11. Climate Change Effects

Five different future climate scenarios were simulated as described in Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal Studies. The scenarios were chosen to bracket the range of results predicted by Global Circulation Models (GCM). Four scenarios correspond to combinations of the 25th and 75th quantiles of the precipitation and temperature predicted by the GCMs for the Upper and Lower Klamath Basins. The fifth is the 50th quantile of the precipitation and temperature (Table 11-1). The precipitation and temperature predicted by the GCMs were downscaled to the Upper and Lower Klamath Basin. This precipitation and temperature provided input into a watershed scale hydrologic model, SAC-SMA. This section compares the hydrology results from the climate change scenarios (CC) to the Index Sequential simulations (IS) that were discussed in Section 6.

Table 11-1. Climate change scenarios.

Simulation ID	Climate Model	Temperature Quantile	Precipitation Quantile
6	cccma_cgcm3_1.4.sresa1b	75th	75th
11	gfdl_cm2_0.1.sresa2	50th	50th
24	miub_echo_g.3.sresa1b	75th	25th
37	mri_cgcm2_3_2a.3.sresa1b	25th	75th
45	ncar_pcm1.1.sresa2	25th	25th

All of the selected climate models predict increasing temperatures for the Upper Klamath Basin, while the climate models are split in terms of predicting increasing or decreasing precipitation. The 25th and 75th quantiles for the change in average temperature in the Upper Klamath Basin during the period 1950 to 1999 and from 2020 to 2069 are 1.4 to 2.2 degrees Celsius (2.5 to 4 degrees Fahrenheit). The same quantiles for the relative average annual precipitation for the same periods in the upper Klamath Basin are 0.95 and 1.05 inches (See Appendix E). Under the climate change scenarios, the average change in total precipitation ranges from a 5% decrease to a 5% increase.

11.1. Effects on Hydrology

The average flows entering UKL are given in Figure 11-1 for the No Action Alternative under the IS and CC scenarios. The Dam Removal Alternative includes an additional 30 acre-feet/yr of water being supplied to UKL, but otherwise is identical. Three of the five climate change simulations show an increase in annual inflow while the other two show a decrease in annual inflow. However, all climate change simulations show a more rapid snow melt period. They all indicate a greater proportion of the annual inflow occurring during the months of November through March and a decrease in the proportion of inflow

occurring May through October. The three wet climate change simulations have greater annual flow volumes, but the average flow in the summer and fall are similar to the IS simulations. Most all the increase in annual flows occurs from December to April. The dry climate change simulations show significantly smaller average flows throughout all months, except for March where the hotter climate can cause more precipitation to fall as rain and also cause a faster snowmelt. The general expectation is that under climate change the flows entering UKL in the later winter and early spring (February to April) will be similar or higher than current flows, but that flows in May through October will be similar or lower than current flows. Flows into UKL during the winter may be either lower or higher than current conditions.

The flows at Iron Gate for the No Action and Dam Removal Alternatives are shown in Figure 11-2 and Figure 11-3 for the IS and CC scenarios. The effect of climate change on the No Action and Dam Removal Alternatives hydrology is similar at the Iron Gate stream gage. The shift in the spring snowmelt under climate change is still evident at Iron Gate, but it is somewhat amiliorated by UKL. Flows could be higher or lower during the months of November through April under climate change. During the months of May through October, the flows will likely be similar under median or wet climate scenarios and less under dry climate scenarios.

There is a more substantial shift in timing of flows at Seiad Valley under the climate change scenarios (Figure 11-4). The flows in Feburary and March are substantially higher under both wet and dry climate scenarios, whereas, the flows in May through July are lower under both wet and dry climate scenarios. The flows during the summer months of August through October are similar for the wet and median climate scenarios, but substantially less under the dry climate scenarios. This general shift in precipitation from late spring to winter is consistent with the study of Koopman et al. (2009) who analyzed the change in precipitation over the entire Klamath Basin for the period 2035 to 2045 relative to 1961 to 1991. They found that three climate models predicted between 4.1 to 2.7 mm less precipitation during the period June to August and a 1.5 to 14.4 mm more precipitation during the months of December through February.

A similar pattern of climate change appears at Orleans on the Klamath River, but the dry scenarios have smaller flows for all months of the year. In addition, most all climate scenarios have significantly smaller flows for April through November (Figure 11-5). The average flow under the IS scenarios in June is approximately 6,000 cfs, whereas, the average flow under the wet climate change scenario in June is approximately 3,700 cfs.

