMA2	2424
GFDLB1	2396
PCMB1	2442

Figure 3. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A2 and GFDLB1-A2 for 2070–2099



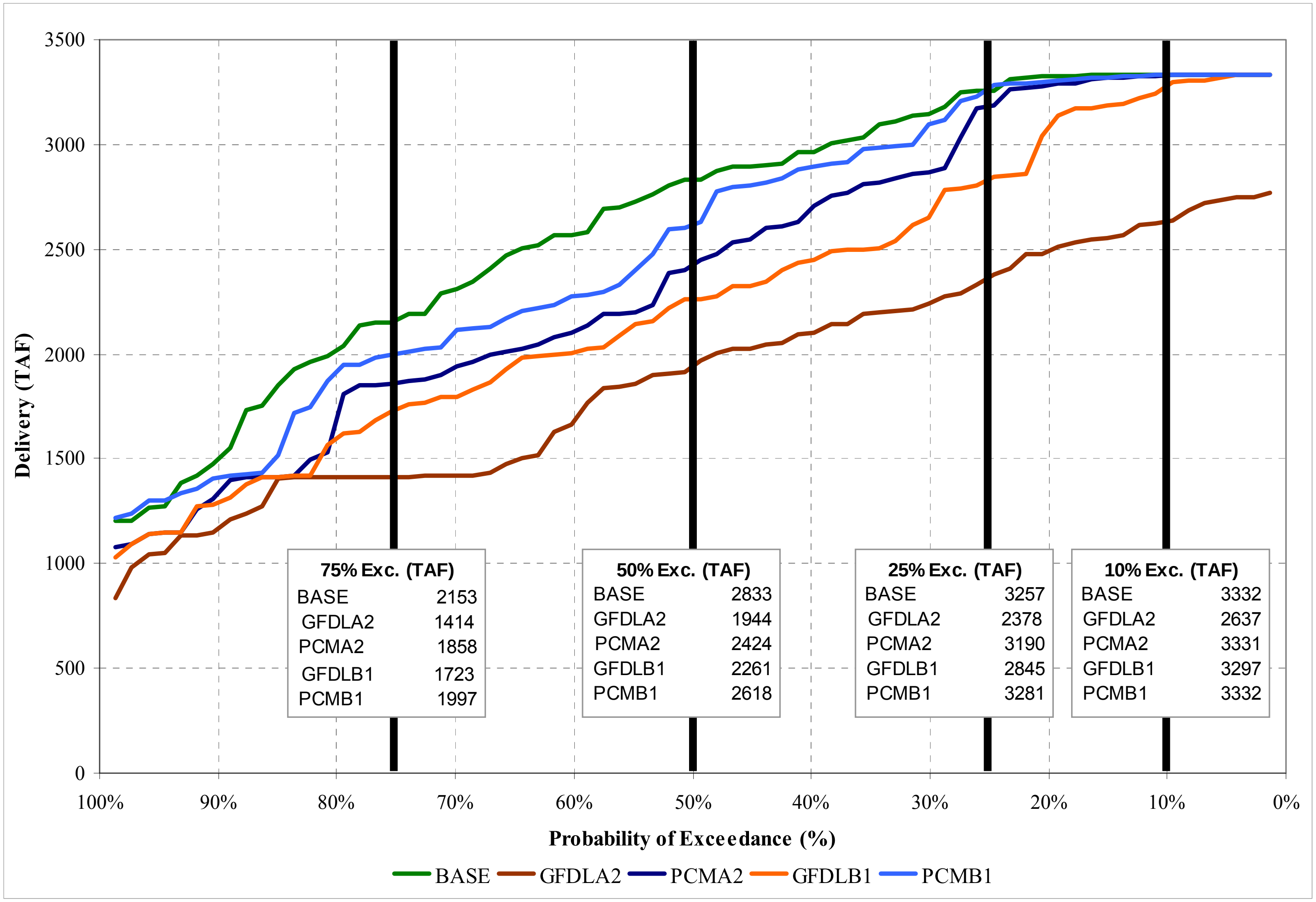
75% Exc. (TAF)	
BASE	2127
HADA1	1863
PCMA1	1765
HADB1	1948
PCMB1	2204

