# Climate and Water Supply in the Santa Ana River Watershed

SAWPA

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### Key Findings

- Annual surface water is likely to decrease over the future periods.
- Precipitation shows somewhat-long term decreasing trends.
- Temperature will increase, which may cause increased water demand and reservoir evaporation.
- April 1st SWE will decrease.

## Results

**Will surface water supply decrease?**

Change analysis between the base reference period (1990s) and three future periods (2020s, 2050s, 2070s) was conducted for precipitation, temperature, April 1st Snow Water Equivalent (SWE), and flow at 36 sites throughout the basin. Figure 1, a summary at the Prado Dam Gage, shows the ensemble median change for precipitation is likely to increase by <1% over the basin during the 2020s, followed by a 5% in the 2050s, with increased decline through the 2070s (8%). Temperature ensemble median changes for the 2020s, 2050s, and 2070s show increasing temperatures throughout of 1.22°F, 3.11°F, and 4.10°F respectively. Spatial distribution of April 1st SWE shows a persistent decline through the future decades at 39% for 2020s, 80% for 2050s, and 93% for the 2070s.

Figure 2 shows annual seasonal streamflow impacts at Prado Dam Gage. The 2020s show an increase in annual runoff and winter runoff, while spring runoff will likely decrease. The 2050s and 2070s show a decrease in annual, winter, and spring runoff.

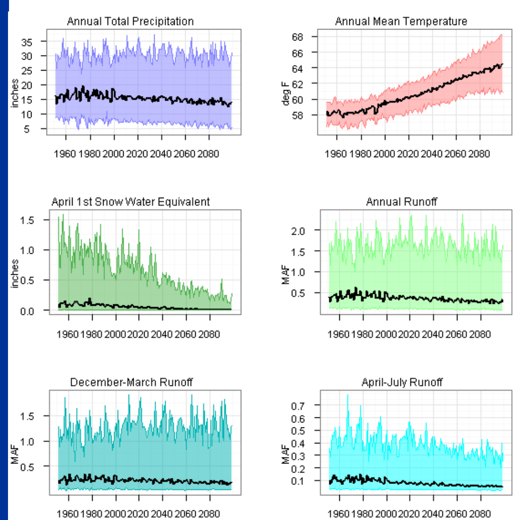


Figure 1 - Hydrology projections at Prado Dam Gage for P, T, SWE., and Flow, solid line is median, 5th and 95th percentile bounds

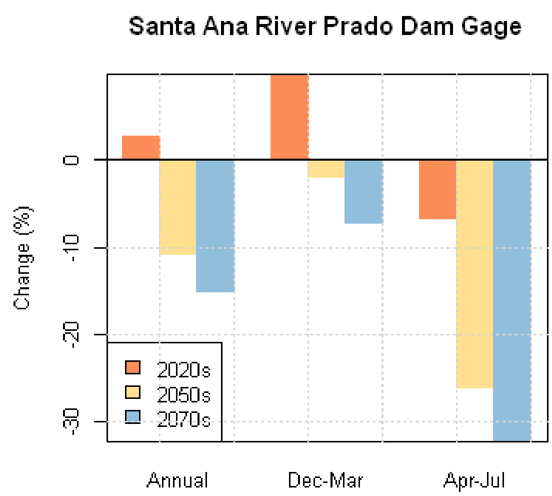


Figure 2 - Annual and seasonal streamflow impacts at Prado Dam Gage

## Methods

The Variable Infiltration Capacity (VIC) model was used to project streamflow for 112 different climate change projections. Daily precipitation, minimum temperature, maximum temperature, and wind speed came from the BCSD-CMIP3 archive. Modeled historical data from 1950-1999 came from Maurer et al. 2002, and subsequent extensions. For each grid cell daily forcings start on January 1, 1950 and run to December 31, 2099. Flow direction files and fractions were developed on a 1/8° x 1/8° (~12 km x 12km) grid. Through coordination with SAWPA key locations in the basin were determined, so that sub-basins could be delineated. Change factors were developed by calculating decade mean total precipitation and temperature, then calculating percent change, and finally calculating the median change for all the 112 projections.

### Additional Considerations

- VIC was an existing model and no refinements were made for this analysis.
- The model is calibrated to reproduce monthly to annual runoff in large sub-basins.
- These models have biases, and are best used for relative change.

