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Comments on Climate Change Modelling in the Bay Delta Conservation Plan EIR/EIS

Modelling of impacts to hydrology of climate change is inadequate. The EIR/EIS also does not have adequate discussion of sensitivity analyses. As a result, risk to projected water supplies and to the environment is not adequately evaluated.

The climate change modeling in the EIR/EIS omits any discussion of likely flows under drier climate change scenarios. Instead the EIR/EIS uses a "Central Tendency" projection which is essentially a 50% exceedance projection

The EIR/EIS discussion of likely impacts of climate change and associated modelling is not sufficient for the public, for stakeholders, or water agencies to evaluate the water supply benefits or water supply risks of the project. The modelling is also not sufficient for the California Department of Fish and Wildlife or the National Marine Fisheries Service to evaluate the potential impacts of the project on endangered species of fish.

The project proponents have done modelling of likely flows under both a "more warming, more drying" scenario [Q1], and a "more warming, less drying" scenario [Q2]. While this information was used in early sensitivity analysis, it has not been released in the EIR/EIS.

An internal presentation on BDCP modelling shows that runoff in the Sacramento River watershed could decrease significantly due to climate change, as much as 13-17% by mid-century. Assuming proportional reductions in BDCP yield, this would mean a greatly reduced yield.

The EIR/EIS should have included projected project yields, reservoir levels, and river flows under these scenarios.

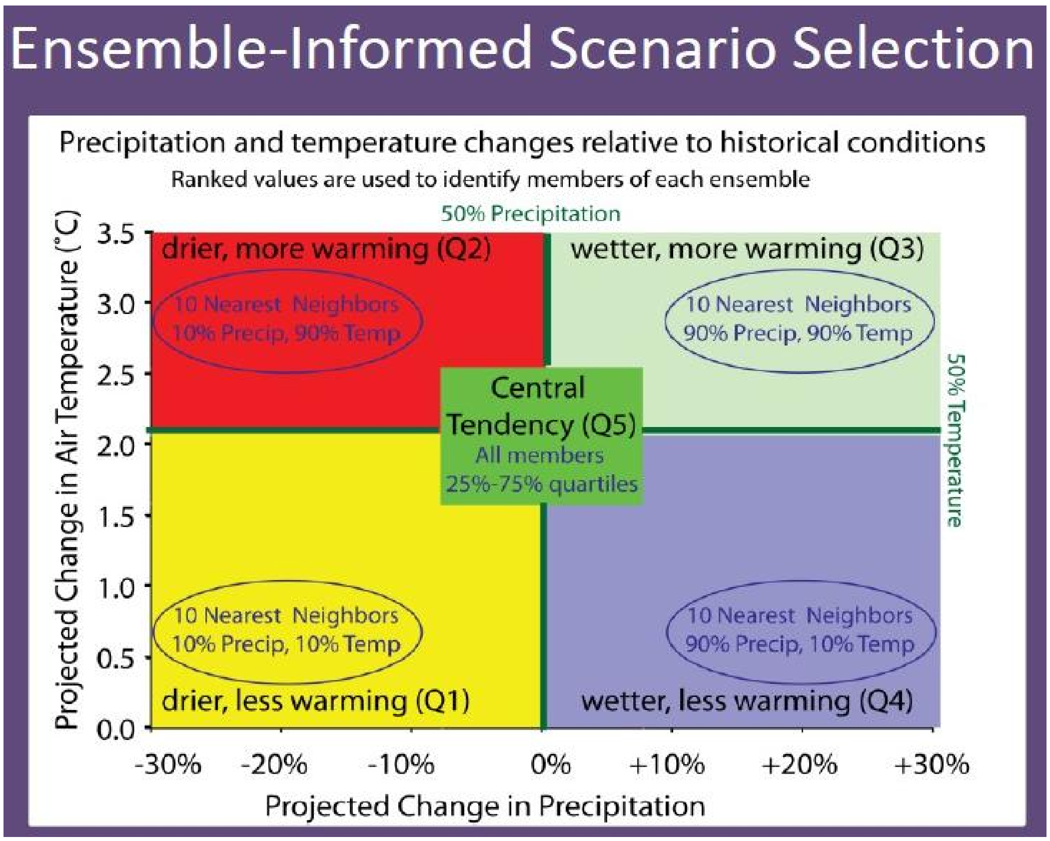
Also, recent modelling by the USGS shows that Sacramento River flows could be reduced by as much as a third by 2070, under some of the drier climate change scenarios. This would reduce the projected yields of the project even more.

For this reason, the entire climate change modelling appendix in the EIR/EIS is inadequate.

BDCP Climate Change Modelling

The "Central Tendency" projection used as input to the BDCP hydrologic models for the Bay Delta Conservation Plan essentially assumes that wetter and drier futures in California are equally likely. By its very structure, the Central Tendency projections are close to current norms of precipitation, since it assumes that wetter and drier futures are equally likely.

BDCP uses the ensemble of 112 climate change model / GHG emissions scenario projections, available from Lawrence Livermore National Lab. The graph below, from an internal presentation by Jamie Anderson on selection of climate change scenarios,[1] illustrates the ensemble scheme.



The 112 projections are broken four different quartiles, based on the mean projected change in temperature and mean projected change in precipitation for the ensemble.

- Drier, less warming [Q1, yellow]
- Drier, more warming [Q2, red]

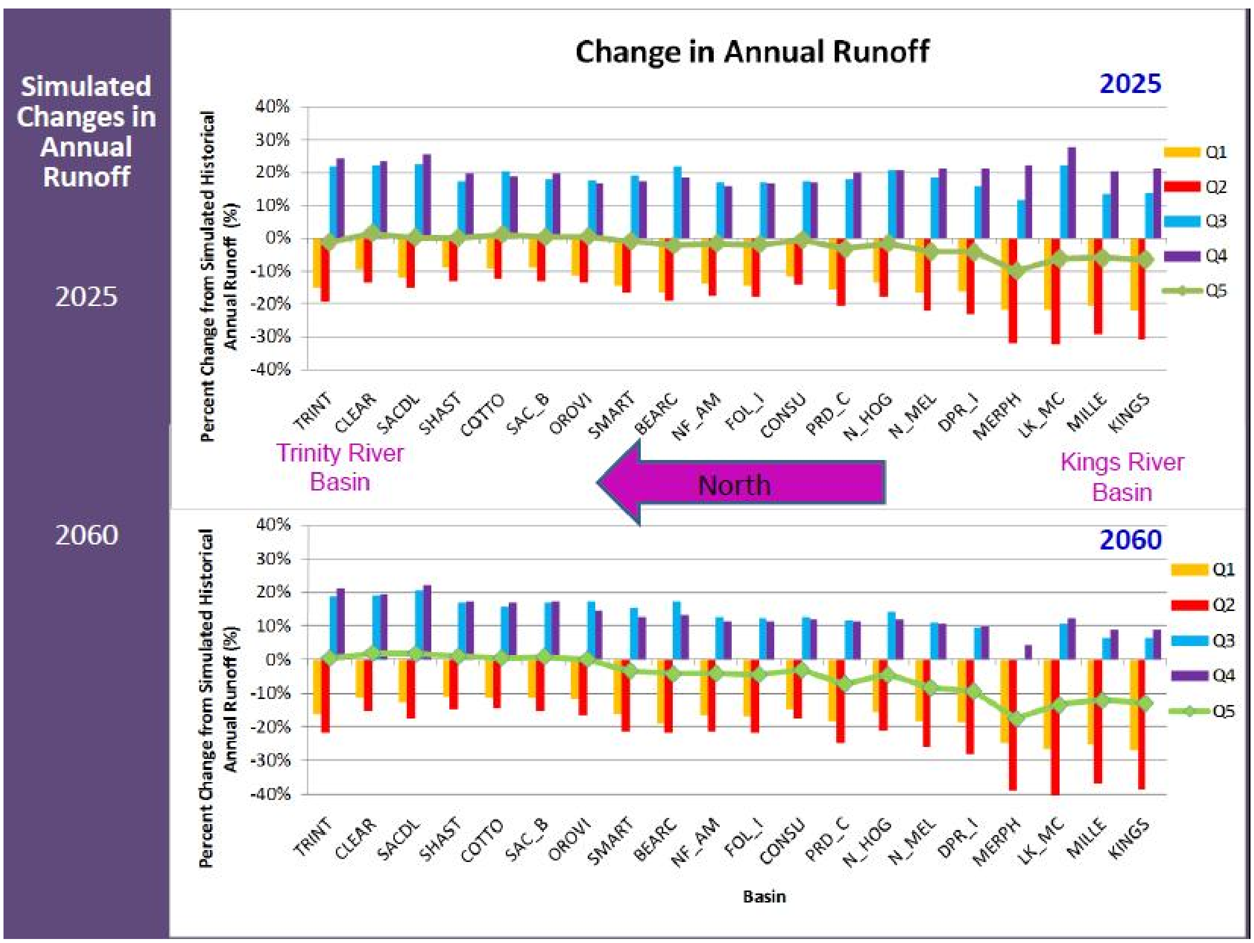
1 Jamie Anderson, presentation on Climate Change Approaches, Department of Water Resources, March 2012. Incorporated by reference. Available at http://www.water.ca.gov/climatechange/docs/CCTAG_climate_change_approaches%20final_3-28-12_Jamie%20Anderson_with%20extra%20slides.pdf

- Wetter, more warming [Q3, light blue]
- Wetter, less warming [Q4, dark blue]

Each quartile was used to produce an ensemble model, after pruning off the 10% driest and 10% wettest models. The output of the ensemble models was not disclosed in the BDCP EIR/EIS.

The graph below, also from the presentation by Anderson, shows different trends in Sacramento River runoff for the different quartiles. The drier, more warming Q2 model predictions include the worst case scenarios. The drier, less warming Q1 model predictions show weaker but still noticeable drying. The predictions of these models are red and yellow, and all show significant reductions in river flows, more by the end of the century.

Although not discussed in BDCP, the Q3 wetter, less warming quartile and Q4 wetter, more warming quartiles generally represent lower GHG emissions scenarios and lower sensitivity climate models, which may be less likely. (See discussion in next section.) Anderson's graph shows the projections of the wetter quartiles in light and dark blue. All the wetter models show increases in streamflow, but less by the end of the century, particularly in the San Joaquin Valley



The predictions of the Central Tendency model, Q5, are shown in green. Q5 is based on the entire ensemble, after throwing out the driest half of the driest models, the wettest half of the wettest models, the warmest half of the warmest models. Throwing out these models from the ensemble may also throw out information on risk.

As you can see, the Central Tendency model tends to reproduce the historical precipitation patterns in the near term. It is only over the long term, when the severe potential drying under the drier models far outweigh the effects of the wetter models, that the Central Tendency model begins to show some drying.