50% Exc. (TAF)	
BASE	2255
HADA1	2091
PCMA1	2091
HADB1	2128
PCMB1	2281

25% Exc. (TAF)	
BASE	2327
HADA1	2216
PCMA1	2194
HADB1	2249
PCMB1	2380

10% Exc. (TAF)	
BASE	2392
HADA1	2262
PCMA1	2268
HADB1	2325
PCMB1	2442

Figure 4. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070–2099



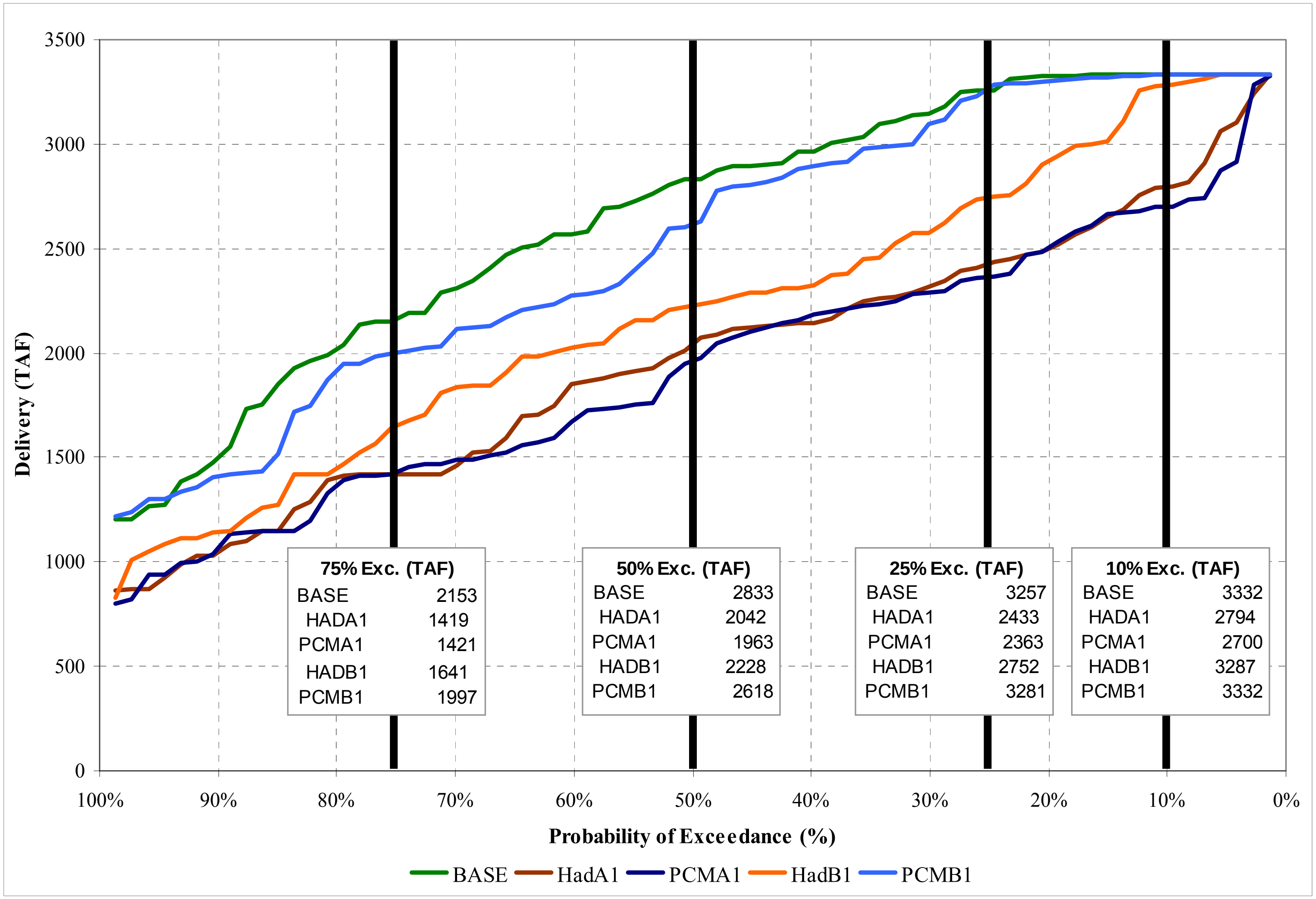
75% Exc. (TAF)	
BASE	2153
GFDLA2	1414
PCMA2	1858
GFDLB1	1723
PCMB1	1997

50% Exc. (TAF)	
BASE	2833
GFDLA2	1944
PCMA2	2424
GFDLB1	2261
PCMB1	2618

25% Exc. (TAF)	
BASE	3257
GFDLA2	2378
PCMA2	3190
GFDLB1	2845
PCMB1	3281

10% Exc. (TAF)	
BASE	3332
GFDLA2	2637
PCMA2	3331
GFDLB1	3297
PCMB1	3332

Figure 5. Exceedance probability plot of CVP South of Delta Annual Deliveries under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070–2099



75% Exc. (TAF)	
BASE	2153
HADA1	1419
PCMA1	1421
HADB1	1641
PCMB1	1997

50% Exc. (TAF)	
BASE	2833
HADA1	2042
PCMA1	1963
HADB1	2228
PCMB1	2618

25% Exc. (TAF)	
BASE	3257
HADA1	2433
PCMA1	2363
HADB1	2752
PCMB1	3281

10% Exc. (TAF)	
BASE	3332
HADA1	2794
PCMA1	2700
HADB1	3287
PCMB1	3332

Figure 6. Exceedance probability plot of CVP South of Delta Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070–2099