Link to full technical report—http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Groundwater Supply in the Santa Ana River Watershed

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### Key Findings

- Groundwater currently provides approximately 54% of total water supply in an average year, and groundwater use is projected to increase over the next 20 years.
- Projected decreases in precipitation and increases in temperature will decrease natural recharge throughout the basin.
- Management actions such as reducing municipal and industrial water demands or increasing trans-basin water imports will be required in order to maintain current groundwater levels.
- A basin-scale groundwater screening tool was developed to facilitate analysis of basin-scale effects of conservation, increasing imported supply, changing agricultural land use, and other factors on basin-scale groundwater conditions.

### Additional Considerations

- Basin-scale groundwater conditions are an important consideration in basin management; however, local-scale groundwater conditions must be considered in evaluating individual projects.
- The groundwater screening tool does not reflect physical constraints on groundwater use, including the usable amount of groundwater available and decreases in pumping as groundwater levels decline.

## Results

**Will climate change reduce groundwater availability in the Santa Ana watershed?**

Future groundwater availability in the Santa Ana watershed will depend on future recharge from precipitation, stream seepage, and managed infiltration facilities, as well as future groundwater withdrawals to for municipal, industrial, and agricultural uses. A groundwater screening tool was developed to evaluate changes in basin-scale groundwater conditions under climate change. Projected increases in temperature and decreases in precipitation will result in increased water demands and decreased groundwater recharge, respectively. Management actions will be required to protect groundwater resources under projected future climate conditions.

Figure 1 illustrates the observed range of basin-averaged groundwater levels in the Orange County groundwater basin for 1990-2009, along with simulated groundwater levels under projected climate conditions. In the absence of groundwater management actions, groundwater levels are projected to decline significantly over the 21st century. It should be noted that projected declines are not constrained by the physical limits of the aquifer—i.e., projected declines may exceed the actual amount of usable groundwater in the basin.

The groundwater screening tool can be used to evaluate potential deficiencies in future supplies and to develop sustainable management alternatives. As an example, potential actions to avoid projected water level declines in Orange County are listed below. Each of the alternatives listed will protect against groundwater declines through 2060. The groundwater screening tool can be used to develop and compare additional management alternatives.

*Projected Impacts of Climate Change on Orange County*

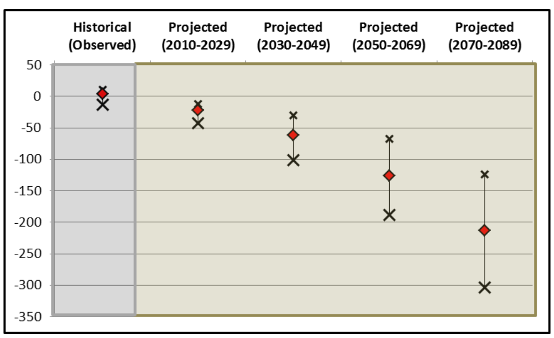


Figure 1 - Range of observed and simulated basin-averaged groundwater elevations for 1990-2009 and projected groundwater elevations for future periods assuming no management action to avoid groundwater deficits

*Groundwater Management Alternatives to Offset Projected Impacts of Orange County Groundwater*

- **Reduce M&I demand**
  Gradual reduction of approx. 15% by 2020 (i.e., reduce per capita use from ~175 gpd in 2010 to ~150 gpd by 2020)
- **Increase imports from Colorado River and SWP**
  Gradual increase in water imports from Colorado River and SWP from ~30,000 AF/yr to ~105,000 AF/yr by 2020 (this may not be feasible due to cost, greenhouse gas emissions, or availability)
- **Increase local water supplies**
  Increase local water supplies by ~75,000 AF/yr through increasing recycled water treatment capacity, development of seawater desalination capacity, and increase storm water capture efficiency

## Methods

A basin-scale groundwater screening tool was developed to facilitate evaluation of basin-averaged groundwater elevations under projected future climate conditions. The tool uses a multiple regression approach to estimate fluctuations in basin-averaged groundwater elevations in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports. The tool allows users to quickly calibrate a regression model for a basin of interest, estimate basin-scale groundwater conditions under future scenarios, and compare management alternatives to protect groundwater resources under climate change.