Conclusion: using the Central Tendency model for BDCP could significantly underestimate the reduction in river flows from the effects of climate change.

Why More Warming is More Likely

Recent research indicates that the climate change models showing a lower level of "climate sensitivity," that is, higher temperature increases for a given level of C02 emissions, may not agree with current observations from satellite data. A recent study by Sherwood, Bony, and Dufresne [2] found that

> … The mixing inferred from observations appears to be sufficiently strong to imply a climate sensitivity of more than 3 degrees for a doubling of carbon dioxide. This is significantly higher than the currently accepted lower bound of 1.5 degrees, thereby constraining model projections towards relatively severe future warming.

Similar results were found in a 2012 study by Fausilio and Treberth, which compared current observations of May through August relative humidity with model projections.[3]

Why More Warming Means More Drying for Higher GHG Scenarios

These studies show that there is potentially huge risk in assuming that low temperature sensitivity models are valid. Although the BDCP EIR/EIS did not consider the properties of the individual IPCC GHG models in the Lawrence Livermore lab dataset , the California Climate Scenario Assessment team, which did modelling for the California Climate Change Adaptation Strategy, did look at the relationship between increases in temperature over California with increasing GHG emissions and projected reductions in precipitation.

Not too surprisingly, the higher sensitivity models generally predict more drying. The graph below shows the difference in projected temperatures over California of the IPCC climate change models, for two GHG scenarios: A2 (medium high) and B1 (low) greenhouse gas emissions scenarios. The models were ranked on difference between projected temperatures. Blue was lowest sensitivity, green medium, and orange highest.

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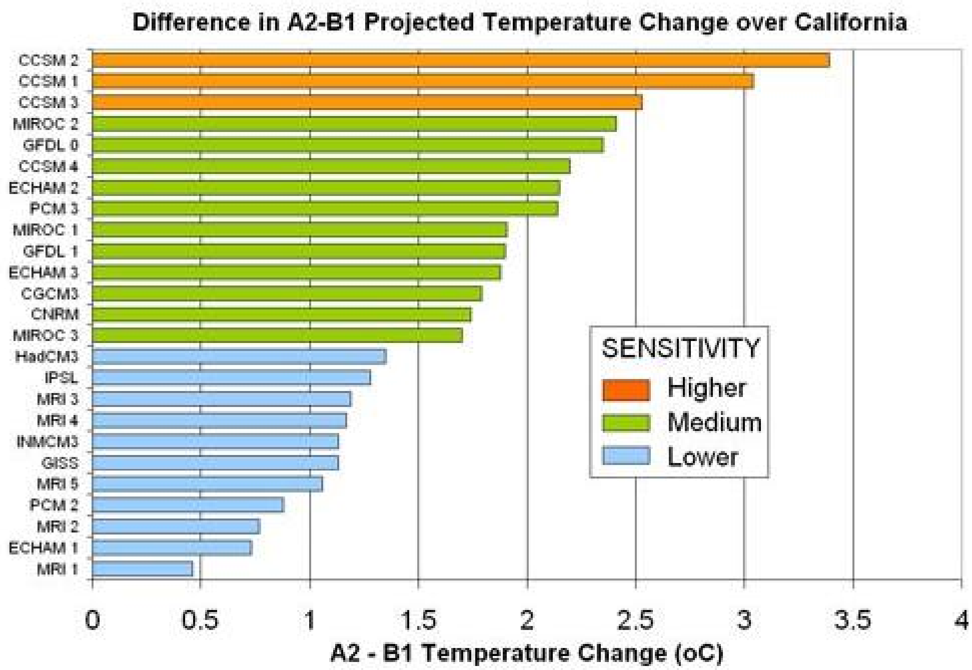
2 S.C. Sherwood, S. Bony, and J. Dufresne, "Spread in model climate sensitivity traced to atmospheric convective mixing", Nature, vol. 505, pp. 37-42, 2014. http://dx.doi.org/10.1038/nature12829. Incorporated by reference.

3 J.T. Fasullo, and K.E. Trenberth, "A Less Cloudy Future: The Role of Subtropical Subsidence in Climate Sensitivity", Science, vol. 338, pp. 792-794, 2012. http://dx.doi.org/10.1126/science.1227465. Incorporated by reference.



The IPCC global climate models which show the highest temperature increases with increased GHG levels also tend to show the largest reductions in precipitation with increased GHG levels. The graph below shows the differences in projected precipitation change over California, between the B2 and A1 scenarios, for 25 models.[4] Of the highest sensitivity models, two thirds showed a marked decrease in precipitation between the A2 and B1 scenarios, and three fourths of the medium sensitivity models.

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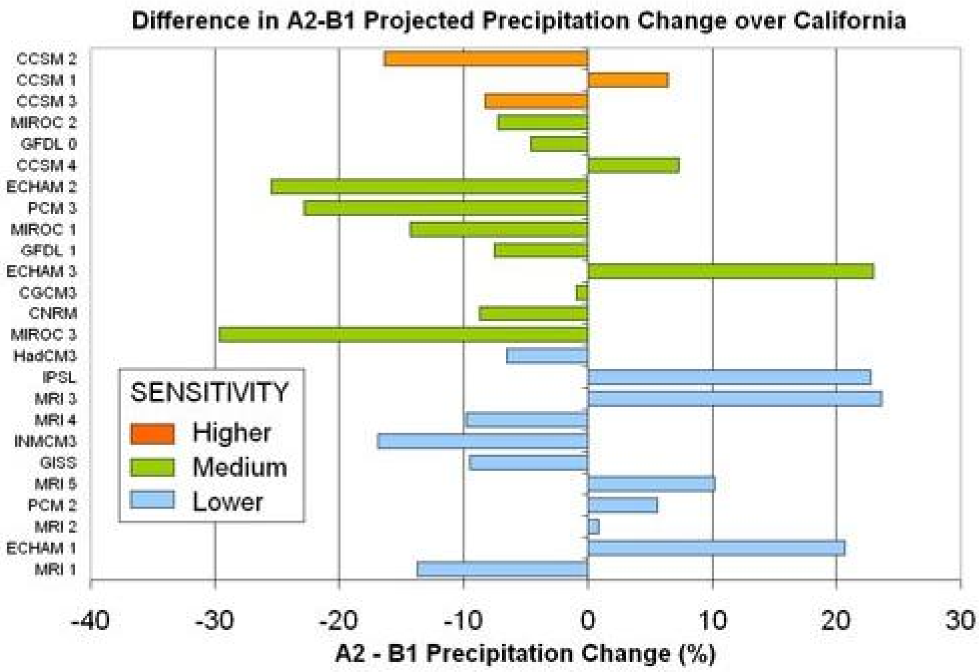
4 California Climate Scenario Asssessment Team, Model Page. Incorporated by reference. Available at http://meteora.ucsd.edu/cap/cccc_model_prelim.html#contents



Source: California Climate Scenario Assessment team, 2005 sensitivity assessment

Why Higher Greenhouse Gas Emissions Scenarios Are More Likely

Unfortunately, the higher GHG emissions scenarios appear to be the most likely, given current trends in global development and the current trajectory of increases in greenhouse gas emissions.

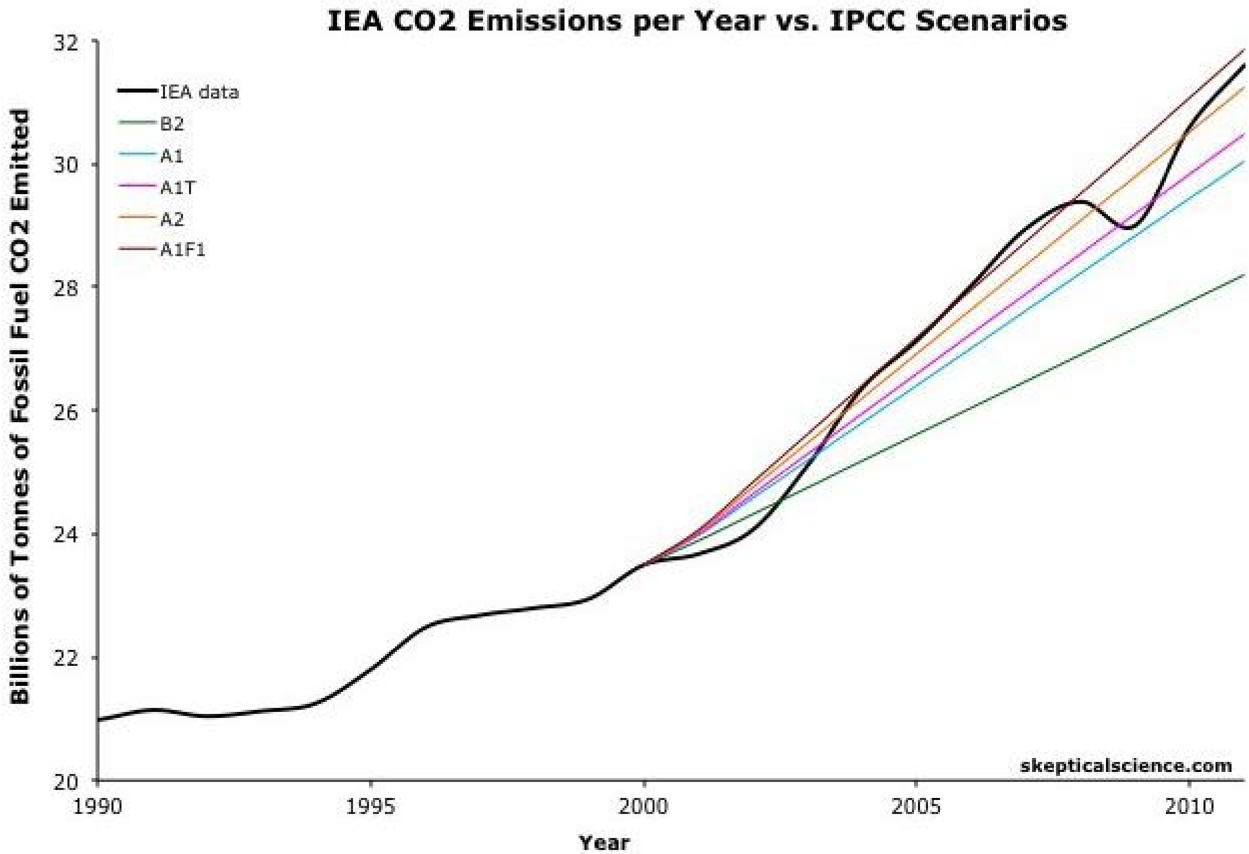
In the discussion for the Cal-Adapt the draft Natural Resources Agency policy on Climate Adaptation states:

> "Of the two options provided by Cal-Adapt, the A2 scenario is the more realistic choice for decision-makers to use for climate adaptation planning. The B1 scenario is optimistic in the high level of international cooperation assumed. This cooperation would necessitate sweeping political and socioeconomic change on a global magnitude that is as yet unprecedented. The roughly two billion-person decline in population over the last half of the century is also reliant on broad assumptions of low mortality and low fertility. Generally, the B1 scenario might be most appropriately viewed as a version of a "best case" or "policy" scenario for emissions, while A2 is more of a status quo scenario incorporating incremental improvements."[5]

At the time the California Climate Change Adaptation Policy guide draft was written, it is clear

5 California Natural Resources Agency, draft California Climate Change Adaptation Policy Guide, April 2012. Incorporated by reference. Available at http://resources.ca.gov/climate_adaptation/docs/APG_-_PUBLIC_DRAFT_4.9.12_small.pdf

that higher greenhouse gas emissions scenarios appeared more likely than lower greenhouse gas emissions scenarios. The graph below shows that world C02 emissions, which had declined during the recession, are back to tracking the higher emissions trajectories, which include A2 (medium high) and A1Fi (highest.)