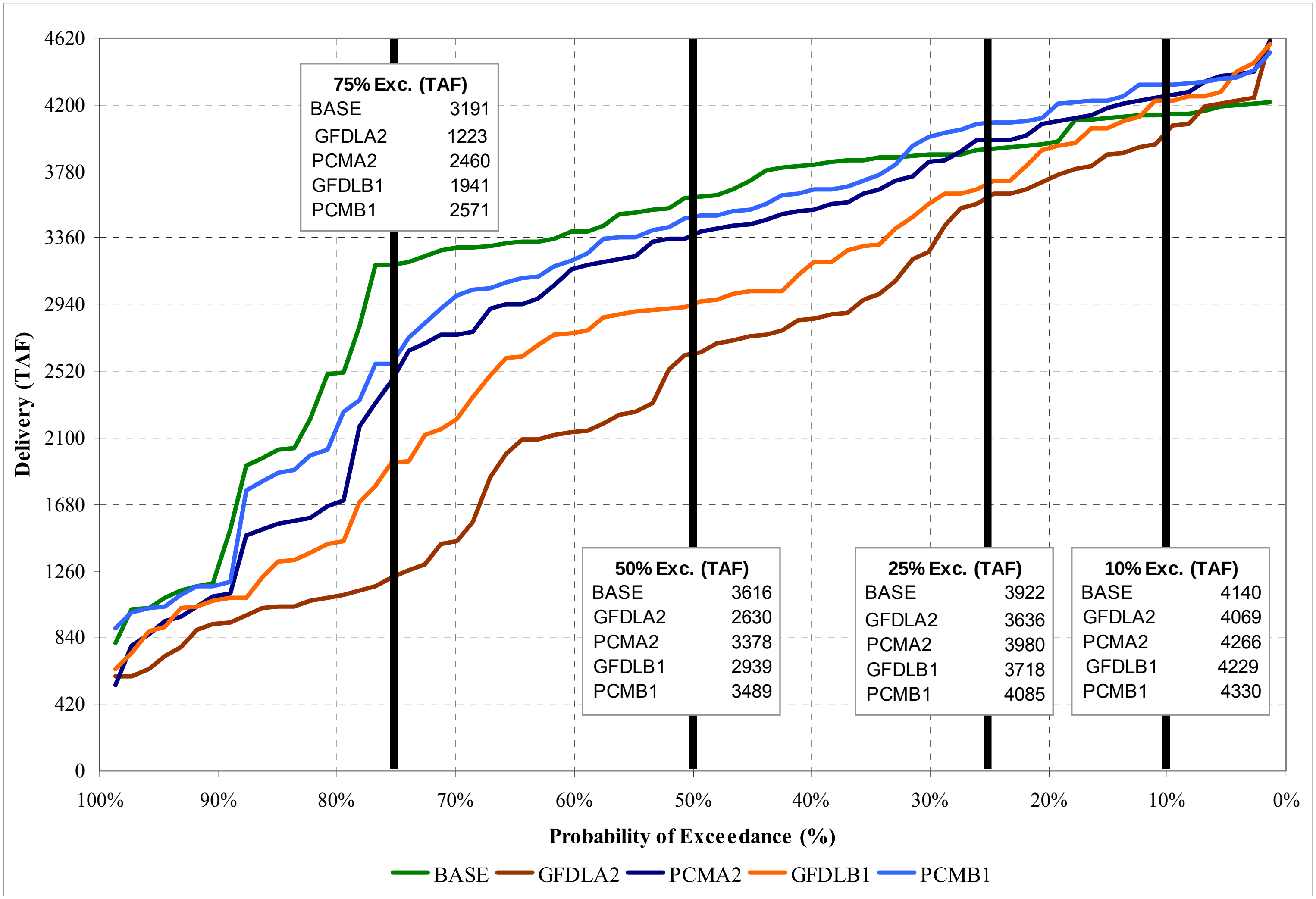
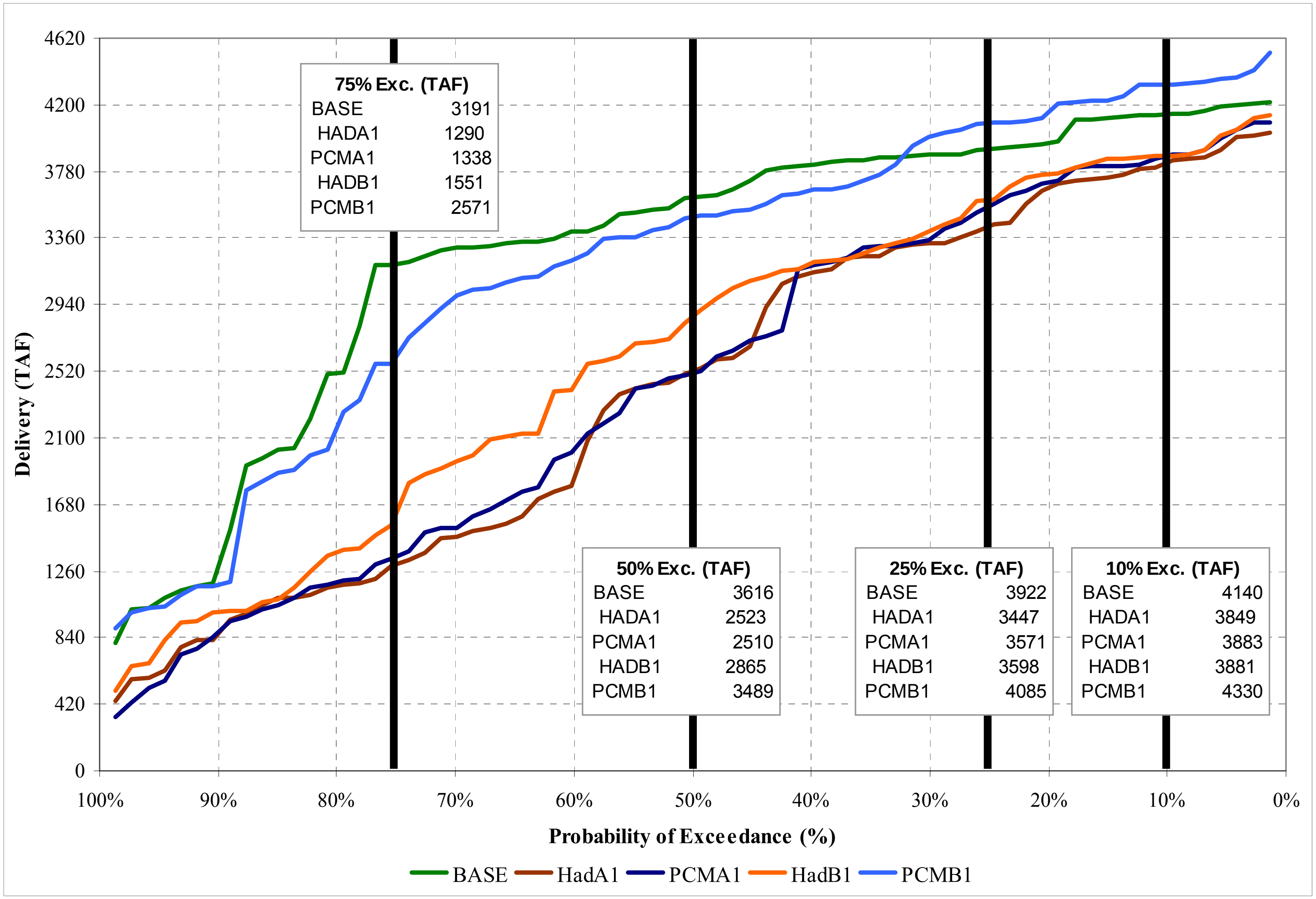