Link to full technical report—http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Recreation in the Santa Ana River Watershed

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## Results

**Is Lake Elsinore in danger of drying up?**

Lake Elsinore, shown in Figure 1, is southern California's largest natural lake and is situated at the bottom of the San Jacinto Watershed. Because Lake Elsinore is a terminal lake, fed only by rain and natural runoff, it has been impacted by low lake levels. In 2005, Elsinore Valley Municipal Water District (EVMWD) began a two year project to introduce recycled water into Lake Elsinore to stabilize lake levels. The project delivers approximately 5 MGD of recycled water to Lake Elsinore, and includes repair and retrofit of three local, shallow groundwater wells that deliver approximately 1 MGD. An analysis was done to determine if these measures would be enough to meet the minimum goal volume of 41,704 acre-ft (elevation of 1,240 ft), avoid low lake levels (below 24,659 acre-ft, elevation of 1,234 ft), or prevent the lake from drying up all together (as occurred in the 1930s).

Figure 2 shows the distribution of projected average annual volume for two future periods, 2000-2049 and 2050-2099, based on 112 different climate change projections. The two future periods where also analyzed with the addition of the EVMWD project. For the 2000-2049 period there is a >50% chance that the average annual lake level will meet the minimum goal, adding in the EVMWD project brings that likelihood up to >75%. For the 2050-2099 period there is a <5% chance that the minimum goal will be met, adding the EVMWD project brings that up to a >25% chance. Both periods are likely to stay above low lake level, with the 2050-2099 period having <10% chance of drying up completely.


Figure 1 - VIC model grid cell used to determine data for Lake Elsinore analysis

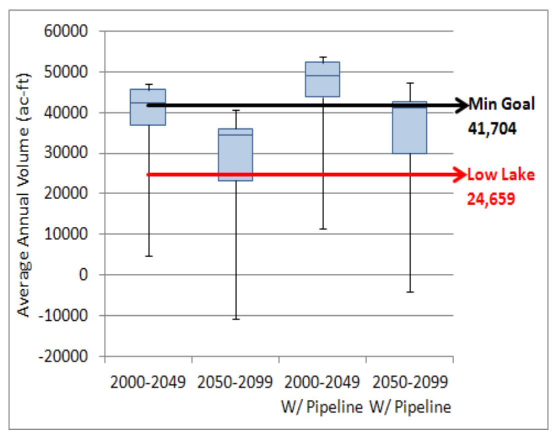


Figure 2 - Boxplot of projected average annual volumes for two future periods, with and without EVMWD project

### Key Findings

- Lake Elsinore has less than a 10% chance of drying up.
- In the future period 2000-2049 Lake Elsinore has a >75% chance of meeting the minimum elevation goal.
- In the future period 2050-2099 Lake Elsinore has a >25% chance of meeting the minimum goal elevation.
- There is <25% chance that Lake Elsinore will drop below low lake levels in either period.
- The EVMWD project does aid in stabilizing lake levels, however, for the period 2050-2099 additional measures will likely be required to meet the minimum goal elevation.

### Additional Considerations

- Operations of Canyon Lake, a reservoir upstream from Lake Elsinore, were not taken into account in this analysis.
- In addition to lake level stress, Lake Elsinore has many water quality issues.
- Lake Elsinore is not used as a drinking water source.

## Methods

Monthly streamflow and open water evaporation values from 1950-2099 were determined by using BCSD-CMIP3 climate projections and the Variable Infiltration Capacity (VIC) macro-scale hydrology model. Historical observed data from 1950-1999 were modeled using the gridded daily data set from Maurer et al. 2002. The upstream contributing basin was determined at the inlet to Lake Elsinore, excluding the effect of any upstream regulation.

A mass balance analysis of Lake Elsinore was conducted, resulting in a natural (unregulated by upstream reservoirs) volume. Change values were determined for each future period using modeled observed average annual volume applied to historic annual average volume.

Link to full technical report—http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

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# Climate and Forest Ecosystems

### Key Findings

- Warmer temperatures will likely cause Jeffrey pines to move to higher elevations and may decrease their total habitat.
- Forest health my also be influenced by changes in the magnitude and frequency of wildfires or infestations.
- Alpine ecosystems are vulnerable to climate change because they have little ability to expand to higher elevations.
- Across the state it is projected that alpine forests will decrease in area by 50-70% by 2100.