Figure 11-6 shows the IS and CC results for the Klamath River at Klamath under the Dam Removal Alternative. The flow pattern at Klamath is similar to that at Orleans. There is a distinct shift of flow to the winter months. For all climate scenarios, there is less flow during the months of April through November.

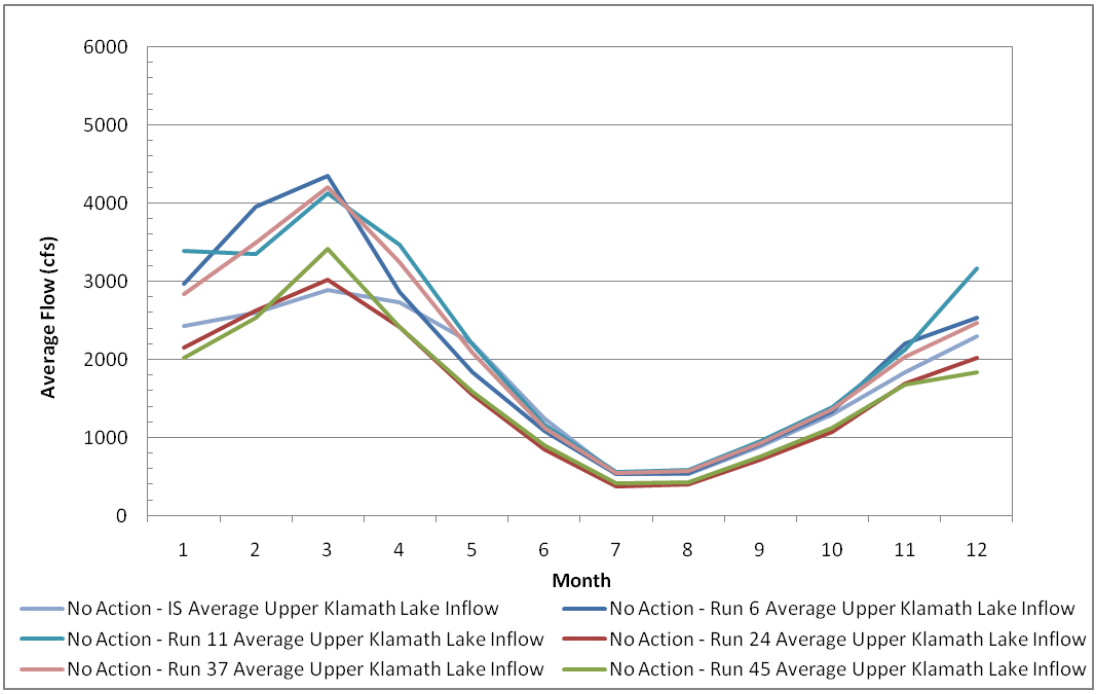

Figure 11-1. Average flows into UKL for the Index Sequential and Climate Change simulations for the No Action Alternative.