Figure 7. Exceedance probability plot of SWP Annual Deliveries under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070–2099



75% Exc. (TAF)	
BASE	3191
HADA1	1290
PCMA1	1338
HADB1	1551
PCMB1	2571

50% Exc. (TAF)	
BASE	3616
HADA1	2523
PCMA1	2510
HADB1	2865
PCMB1	3489

25% Exc. (TAF)	
BASE	3922
HADA1	3447
PCMA1	3571
HADB1	3598
PCMB1	4085

10% Exc. (TAF)	
BASE	4140
HADA1	3849
PCMA1	3883
HADB1	3881
PCMB1	4330

Figure 8. Exceedance probability plot of SWP Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070–2099

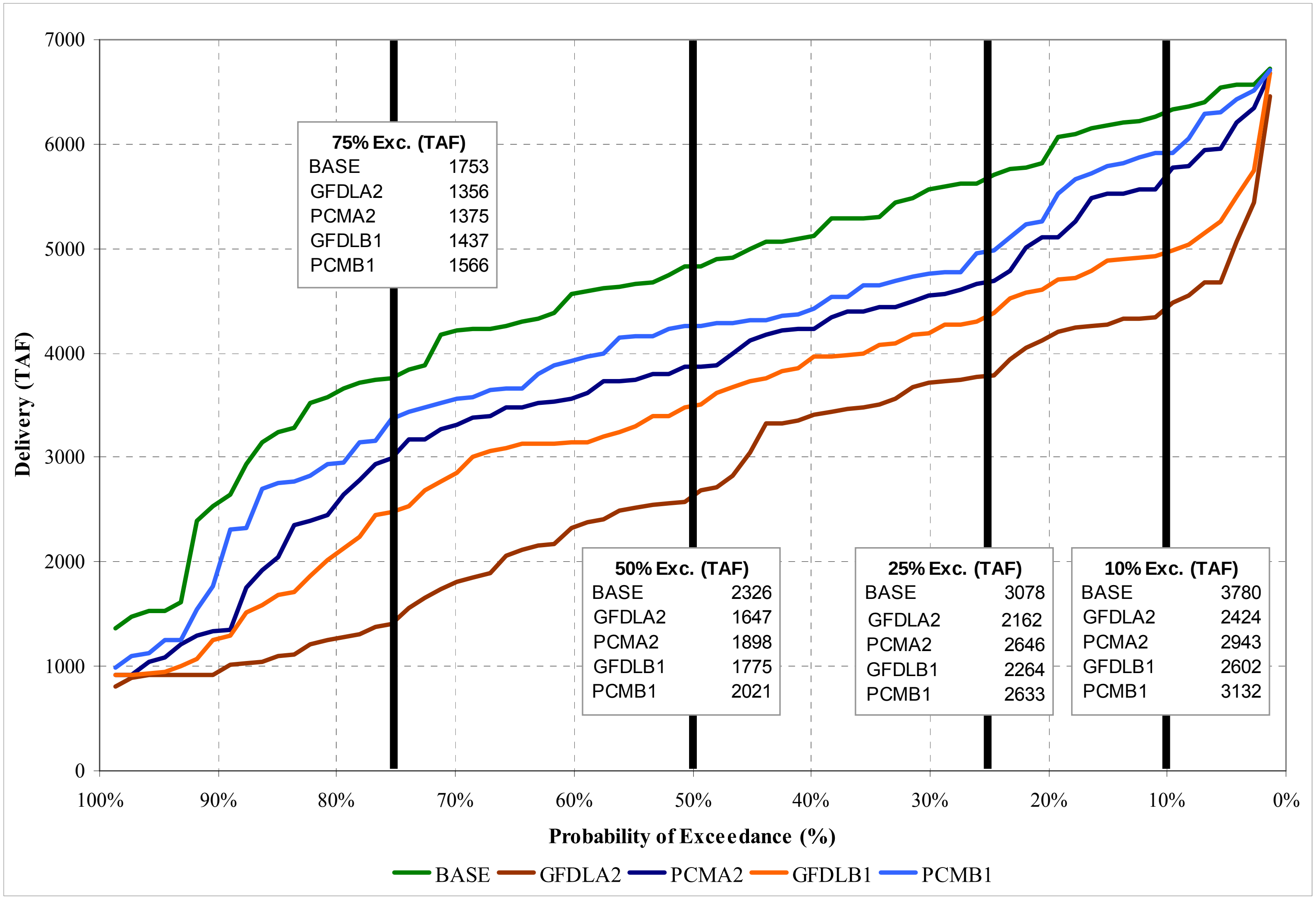


Figure 9. Exceedance probability plot of CVP end of September Carryover Storage under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 (includes storage in Shasta, Trinity, Folsom, and CVP San Luis)