IEA fossil fuel CO2 emissions estimates vs. IPCC SRES emissions scenarios.

Source: Skeptical Science[6]

This information on the likely trajectory of GHG emissions was clearly available to the Natural Resources Agency when the BDCP EIR/EIS was drafted. However, there is no disclosed analysis of sensitivity to GHG emissions scenarios.

While the BDCP document states that the modelling was agreed to after extensive consultation with representatives from DFW, NMFS and USFWS, fish biologists do not have any particular expertise in climate change modelling, and could not be expected to make authoritative comments on the potential impacts of the modelling choices.   The sensitivity analyses used in

6 IEA CO2 Emissions Update 2011 - the Good News and the Bad, Skeptical Science, May 30, 2012. Available at http://www.skepticalscience.com/iea-co2-emissions-update-2011.html.   Incorporated by reference.

discussions with NMFS and USFWS should have been disclosed in the EIR/EIS so that a wider range of stakeholders could comment.

The end result of these omissions is to eliminate any real information in the EIR/EIS on the risk of climate change to the projected yields from BDCP, and also to minimize the potential ecological risks of the proposed diversion on the Sacramento River.

A Very Possible Worst Case Scenario under Higher GHG Emissions

The US Geological Survey released a paper in 2012 using the Global Fluid Dynamics Lab (GFDL) climate model with the A2 (medium high) emissions scenario. [7] The study was done by R.T. Hanson and other researchers at USGS in collaboration with Daniel Cayan, who oversaw the modeling for the California Climate Adaptation Strategy.

The GFDL A2 projection is drier projection which was used in the California Climate Adaptation Strategy. On the next page is a graph of predicted river flows in the Central Valley. The USGS models predict a 16-17% reduction in Sacramento River flows from 2020-2030 and 2040-2050, and a 34% reduction by 2080-2090. Similar reductions are predicted for the Tuolumne and Kern Rivers.

7 R.T. Hanson et. al., "A method for physically based model analysis of conjunctive use in response to potential climate changes," Feb 4, 2012. Incorporated by reference. Available at http://ca.water.usgs.gov/projects/cvhm/Hanson_etal_2012_WRR.pdf.

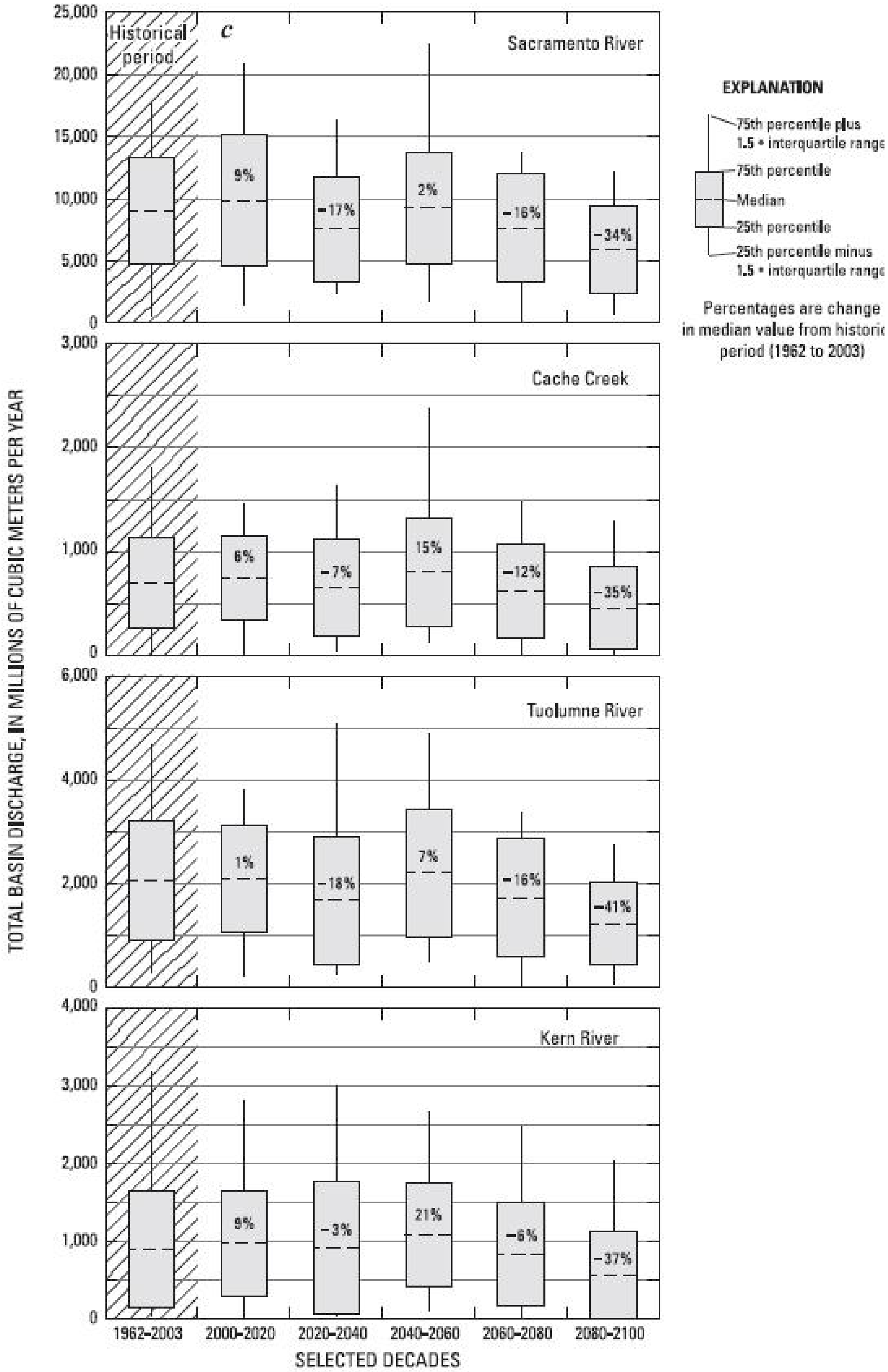


Figure 3. (continued)

The maps below show details of the reduction in river inflows from the USGS modeling. The different basins are color-coded, based on flow. There is a marked reduction in flows in all basins in the Central Valley by the end of the century.

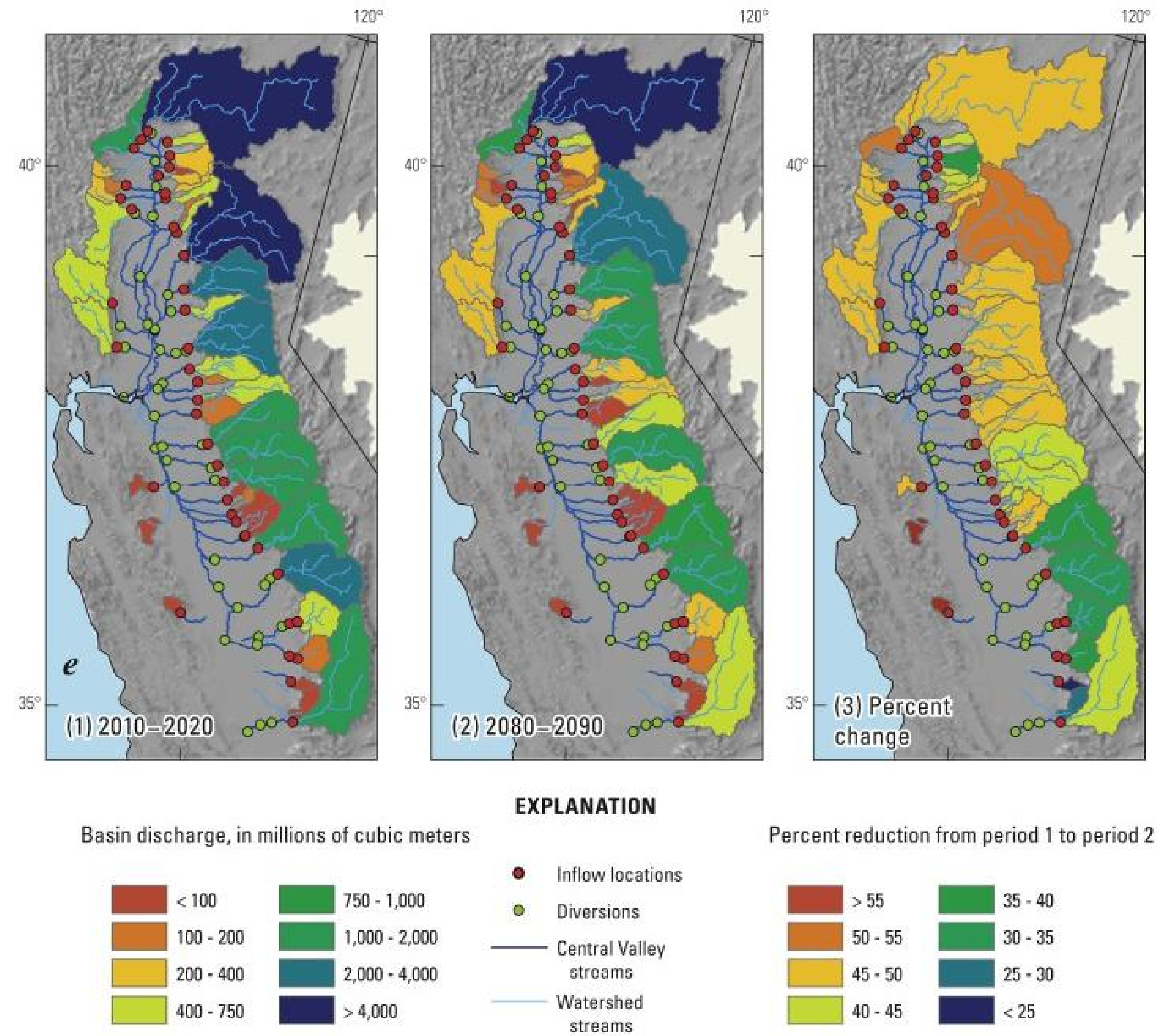


Figure 3. (continued)