### Additional Considerations

- The rate of climate change determines how quickly ecosystems must adapt and influences the total impact.
- There is significant uncertainty about the role of increased $CO_2$ levels on forest productivity.
- In general predictions about forest productivity are uncertain and will rely mainly on future precipitation.
- Most available research has focused on the state of California as a whole and no studies explicitly consider the future of Jeffery Pines or alpine ecosystems within the SAWPA area.

## Results

**Projected climate change impacts on forest ecosystems:**

While there is significant variability between climate change scenarios, all projections include increased temperature and increased levels of atmospheric carbon dioxide. As a result, the following general trends are predicted:

- ♦ Warmer temperatures will cause trees to move northward and to higher elevations
- ♦ Changes in total forest cover for California are projected by one study to range from a 25% decrease to a 23% increase by 2100 (Lenihan et al., 2008)
- ♦ Species with the smallest geographical and climate ranges are expected to be the most vulnerable to change
- ♦ Extended droughts and earlier snowmelt could cause fire season to start earlier and last longer (California, 2010)
- ♦ Temperature increases may change the frequency and magnitude of pest infestations such as the pine beetle

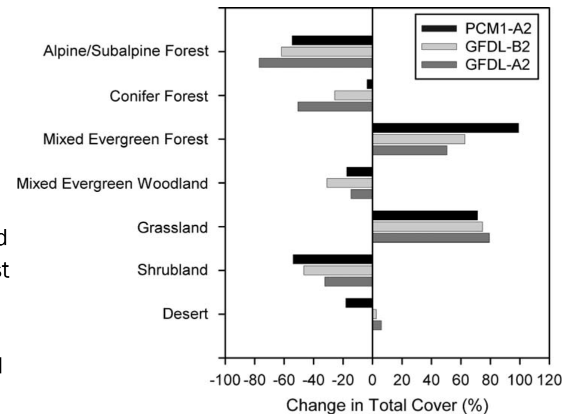


Figure 1 - Fig. 4 from Lenihan et al. 2008. Percent change in total land cover for vegetation classes by 2010 for three climate change scenarios predicted using the MC1 Dynamic Vegetation Model.

**How will the Jeffrey Pine ecosystem be impacted?**

The Jeffery Pine is a high altitude Coniferous evergreen tree that can occupy a range of sites and climate conditions (Moore, 2006). Based on the general trends noted above it is likely that the Jeffery Pines will migrate to higher elevation and some lower elevation forest area will be lost. Several studies predict that warming temperatures will result in the displacement of evergreen conifer forests by mixed evergreen forests across California (Hayhoe et al., 2004; California, 2010). However, no study has explicitly considered the migration of the Jeffery pine. Given its versatility it is possible that impacts to the Jeffery pine may be less than some other species.

**Will the Region continue to support an alpine climate in the local mountains?**

Alpine ecosystems are particularly vulnerable to increased temperatures because their habitat range is already limited and they cannot shift to higher elevations. One study projects that Alpine and subalpine forests will decrease in area by 50-70% by 2100 (Hayhoe et al., 2004).

## References


California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. 2010. *California's Forests and Rangelands: 2010 Assessment.* Chapter 3.7. http://frap.fire.ca.gov/assessment2010.html.

Hayhoe, K. et al. 2004. *Emissions pathways, climate change, and impacts on California.* PNAS, 101:34, pp 12422-12427.

Lenihan, J. M., D. Bahelet, D. P. Nielson, R. Drapek. 2008. *Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California.* Climate Change, 87 (supply 1), pp. S215-S230. Doi 10.1007/s10584-007-9362-0.

Moore, L. M. 2006. *Jeffrey Pine Plant Guide.* United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS)


Link to full technical report-http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Snowpack at Big Bear

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## Results

**Will skiing at Big Bear be sustained?**

It is likely that future snowpack at Big Bear will be significantly less than what is currently normal and accumulated snowpack will remain on the ground for a shorter season. Projected declines in April 1st snowpack are between 30% and 40% by the 2020s and are generally projected to be greater than 70% by the 2070s. These changes are largely a result of increased winter temperatures and potential declines in winter precipitation. Warmer temperatures will result in a delayed onset of the ski season as well as earlier spring melting. Future precipitation is much more uncertain but many projections show decreased winter precipitation. Lower altitudes will likely be the most sensitive to increased temperature because small temperature changes can results in precipitation falling as rain rather than snow. Hayhoe et al. (2004) note that reductions in SWE are most pronounced below 3,000 m where roughly 80% of California's snowpack storage currently occurs. The Big Bear and Snow Summit ski areas both fall between roughly 2,100 and 2,600 m, making them vulnerable to increased temperatures.