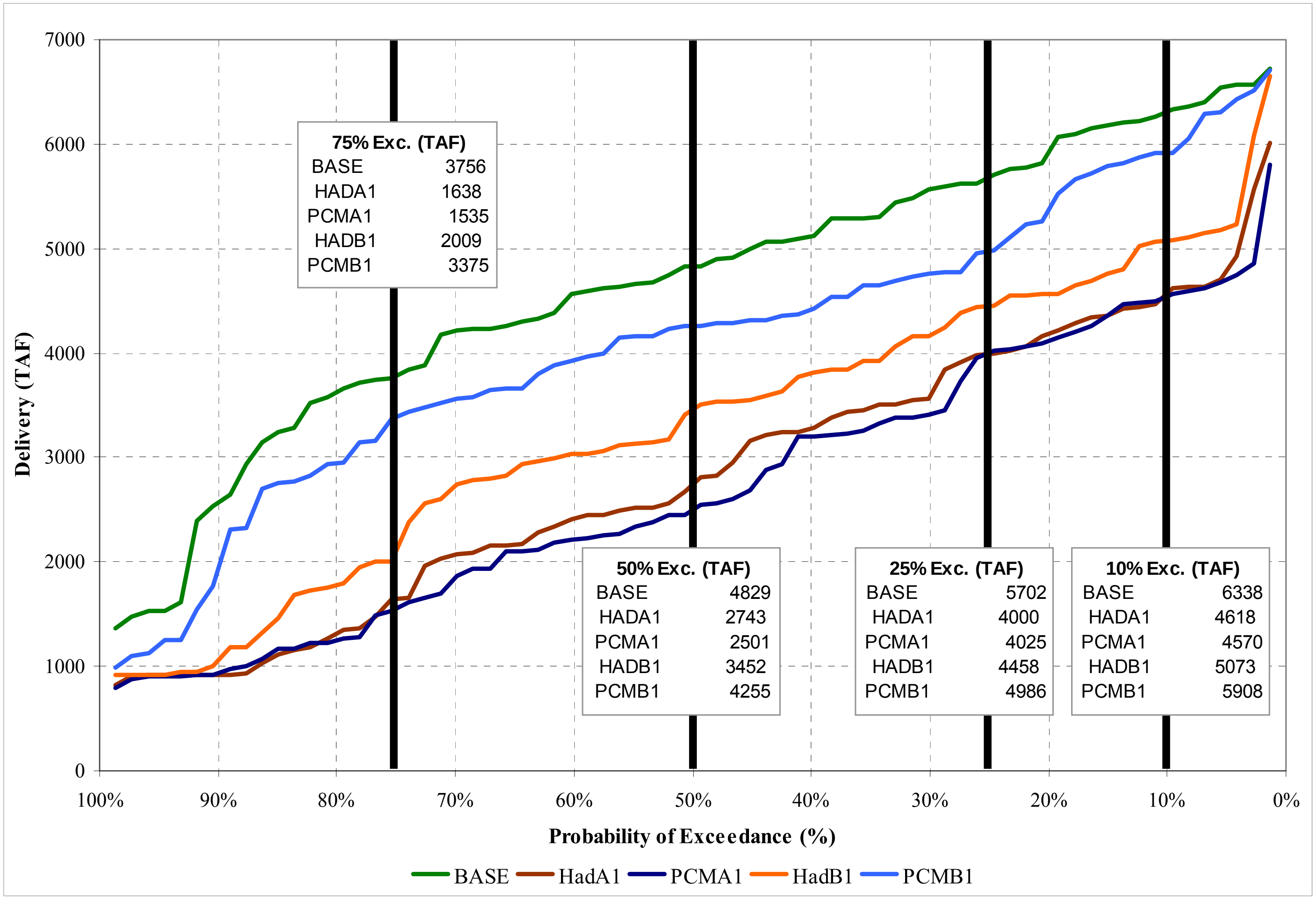


Figure 10. Exceedance probability plot of CVP end of September Carryover Storage under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070–2099 (includes storage in Shasta, Trinity, Folsom, and CVP San Luis)