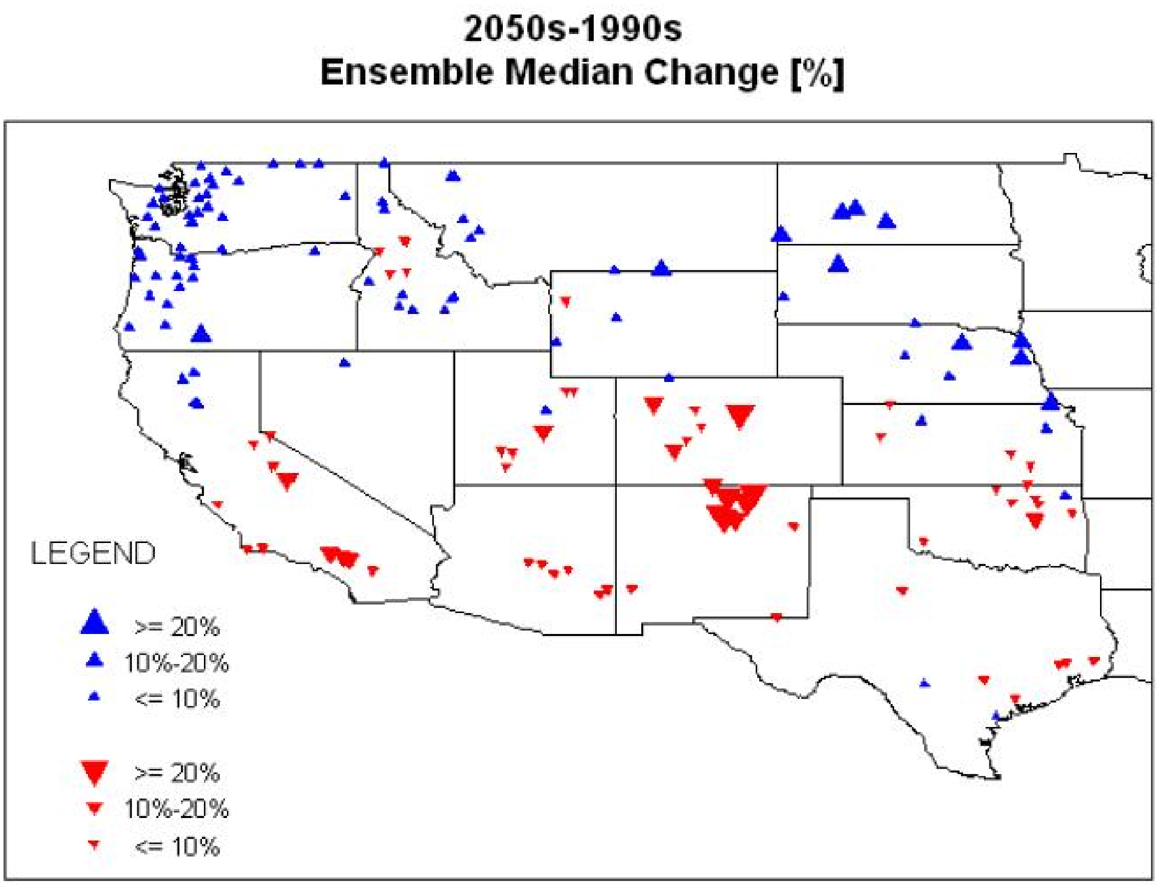
The Central Tendency model for the Bay Delta Conservation Plan may not have even included the GFDL / A2 projection, since the algorithm threw out the driest half of the drier quadrant projections before any further computation. (25% -75% pruning algorithm.)

The algorithm for computing the Central Tendency model is also not adequately described in the BDCP EIR/EIS climate change technical appendix. The model pruning step could have thrown out a large number of high sensitivity, higher greenhouse gas emissions projections which recent may be more likely. The BDCP EIR / EIS climate change modelling technical appendix is inadequate because it contains no information on which models are thrown out under the 25%-75% pruning, and so it is impossible to estimate the effect on the hydrologic modelling.

More on Effects of Model Pruning

The U.S. Bureau of Reclamation for the 2011 Westwide Climate Risk Assessment also used the Lawrence Livermore ensemble of 112 projections for the 2011 Westwide Climate Risk Assessment.[8] The Westwide Climate Risk Assessment also used a median of the entire ensemble. This approach was similar to the BDCP "Central Tendency" model. However, the Bureau modellers used less severe pruning of the model space prior to taking the median. The Bureau models only tossed out the 10% outlying models, rather than the 25% outlying models.

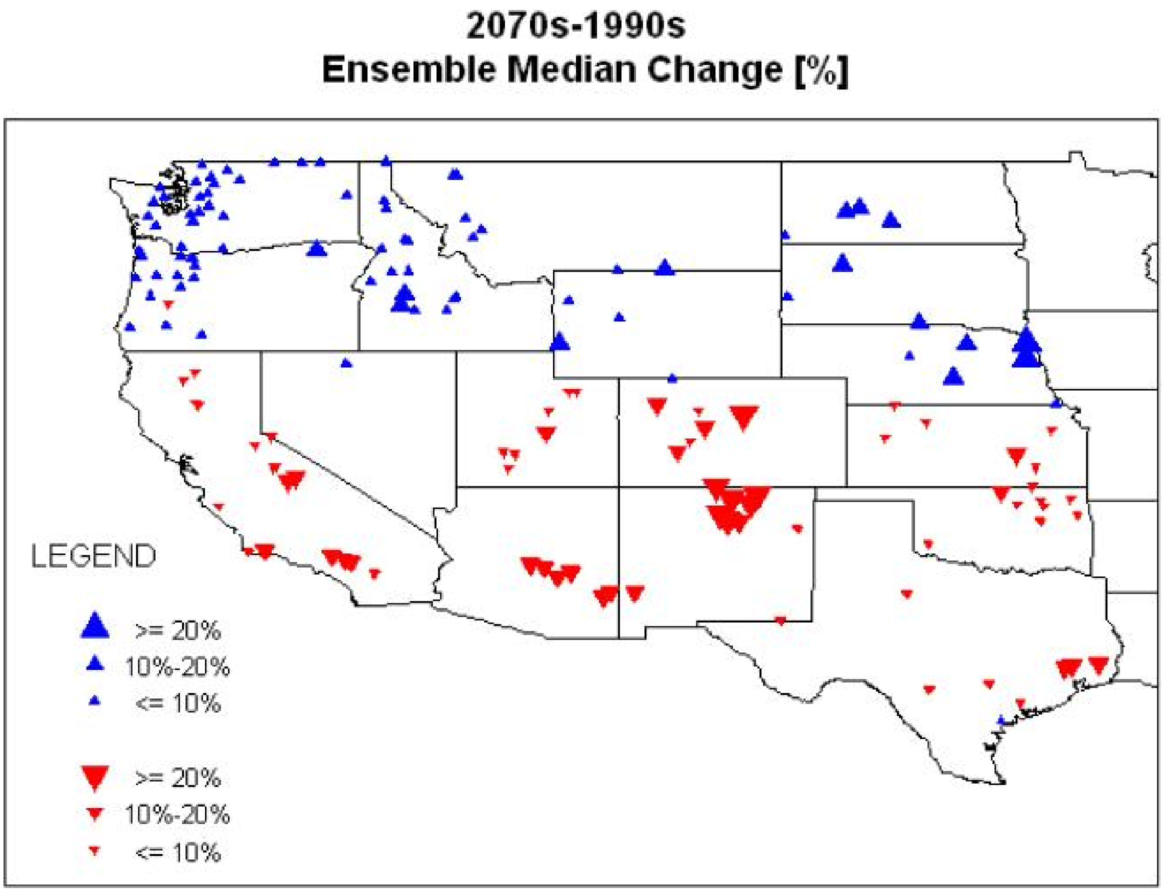
The results show significant projected drying in Southern California and the Central Sierras by mid-century, as well as drying across the Southwest. By the 2070s, the ensemble median projected drying throughout California.



1 Median projected changes in annual precipitation from ensemble of 112 GCM / scenario combinations, mid-century

Source: US Bureau of Reclamation, West-wide Climate Risk Assessment, 2011.

8 West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections, U.S. Department of the Interior Bureau of Reclamation Technical Memorandum No. 86-68210-2011-01, March 2011. Available at http://www.usbr.gov/WaterSMART/docs/west-wide-climate-risk-assessments.pdf