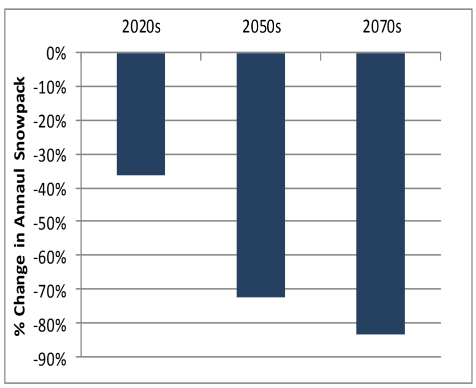


Figure 1 - Median percent change (from 112 climate scenarios) in April 1st SWE for the grid cells containing the Big Bear and Snow Summit ski areas

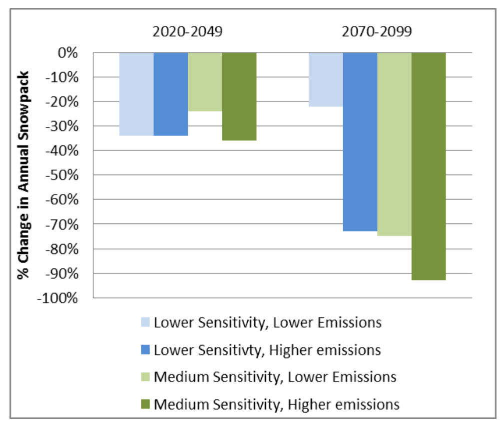


Figure 2 - Percent change in April 1st snowpack (SWE) from Hayhoe et al. (2004). for areas of 2,000 to 3,000 m elevation

### Key Findings

- Simulations indicate significant decreases in April 1st snowpack that amplify throughout the 21st century.
- Warmer temperatures will also result in a delayed onset and shortened ski season.
- Lower elevations are most vulnerable to increasing temperatures.
- Both Big Bear and Snow Summit lie below 3,000 m and are projected to experience declining snowpack that could exceed 70% by 2070.

### Additional Considerations

- Downscaled climate variables can be biased and there is significant variability between projections. For example, note that the low sensitivity low emissions scenario in Figure 2 projects only a 20% decrease in snowpack by 2070 while the other scenarios project greater than 70% decreases.
- The grid resolution for both methodologies is 1/8th degree which is much larger than either ski area and therefore results have been averaged over the ski area in addition to surrounding areas at lower elevation.

## Methods

April 1st Snow Water Equivalent (SWE) values from 1950 to 2099 are generated for 112 CMIP-3 climate projections using the VIC model forced with downscaled climate variables. Each climate projection has 1/8th degree x 1/8th degree (~12 km x 12km) grid cell daily forcings. For this analysis the locations of the Big Bear and Snow Summit ski areas were mapped the single grid cell that contained them. Results summarize the median change (take from the 112 projections) in April 1st SWE compared to the 1990s.

Results are also provided from a study of climate change impacts in California. Hayhoe et al. (2004) analyzed climate change scenarios. They use climate forcing data generated with two climate models of low (Parallel Climate Model, PCM) and medium (Hadley Center Climate Model version 3, HadCM3) sensitivity, forced using two emissions scenarios, one lower (B1) and one higher (A1fi). SWE results were generating using the VIC model forced with the bias-corrected and spatially downscaled temperature and precipitation. Results are provided on a statewide basis grouped by elevation


Hayhoe, K. et al. 2004. *Emissions pathways, climate change, and impacts on California.* PNAS, 101:34, pp 12422-12427.