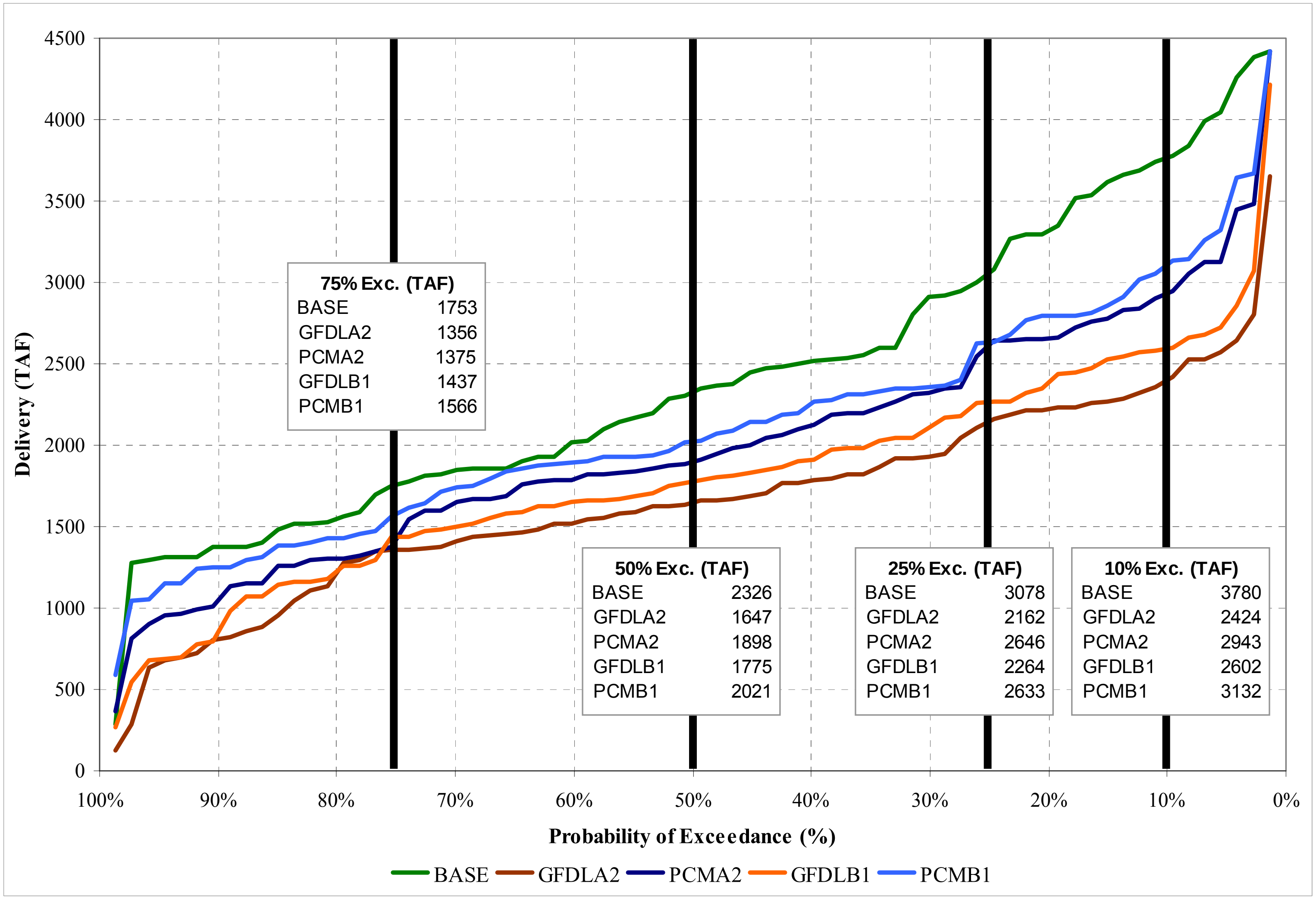
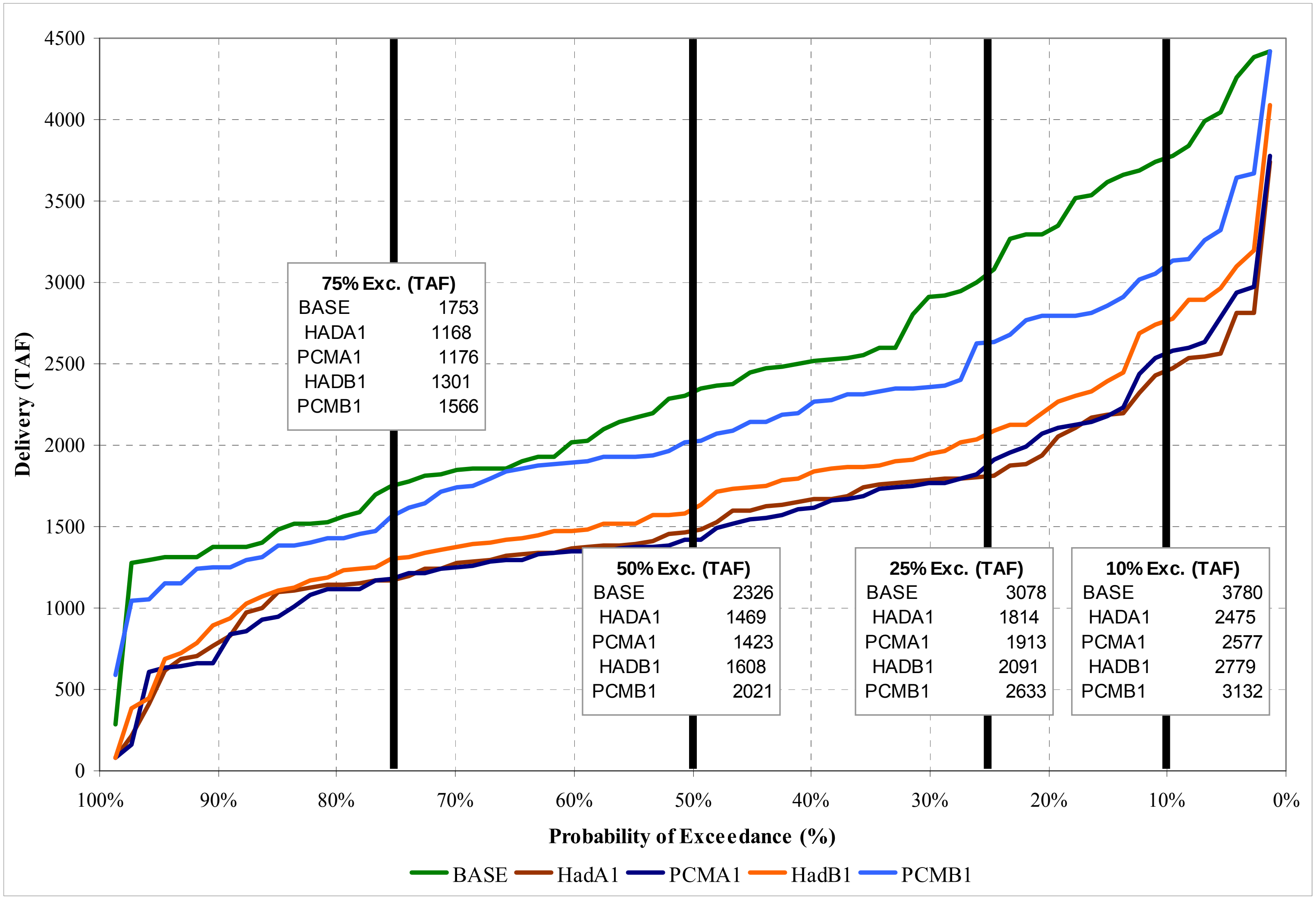