2 Median projected changes in annual precipitation from ensemble of 112 GCM / scenario combinations end of century

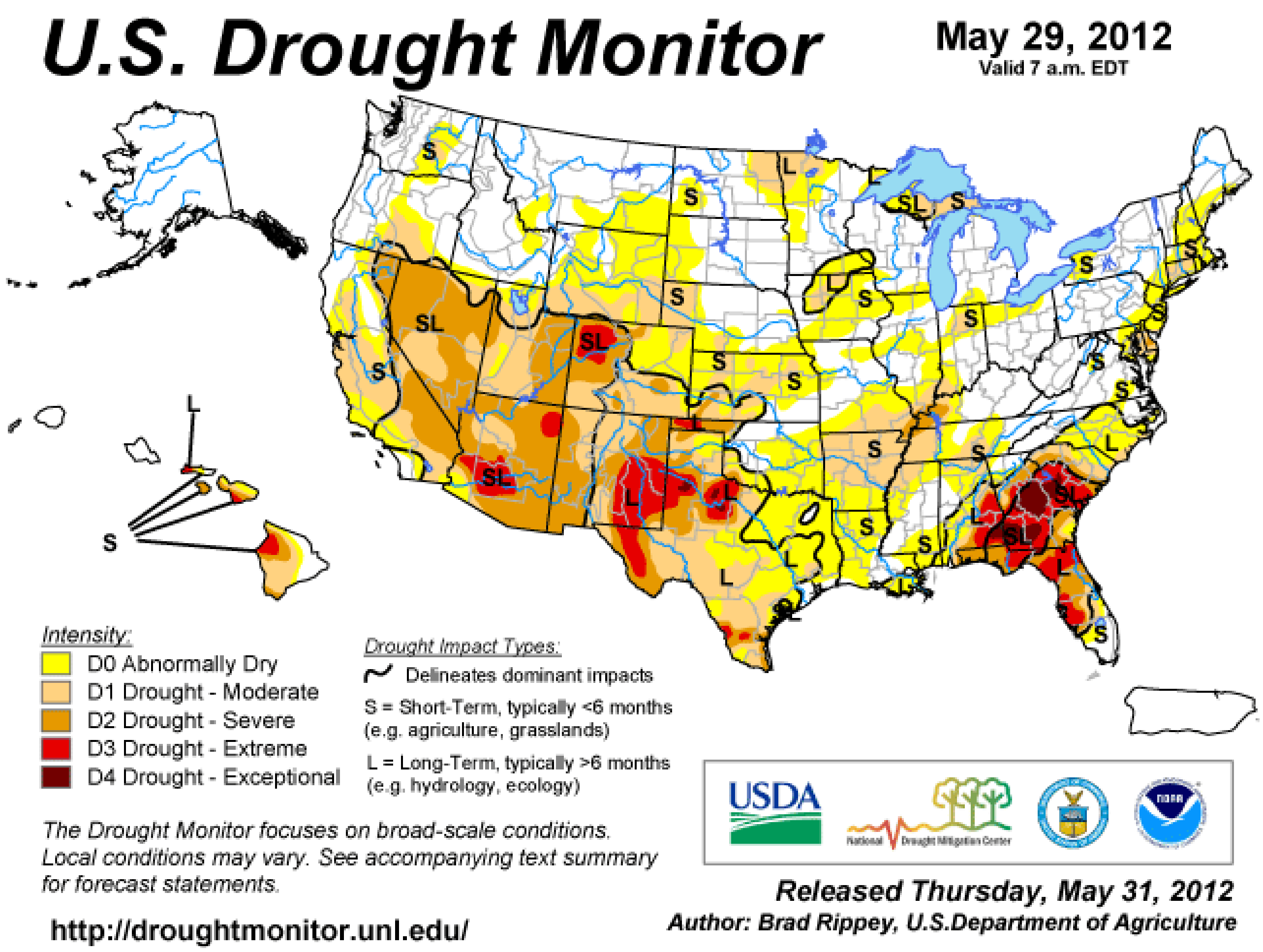
Source: US Bureau of Reclamation, West-wide Climate Risk Assessment, 2011.

While the BDCP technical appendix includes a table of other modelling approaches, there are no comparisons of actual precipitation projections between the BDCP Central Tendency model and the Bureau model.

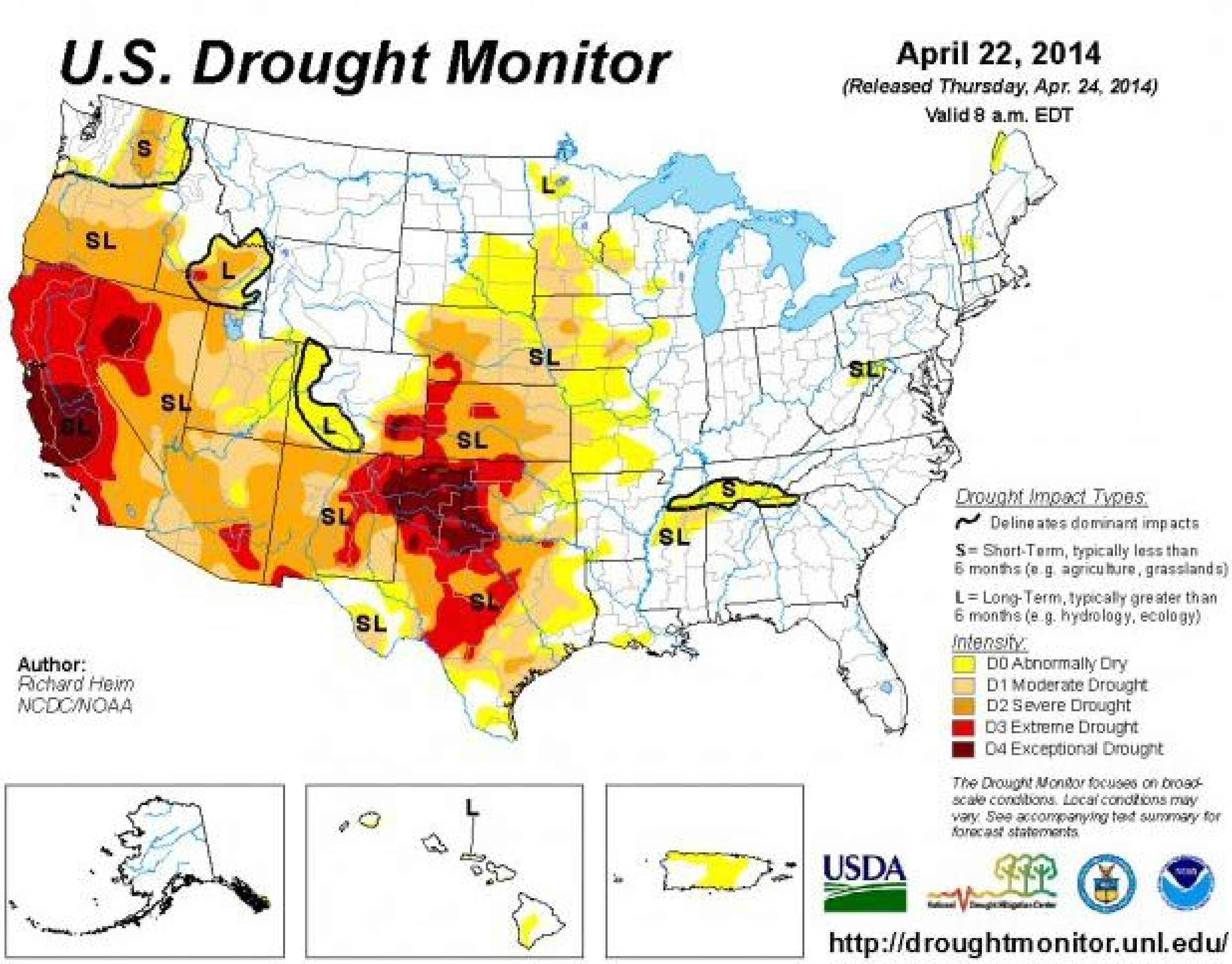
The lack of comparison with other modelling means that the BDCP Central Tendency model has little validation. Approval by biologists is not an acceptable validation procedure.

Recent droughts in California and the Southwest

The Bureau maps are striking, when compared with recent droughts in California and the Southwest. The 2013-2014 California water year has been the second driest in recorded history. The California drought followed a record drought in New Mexico in 2012 and in Texas in 2011. The droughts were exceptional for the combination of record heat and reduced precipitation, and some for unprecedented length.



Source: US Drought Monitor



Source: US Drought Monitor

Richard Seager's climate change team published a study in 2007, "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America."[9] The study by Seager et. al. was consistent with the recent droughts. The authors pointed out that it is not only precipitation changes that affect runoff, but precipitation minus evapotranspiration. Even if precipitation does not change, runoff can decrease due to increased temperatures and increased evapotranspiration. The BDCP EIR/EIS only discusses potential precipitation shifts in California. For this reason, the sensitivity study is inadequate.

Limitations of downscaling method

9 Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America, Richard Seager, Mingfang Ting, Isaac Held, et. al., Science, Vol 316 no. 5828 p. 1181-1184, May 25, 2007. Available at http://www.sciencemag.org/content/316/5828/1181.short

The problems with the BDCP climate change modelling are not limited to the method of generating forcing under global climate change model / greenhouse gas projections.

BDCP is using a bias-corrected method of downscaling. The statistical downscaling has a tendency to reproduce the same frequency and severity of droughts as in the historical period. In an early draft of a 2006 report, one of the modelers for DWR commented,

> "...Furthermore, the method of downscaling global climate model information for CalSim-II input only captures the general trends of average rainfall and seasonal shifts in runoff. There is no information included about changes in weather variability. In each of the scenarios, the frequency and length of the droughts remained the same. If climate change influences these underlying weather phenomena, then we are missing important information necessary to determine impacts to CVP and SWP operations. "

Two studies sponsored by the California Climate Change Center in conjunction with the 2009 and 2012 California Climate Change Assessments, show that the limitations of bias correction using the historical water sequence could be significant. Both studies, using completely independent models, projected increased frequency and severity of droughts in California, based on projected changes in runoff. The studies are described below.

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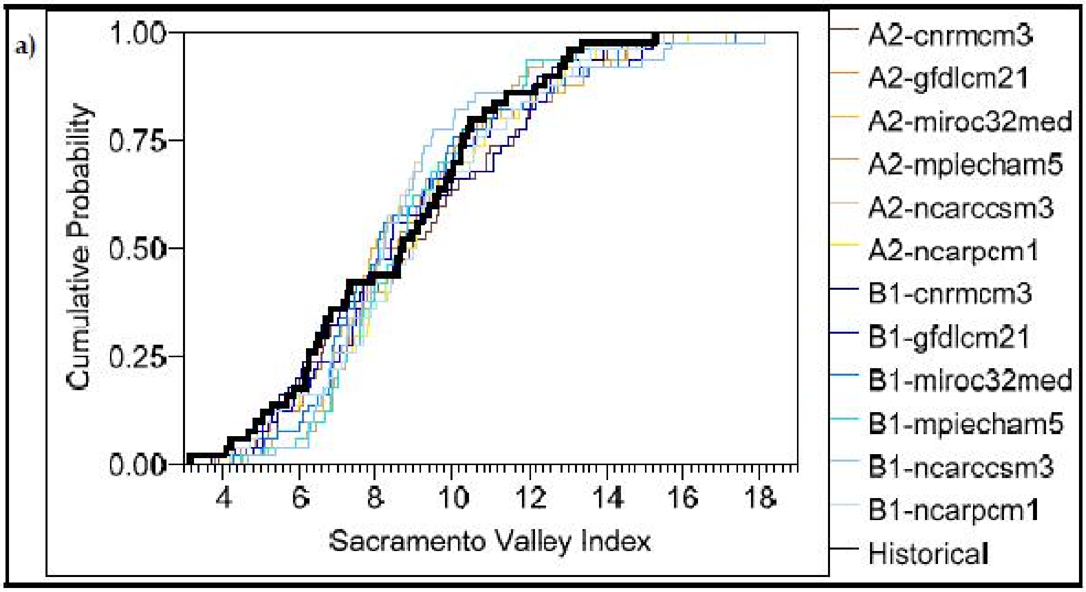
1. Water and Energy Sector Vulnerability to Climate Warming in the Sierra Nevada: Water Year Classification in Non-Stationary Climates, July 31, 2012.

As part of the 3rd California Climate Change Assessment in 2012, the California Climate Change Center released this study by Sarah Null and Josh Viers at UC Davis.