Link to full technical report-http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Temperature in the Santa Ana River Watershed

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## Results

**How many more days over 95°F are expected in Anaheim, Riverside and Big Bear City?**

Figure 1 shows the distribution of the annual number of days above 95°F from 1950-2099 for each of the cities for all 112 climate projections. As shown here, there is a clear increasing trend in the number of days above 95°F for all three locations. Riverside has the most days followed by Anaheim. Big Bear City has the least number of days with a median of zero for all years prior to about 2030. The red shading in Figure 1 shows the range of the 112 climate projections and demonstrates a large spread in projected results. Table 1 summarizes the median number of days above 95°F for each location for the historical time period (1951-1999) and three 30 year future time periods centered around 2020, 2050 and 2070. As shown in Table 1 the number of days increases for all stations as you move further into the future. Changes are quite significant; for example, the median value for Anaheim quadrupled from 4 to 16 days between the historical time period and 2070. Similarly the median value for Riverside nearly doubled between the historical time period and 2070 going from 43 to 82 days.

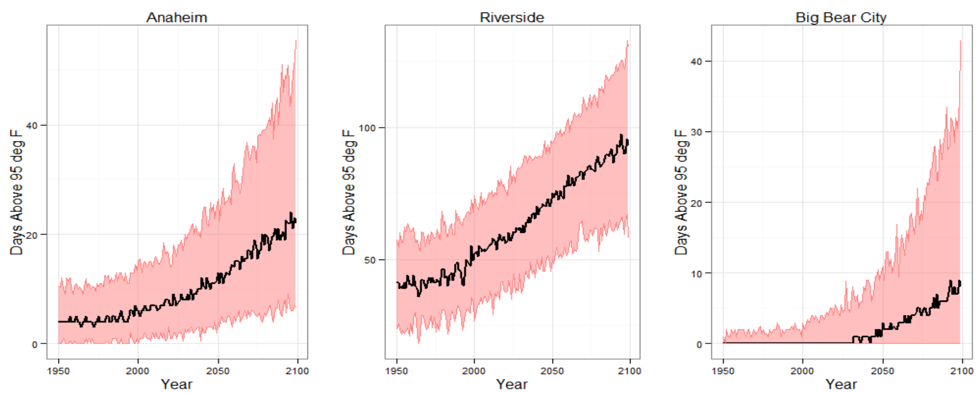


Figure 1 - Projected annual number of days above 95°F. Solid black line is the median and the red shading denotes the 5th and 95th percentile bounds

| | Historical | 2020 | 2050 | 2070 |
|---|---|---|---|---|
| Anaheim | 4 | 7 | 12 | 16 |
| Riverside | 43 | 58 | 72 | 82 |
| Big Bear City | 0 | 0 | 2 | 4 |

Table 1 - Median annual number of days above 95°F for one historical (1951-1999), and three future (2005-2034, 2035-2064, 2055-2084) time periods

## Methods

Daily maximum temperature values came from the BCSD-CMIP3 archive for 112 climate projections. Each projection has 1/8° x 1/8° (~12 km x 12km) grid cell daily forcings that start on January 1, 1950 and run to December 31, 2099. For this analysis the location of each city was matched to the single grid cell that contains it. Results summarize temperature trends for all 112 projections from 1950 to 2099 for the selected grid cell.

### Key Findings

- All of the climate projections demonstrate clear increasing temperature trends.
- Increasing temperatures will result in a greater number of days above 95°F in the future.
- The number of days above 95°F gets progressively larger for all stations as you move further into the future.
- By 2070 it's projected that the number of days above 95°F will quadruple in Anaheim and nearly double in Riverside . Big Bear City is projected to increase from 0 days historically to 4 days in 2070.
- Although there are clear trends in the median values, the spread of results (shown by the red shading in Figure 1) is also quite large.

### Additional Considerations

- Results are shown for the single grid cell where the city is located. Additional analysis could consider regionally averaged temperature trends.
- Downscaled climate variables can be biased . Reported temperature values were not bias corrected to match projected historical values to local temperature gages.

Link to full technical report-http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Flood Frequency in the Santa Ana River Watershed

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## Results

**Will floods become more severe and threaten flood infrastructure?**

It is projected that floods will be more severe in the future. Figure 1 shows the distribution of 200 year flood estimates for the Prado Dam gage based on results from 112 CMIP-3 climate change projections. As shown here, the median 200 year flood value is projected to increase significantly in all future periods (from ~134,000 cfs in the historical period to ~239,000 cfs in the last future period (2055-2084)). However, there is significant variability between projections so there are cases where the 200 year flood intensity is projected to decrease.