Figure 11. Exceedance probability plot of SWP end of September Carryover Storage under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070–2099 (includes storage in Oroville and SWP San Luis)



75% Exc. (TAF)

BASE	1753
HADA1	1168
PCMA1	1176
HADB1	1301
PCMB1	1566

50% Exc. (TAF)

BASE	2326
HADA1	1469
PCMA1	1423
HADB1	1608
PCMB1	2021

25% Exc. (TAF)

BASE	3078
HADA1	1814
PCMA1	1913
HADB1	2091
PCMB1	2633

10% Exc. (TAF)

BASE	3780
HADA1	2475
PCMA1	2577
HADB1	2779
PCMB1	3132

Figure 12. Exceedance probability plot of SWP end of September Carryover Storage under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 (includes storage in Oroville and SWP San Luis)

Results show great negative impacts on California hydrology and water resources associated with most of climate change scenarios analyzed. Only one scenario PCM run under B1 emission scenarios show just mild negative impacts.

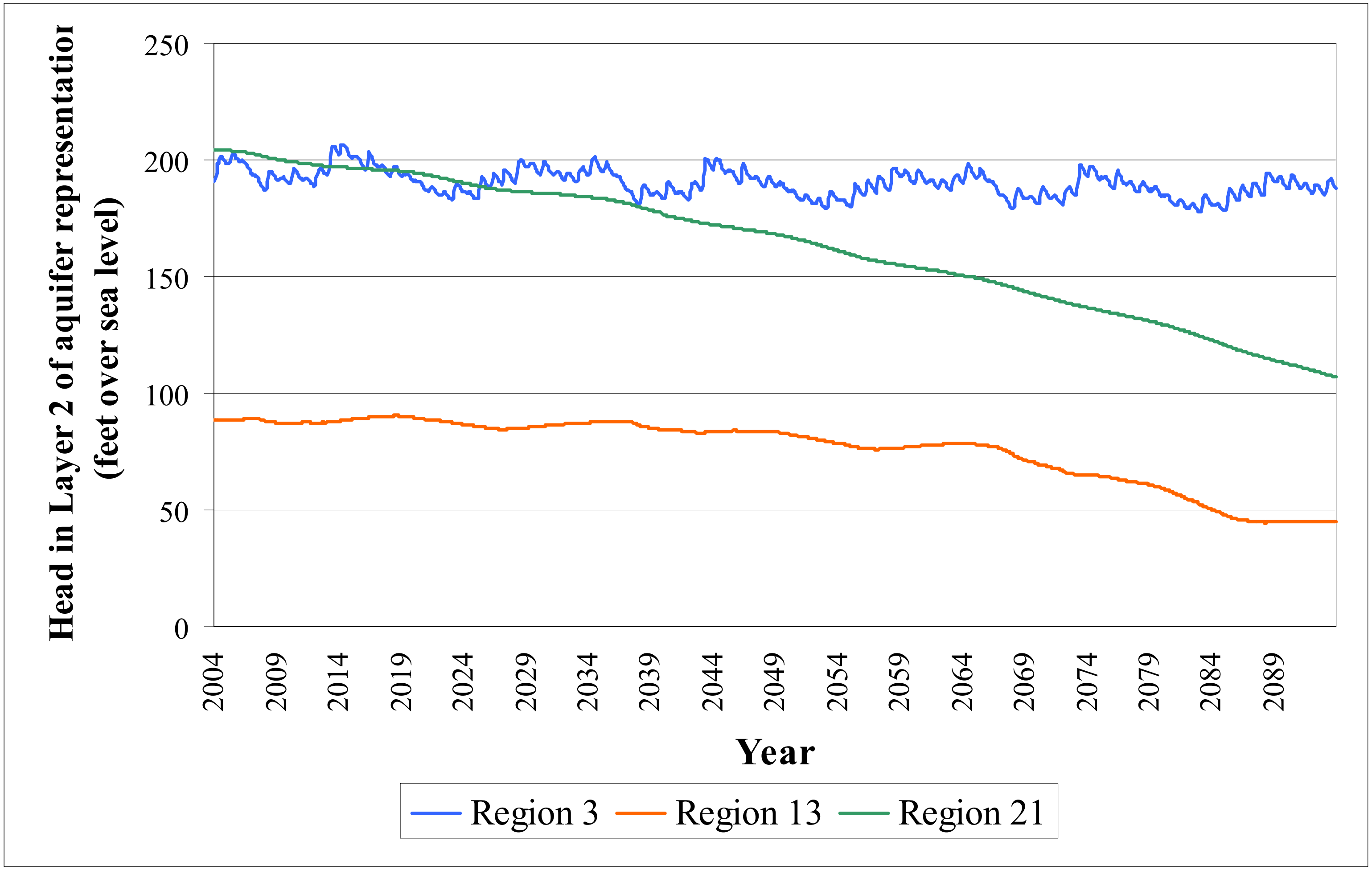


Figure 13. Groundwater levels for different Central Valley regions as simulated by C2VSIM for GFDLA2 climate change conditions (using CalSim II results)

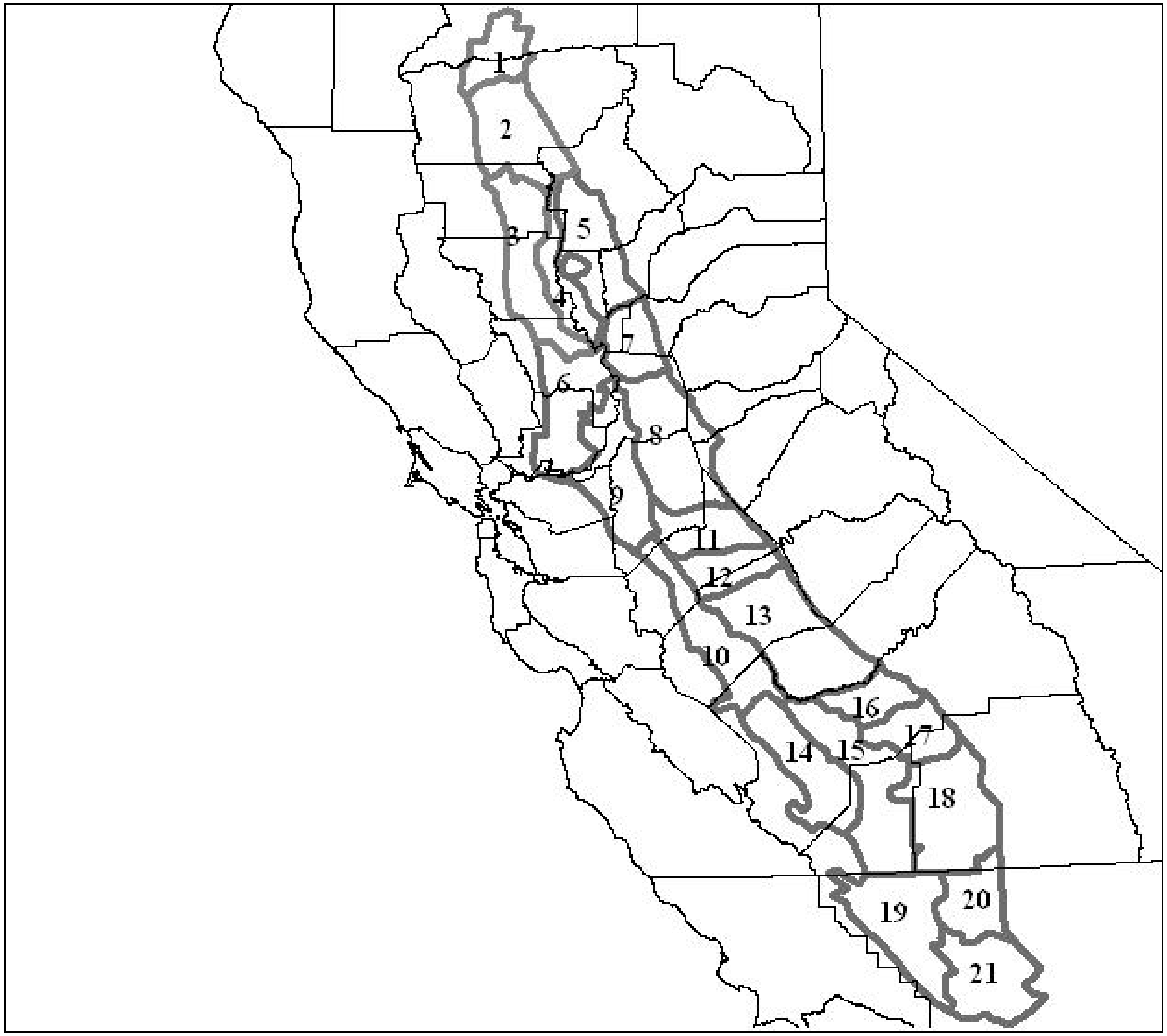


Figure 14. Regions represented in C2VSIM

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