The study used the six global climate models from the second California Climate Assessment, and made projections under the A2 (medium-high) and B1 (low) greenhouse gas emissions scenarios that were used in that assessment. The study also used the same Variable Infiltration Capacity model that DWR used for downscaling in BDCP, with Bias-Corrected Spatial Disaggregation.

The main difference between the non-stationary study and other modeling by the Department of Water Resources, is that the non-stationary study did not correct model outputs to the historical hydrology. Instead, researchers ran the models without climate forcing, and compared the results to the historical hydrology. The graph below shows the cumulative probability of the different models compared with the observed 1951-2000 hydrology.



ANOVA and t-tests using a 95 percent confidence level found that results were not significantly different from historic hydrology. The graph and the statistical tests show that the models do a good job of capturing historic hydrology. This was one of the criteria for model selection for by the California Climate Assessment team.[10]

The results of the models under the A2 and B1 scenarios show a marked shift in climate. Most of the models show major increases in dry and critically dry years, and decreases in wet and below-normal years. The histograms on the next page shows the changes in the frequency of water year types for the Sacramento Valley Index.

All of the models show a significant increase in dry and critically dry years by the latter half of the century, with a corresponding decrease in wet and above normal years. Many of the models also show an increase in dry and critically dry years in the first half.

The table below shows water year types, averaged over all six GCM models, for the two scenarios.

10 Climate Change Scenarios And Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment, A Paper From the California Climate Change Center. Cayan et. al. Incorporated by reference.

Table 6. Percentage of Years in Each Water Type by Modeled Time Period and Emissions Scenario (italicized values are percent change from historical period)

	SVI					
	1951-2000 (%)		2001-2050 (%)		2051-2099 (%)	
	A2	B1	A2	B1	A2	B1
Critical	8.7	8.3	11.3 *(2.7)*	6.7 *(-1.7)*	18.4 *(9.7)*	14.0 *(5.6)*
Dry	7.7	10.0	12.0 *(4.3)*	15.7 *(5.7)*	19.4 *(11.7)*	20.1 *(10.1)*
Below Normal	23.3	21.3	23.3 *(0.0)*	17.3 *(-4.0)*	18.7 *(-4.6)*	19.4 *(-1.9)*
Above Normal	21.0	22.7	16.7 *(-4.3)*	20.7 *(-2.0)*	12.9 *(-8.1)*	18.4 *(-4.3)*
Wet	39.3	37.7	36.7 *(-2.7)*	39.7 *(2.0)*	30.6 *(-8.7)*	28.2 *(-9.4)*

The medium-high emissions scenario (A2) projections showed dry and critically dry years in the Sacramento Valley increasing to 23% of all years between 2000 and 2050, and to 38% of all years in the latter half of the century. Under this scenario, the incidence of dry and critically dry years would more than double.

The projections also showed a decrease in wet years.

In the Sacramento Valley, the A2 projections showed wet and above normal years decreased to 53% of all years in 2000-2050, and to 41.5% of years by the latter half of the century.

The lower greenhouse gas emissions scenario (B1) showed similar but less dramatic shifts.

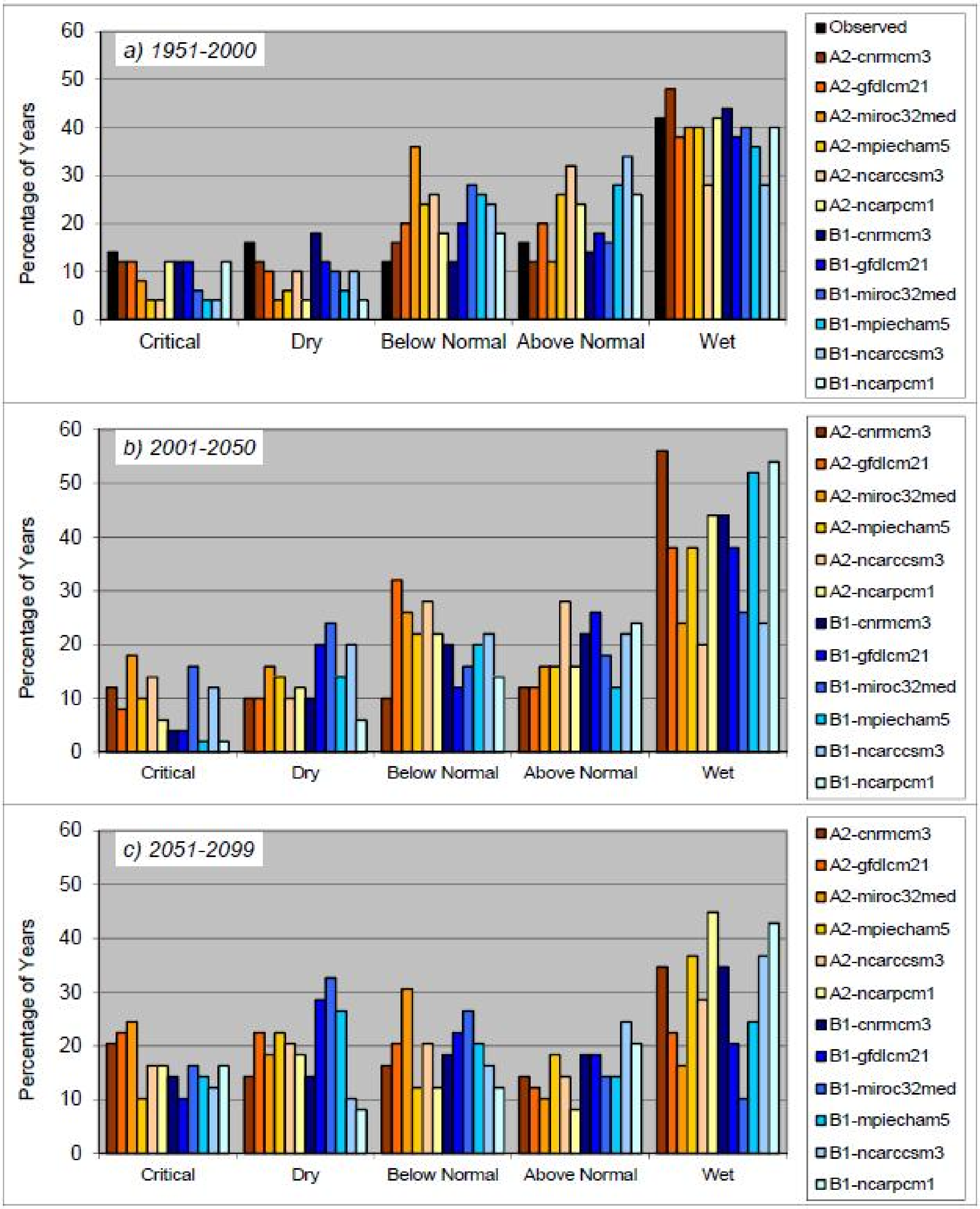
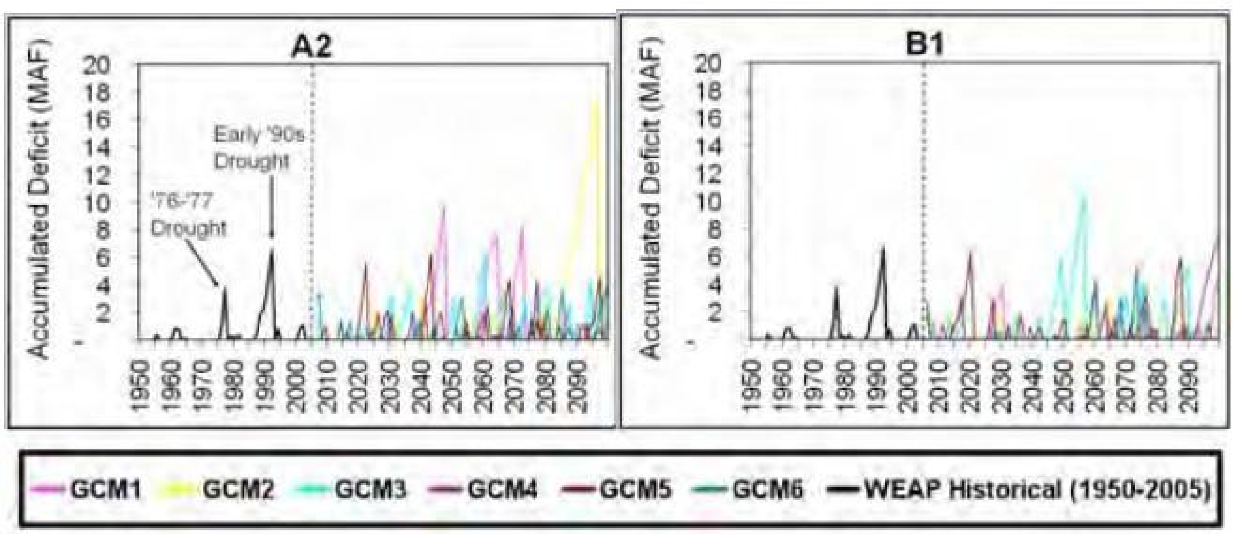


Figure 6. SVI Relative Frequency Histograms for (a) 1951-2000, (b) 2001-2050, and (c) 2051-2099

2. Climate Change Impacts on Water Supply and Agricultural Water Management In California's Western San Joaquin Valley, and Potential Adaptation Strategies, August 2009.[11]

This study, done by Brian Joyce, Vishal Mehta and David Purkey from the U.S. Center for the Stockholm Environmental Institute, Larry Dale from Lawrence Berkeley National Lab, and Michael Hanemann from the California Climate Center, was released as part of the second California Climate Change Assessment in 2009, and used the same set of twelve global climate models / climate change scenarios. The study used an application of the Water Evaluation and Planning (WEAP) system developed for the Sacramento River basin and Sacramento Delta. WEAP is an integrated rainfall / runoff and water resources modeling framework that was developed in Stockholm, and has been used for water resources planning around the world. WEAP has also been used in climate modeling for the 2009 California Water Plan, and is being used in preparing the 2013 California Water Plan.

WEAP has the advantage that it does not rely on perturbation of historical precipitation or runoff patterns for projections. This allows the model to capture major shifts in historical patterns. The study found marked increases in the frequency of droughts, and under the A2 scenario, a mega-drought towards the end of the century. The graph below shows the results for different models.



In sum, two recent studies using two different methods of downscaling showed major changes in

11 Climate Change Impacts on Water Supplies and Agricultural Water Management in the Western San Joaquin Valley and Possible Adaptation Strategies, Brian A. Joyce, Vishal K. Mehta, David R. Purkey, Larry L. Dale, and Michael Hanemann. California Climate Change Center, August 2009. Available at http://www.energy.ca.gov/2009publications/CEC-500-2009-051/CEC-500-2009-051-F.PDF Incorporated by reference.

the structure of droughts in California.   Both indicated an increase in the frequency and severity of droughts.