**Are dams sufficiently sized for the 200 year storm, or does the risk level increase?**

The risk level is expected in increase significantly. Figure 2 shows the distribution of return periods for the median 200 year historical flood estimate (~134,000 cfs). In all future periods the median return period for the historical 200 year flood is decreased significantly (~80 years by 2020 and 2050 and ~70 years by 2070). This indicates an increase in the risk of a 200 year and larger storm events and potential for negative impacts to infrastructure. This same point can also be seen in Figure 1 with the increased flow values for a 200 year event. However, once again it should be noted that there is significant variability in results. While the median indicates a decrease return period for the historical 200 year flow value, there are outlying simulations where the return period increases.

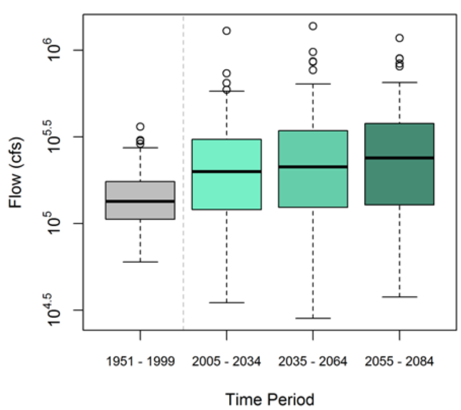


Figure 1 - Boxplot of 200 year flood estimates from 112 climate projections at the Prado Dam Gage

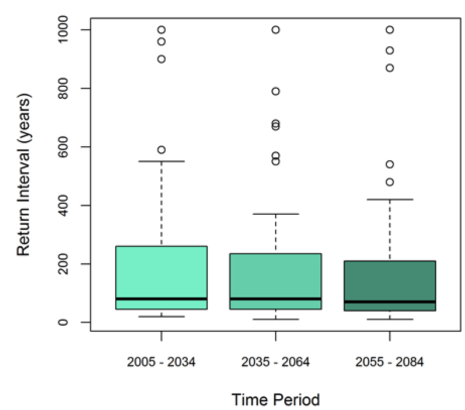


Figure 2 - Boxplot of return intervals for the median 200 year historical flood (134,000cfs) at the Prado Dam Gage

## Methods

Daily stream flow values from 1950 to 2099 are generated for 112 CMIP-3 climate projections using the VIC model forced with downscaled climate variables. Flood frequencies are estimated following the method outlined in Bulletin 17-B published by the Interagency Advisory Committee on Water Data (1982). For this methodology, annual one-day flow maximums are generated and fit to a log-Pearson III distribution for each time period and climate scenario using the L-moments approach. Using the parameters for the log-Pearson III distributions, the 200 year return period flow value are estimated for every climate simulation and analysis period. The distribution is also used to calculate the return period for the median historical 200 year flood for each climate simulation and future time period.

### Key Findings

- Simulations indicate a significant increase in flow for 200 year storm events in the future.
- Similarly the likelihood of experiencing what was historically a 200 year event will nearly double (i.e. the 200 year historical event is likely to be closer to a 100 year event in the future).
- Findings indicate an increased risk of severe floods in the future.
- There is large variability between climate simulations.
- Although there are clear trends in the median values, the range of flows is also large.

### Additional Considerations

- Results are demonstrated for the Prado Dam gage but they can be easily replicated for other locations.
- Future work should expand this analysis to consider floods of different return periods as well as longer flood durations.
- Pearson Log III distributions were fit for this analysis, however, other extreme value functions may also be relevant (e.g. distributions with time varying parameters) .

Link to full technical report-http://www.usbr.gov/lc/socal/basinstudies/OWOW.html

# Climate and Sea Level Rise in the Santa Ana River Watershed

## Results

**Will climate change contribute to sea level rise (SLR)?**

Increasing temperatures will melt ice sheets and glaciers and cause thermal expansion of ocean water, both of which will increase the volume of water in the oceans and thus contribute to global mean sea level rise (SLR). Regional SLR may be higher or lower than global mean SLR due to regional changes in atmospheric and ocean circulation patterns. Figure 1 shows the range of projected global mean SLR by 2100. Regional mean sea level along the Southern California coast is projected to rise by 40-300 mm (1.5-12 in) by 2030, 125--610mm (5-24 in) by 2050, and 405-1675 mm (16-66 in) by 2100.