The BDCP EIR/EIS should specifically address the possibility of increases in drought frequency and severity.   The BDCP EIR/EIS also needs to include more information on projected reservoir levels, export levels, river flows, and Delta outflows in repeats of the 1929-34 drought, as well as the 1987-92 drought.

Currently projected tables of projected reservoir levels, river flows, and Delta outflows only show exceedances for an individual year.

Early BDCP modelling and problems with reservoirs

In 2010, Francis Chung, head of the DWR climate change modelling team, presented results on modeling for BDCP at the California Water and Environmental Modelling Forum at Asilomar.[12]

Chung showed results from a range of models, including the proposed operations under the "Preferred Project" with a 50% probability of excedance of 5.5 MAF/year SWP and CVP exports.   The models showed that there was a significant increase in months with dead storage in North of Delta reservoirs over current conditions.   The Table is reproduced below.

Numbers of Dead Storage Months for North-of-Delta Reservoirs from Climate Change

Scenario	Trinity	Shasta	Oroville	Folsom	Total
D1641	3	6	0	6	15
(+) Wanger with CC	9	24	21	25	79
(+) BDCP with CC	12	21	10	39	82
(+) NODOS with CC	15	24	17	42	98
(+) SOD GW Bank with CC	17	27	23	46	113

Chung concluded:

12 Francis Chung, An Assessment of CVP-SWP Performance Under Alternative Delta Regulations, Infrastructure and Climate Change Scenarios Regarding CAlSiM II, California Water and Environmental Modelling Forum, Feb 22, 2010.   Incorporated by reference. Available at http://www.cwemf.org/Asilomar/FrancisChungCWEMFPres.pdf

"Results appear to be unsustainable. The relative frequency of dead storage conditions in upstream reservoirs indicate that significantly modified operations will be required with climate changed conditions."

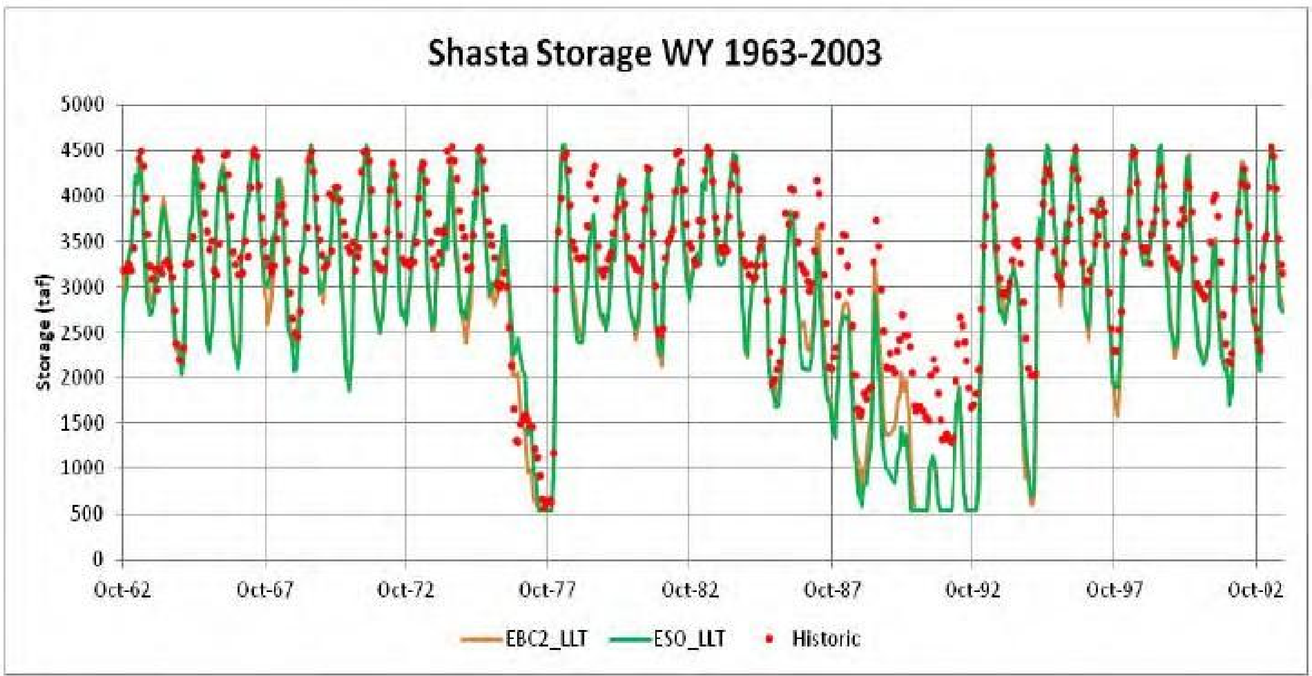
and went on to say

"We recommend that DWR develop a reoperation strategy for the CVP and SWP that includes modified operations scenarios to mitigate the effects of dead storage during climate change conditions prior to release of any studies (either these or BDCP) that include climate change."

This was not done.

Effects on Reservoirs

The proposed reservoir operations under Bay Delta Conservation Plan increase water supply conflicts in prolonged droughts. The reason is that major Sacramento reservoirs are essentially exhausted by the third year of drought.



Graph from BDCP March 2013 Appendix 5.C A., showing water levels in Shasta Reservoir under BDCP Evaluated Starting Operations (ESO), compared with Historic levels (red), Late Long Term (2060)

Brown is Existing Biological Conditions (no tunnel), but with high levels of exports

Simulations show that, by the time there is 18 inches of sea level rise, the proposed operations under the Bay Delta Conservation Plan would drain Shasta and Trinity Reservoirs to minimum pool for many months in a multi-year drought. This would devastate water supplies for Northern California communities, and dry up rivers from Humboldt County south to the Delta, with devastating impacts on fish populations.

The Bay Delta Conservation Plan technical appendix 5.C A does not show sequences of reservoir levels or river levels during multi-year droughts, and so does not adequately disclose potential impacts of the project on the Sacramento Valley.

Reservoir storage constraints and CALSIM code

The BDCP EIR/EIS states that reservoir storage levels under BDCP would not be substantially increased over the No Action alternative. However, the reservoir storage constraints in the CALSIM No Action alternative model appears to have been substantially altered. These alterations must be discussed in the Climate Change technical appendix. The new model also needs to be validated.

In particular, the projected upstream reservoir operations during droughts appear to be inconsistent with actual operations of the reservoirs. The reservoirs were operated conservatively in the 2013-2014 to protect storage, not drained to minimum pool.

Salinity intrusion

Although the Bay Delta Conservation Plan is presented as a solution to sea level rise in the Delta, there are no simulations of the operations of the proposed project under higher levels of sea level rise, nor under conditions of levee failure. Nor do the proposed habitat restoration plans take into account the potential salinity intrusion.

Recent modelling by the Army Corps of Engineers[13] shows the potential extent of salinity intrusion in the Delta under higher sea level rise scenarios. The maps show high levels of salinity going up the Sacramento River as far as Rio Vista (see below).

This salinity intrusion is without increased diversions on the Sacramento River. Such diversions would likely pull salt water up to the vicinity of the proposed tunnel intakes.

In addition, the impacts of salinity intrusion from proposed tunnel diversions and multi-year droughts are inadequately analyzed. Again, the diversions could pull salt water up to the vicinity of the proposed tunnel intakes.

The BDCP EIR/EIS sensitivity analysis does not look at an adequate number of spatial locations to estimate the effects of sea level rise and increased diversions on the Sacramento River.