**How will climate change and SLR affect coastal communities and beaches in Southern California?**

Inundation due to SLR is likely to reduce the area of beaches and wetlands along the Southern California coast. In addition, SLR is likely to increase erosion of sea cliffs, bluffs, sand bars, dunes, and beaches along the California coast. However, the overall effects of climate change on local beaches will depend on changes in coastal ocean currents and storm intensities, which are less certain at this time.

SLR is likely to increase the coastal area vulnerable to flooding during storm events. Figure 2 shows the areas of Orange County that are currently vulnerable to inundation due to a 100-year flood event (blue) and areas that will be vulnerable to inundation with a 1400 mm (55 in) rise in mean sea level (source: http://cal-adapt.org/sealevel/).

**Will SLR increase seawater intrusion into coastal aquifers?**

Detailed analysis carried out by Orange County Water District found that the Talbert Barrier would be effective at preventing seawater intrusions through the Tablert Gap under a 3-foot sea level rise. In the case of the Alamitos Barrier, seawater intrusion through the Alamitos Gap would likely be prevented once current plans to construct additional injection wells are implemented. At both barriers, however, shallow groundwater concerns could limit injection rates and thus reduce the effectiveness of barriers at preventing seawater intrusion under rising sea levels.

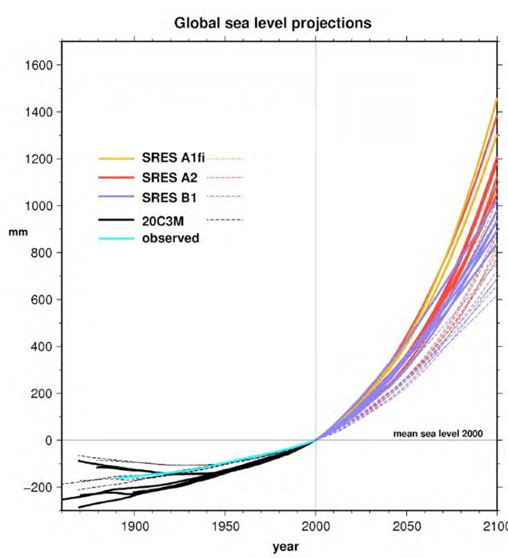


Figure 1 - Projections of global mean sea level rise based on selected climate projections.

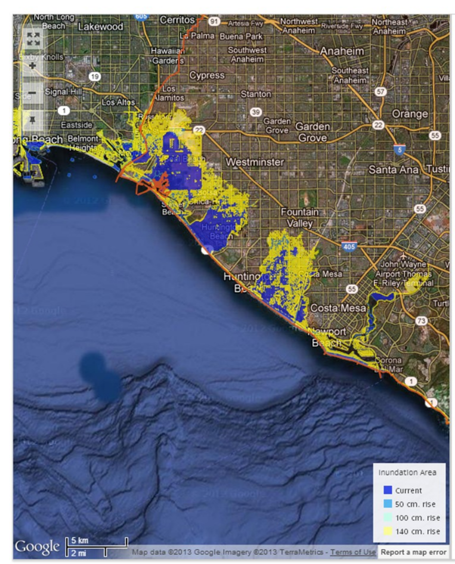


Figure 2 - Area at risk of inundation from 100-year flood event under current conditions (blue) and under 1400 mm sea level rise (yellow)

### Key Findings

- Climate change will contribute to global sea level rise (SLR) through melting of glaciers and ice caps and thermal expansion of ocean waters, both of which increase the volume of water in the oceans.
- Regional SLR may be higher or lower than global SLR due to effects of regional ocean and atmospheric circulation.
- Average sea levels along the Southern California coast is projected to rise by 5-24 inches by 2050 and 16-66 inches by 2100.
- SLR is likely to inundate beaches and coastal wetlands and may increase coastal erosion. Effects on local beaches depend on changes in coastal ocean currents and storm intensity, which are highly uncertain at this time.
- SLR will increase the area at risk of inundation due to a 100-year flood event.
- Existing barriers are sufficient to deter seawater intrusion at Talbert and Alamitos gaps under a 3-foot rise in sea levels. However, operation of barriers under SLR may be constrained by shallow groundwater concerns.

### Additional Considerations

- Results were obtained from previous analysis, no additional modeling was done.

Link to full technical report—http://www.usbr.gov/lc/socal/basinstudies/OWOW.html