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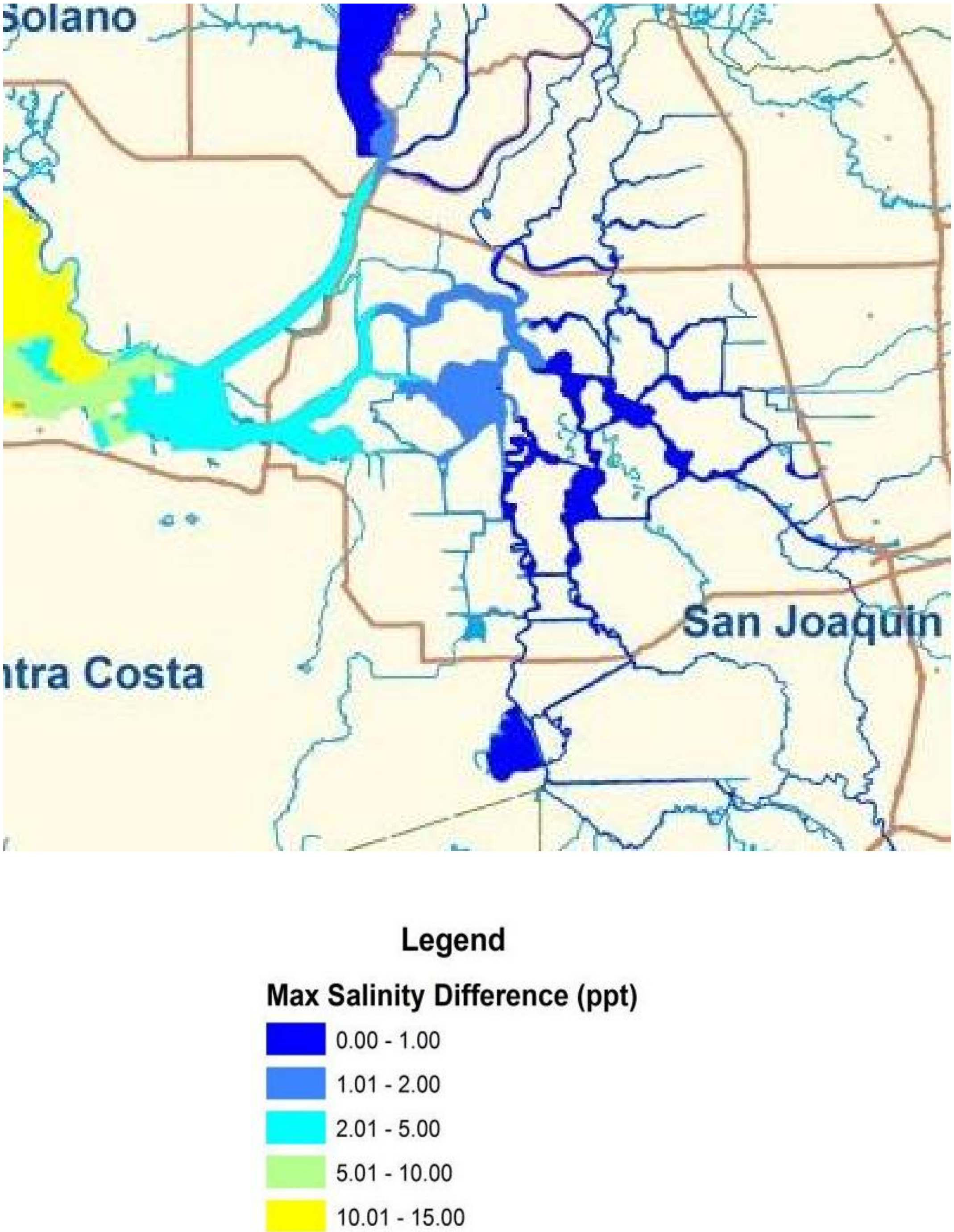
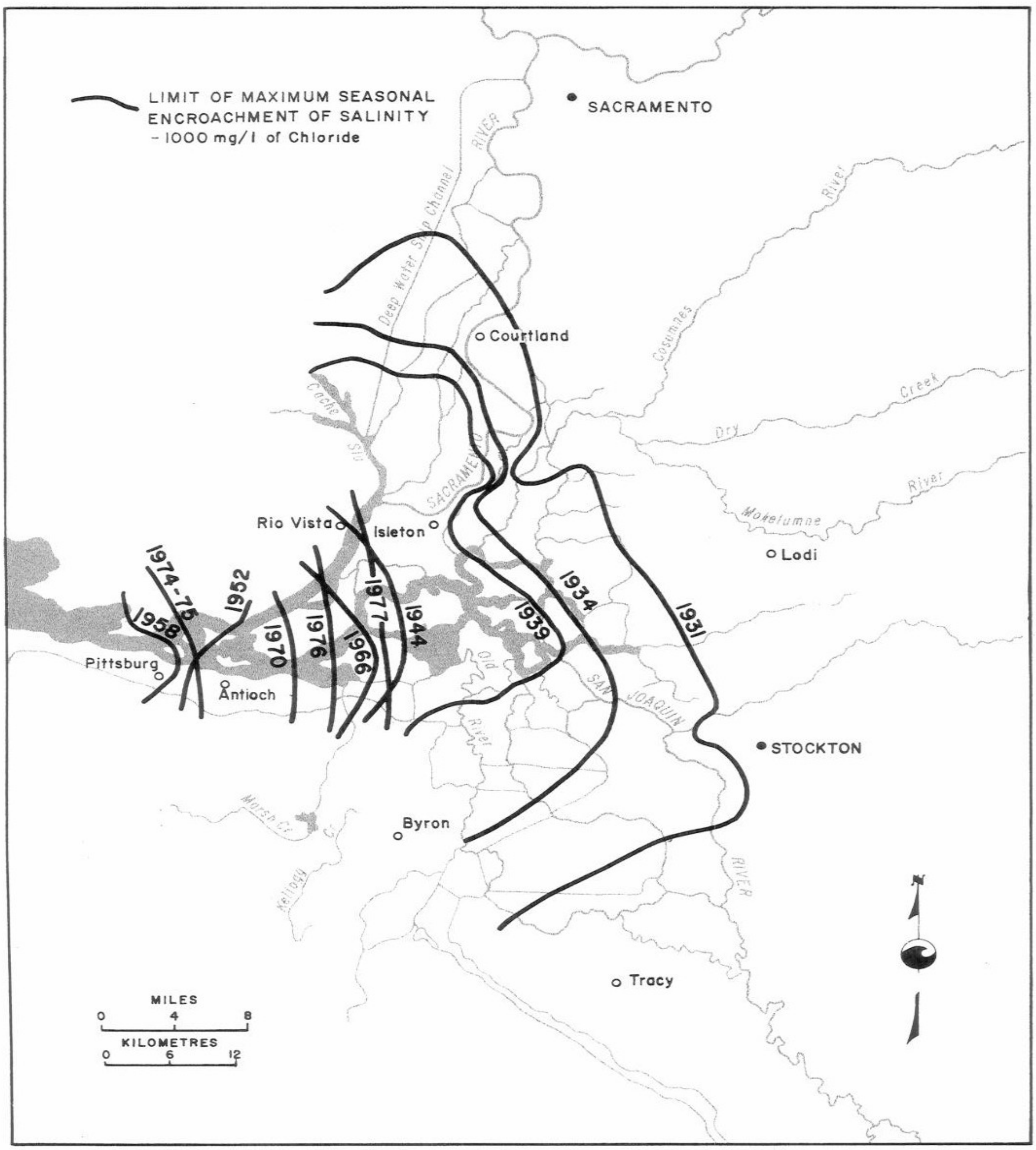
13 Lu, S., P. Craig, C. Wallen, Z. Liu,A. Stoddard, W. McAnnally and E. Maak
Dynamic Solutions modelling for Army Corps of Engineers Presented at 2012 CWEMF Forum. Incorporated by reference.



Salinity intrusion under high levels of sea level rise (1.68 m), by 2100

From Lu, S., P. Craig, C. Wallen, Z. Liu,A. Stoddard, W. McAnnally and E. Maak
Dynamic Solutions modelling for Army Corps of Engineers
Presented at 2012 CWEMF Forum

Figure 16.
SALT-WATER INTRUSION IN THE SACRAMENTO-SAN JOAQUIN DELTA



Salinity intrusion during historical droughts

From The 1976-77 California Drought: A Review, Department of Water Resources, 1978 incorporated by reference

Appendix A

Historical droughts in the Sacramento River basin

Sacramento River Multi-year Droughts since 1906		
Years	Length	% of avg flow
2007-2009	3	62%
2001-2002	2	68%
1987-1992	6	56%
1976-1977	2	37%
1959-1961	3	69%
1947-1950	4	73%
1929-1935	6	60%
1923-1926	4	65%
1918-1920	3	67%
1912-1913	2	68%

Source: California Water Research

Since records started in 1906, there have been two severe, long-term droughts in the Sacramento River basin. The most recent was the six year drought from 1987 to 1992, when the river flow was a little over half of normal.

Some droughts can be significantly longer, or can occur in clusters. The dust bowl era from 1923 to 1934 saw two prolonged droughts back to back, with only one normal and one wet year in between. The twelve year average flow was 26% below normal.

Pre-1906 droughts in the Sacramento Valley

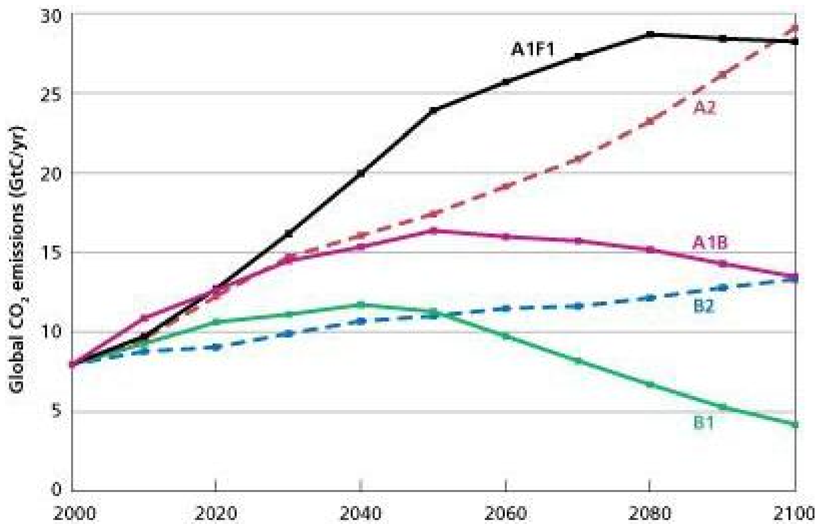
David Meko at the University of Arizona estimated Sacramento River flows from tree ring cores, back to 901 A.D. The reconstructed flows show 23 droughts in the last 1100 years with a six year average flow below 80% of normal. So we would expect about two droughts per century that are six years or longer. The reconstructed flows also show seven mega-droughts that have lasted for 12 years or more in the last 1100 years. So we'd expect one mega-drought of 12 years or longer every 150 years.

Tree ring data from many areas in the Western U.S. show that some centuries have been far drier than average. The Medieval mega-drought was a series of prolonged dry periods between 1100 and 1400. Research has linked the Medieval mega-drought to a warmer climate from increased solar activity.

Appendix B

Climate Change Scenarios and Predicted Hydrology

The graph below shows C02 emissions under the different scenarios from the IPCC [Special Report on Emissions Scenarios](#).



The A2 scenario is a medium-high emissions scenario. It is was one of two emissions scenarios chosen for modelling for California's 2009 Climate Adaptation Strategy, as well as modeling for the 2008 OCAP assessment, and modelling by the Stockholm Environmental Institute in collaboration with researchers at UC Berkeley and the California Climate Change Center.[14] The A2 scenario has continuously increasing population, and regionally oriented economic development.

The A2 scenario has slower growth in C02 emissions than the A1 scenarios. It appears to be less likely than the A1FI scenario under the current economic and political trajectory, but much more likely than the environmentally friendly B1 and B2 scenarios, described below. In California, most global climate models run with the A2 scenarios show frequent droughts in mid-century, and reductions in precipitation, but some show precipitation increase.

The other scenario used in the California Climate Adaption Strategy was the B1 scenario, which has decreasing emissions after mid-century. The B1 scenario assumes rapid changes towards resource efficient technologies, and population declining after 2050. Some of the B1 scenarios show modest drying, others show a modestly wetter climate.

In addition to the A2 and B1 scenarios, two other scenarios are commonly used in climate

14 D.R. Purkey & B. Joyce et. al., Robust analysis of future climate change impacts on water for agriculture and other sectors: a case study in the Sacramento Valley, Climate Change 87 (Suppl. 1) S109-S122 Incorporated by reference. Available at http://meteora.ucsd.edu/cap/pdffiles/Purkey_sacvalley_jan2008.pdf.

modeling, and were included in the Lawrence Livermore ensemble of models used in BDCP.

The A1Fi scenario is the scenario with the highest growth in emissions. While it was not included in the California Climate Adaptation Strategy modelling, it has been used by researchers in modelling impacts on water supply in California because it is closest to the growth in GHG emissions from 2000-2007. The A1Fi scenario assumes rapid economic growth, with an emphasis on fossil fuels. A1Fi was used in modelling by David Purkey of the Stockholm Environmental Institute, cited above. [15]

Modelling using A1FI shows strong warming and drying. The Stockhom Environmental Insitute models used by David Purkey showed frequent droughts in mid-century, on the order of the 91-92 drought, as well as marked reductions in precipitation.

The B2 scenario was not included in the California Climate Change modelling. It assumes local economic growth and slowly increasing population, but has been used in ensemble modeling by the Department of Water Resources. The B2 model is not in agreement with current population growth.

15 Ibid.