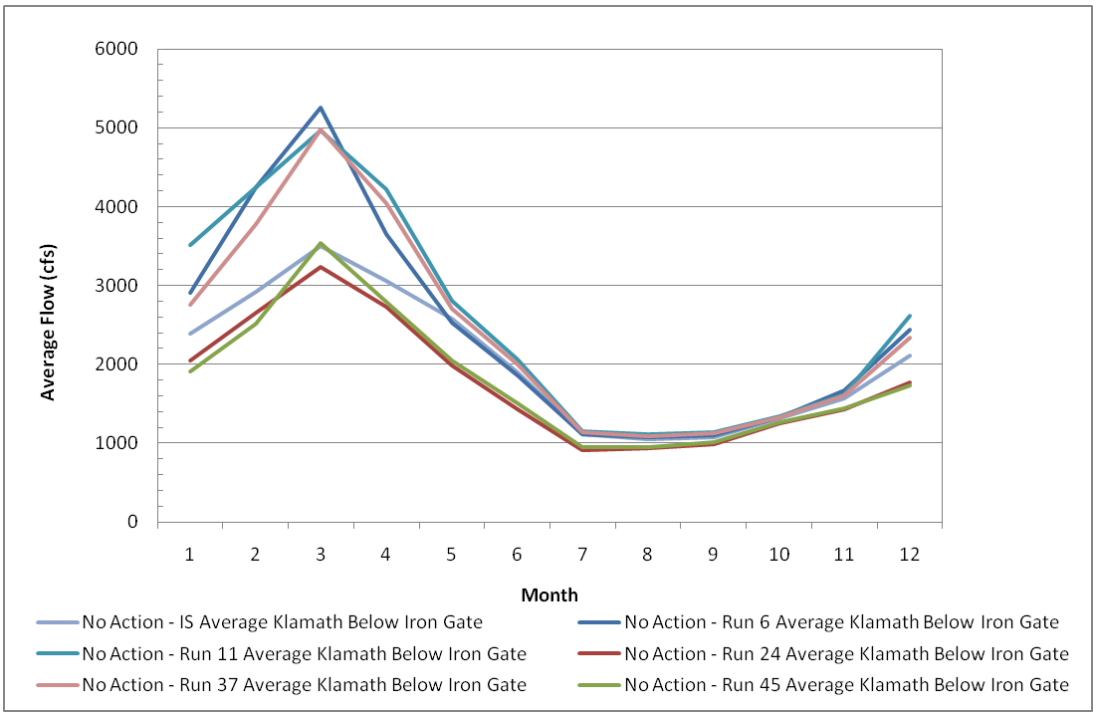

Figure 11-2. Average flows in the Klamath River below Iron Gate Dam for the Index Sequential and Climate Change simulations for the No Action Alternative.

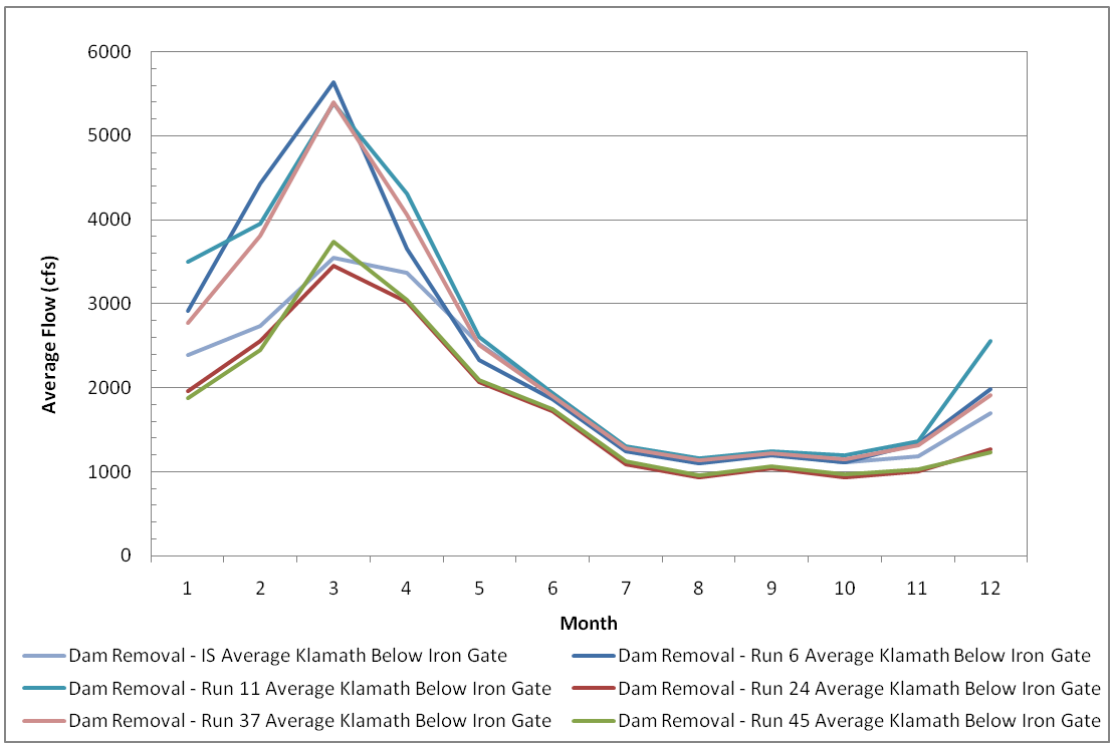

Figure 11-3. Average flows in the Klamath River below Iron Gate Dam for the Index Sequential and Climate Change simulations for the Dam Removal Alternative.

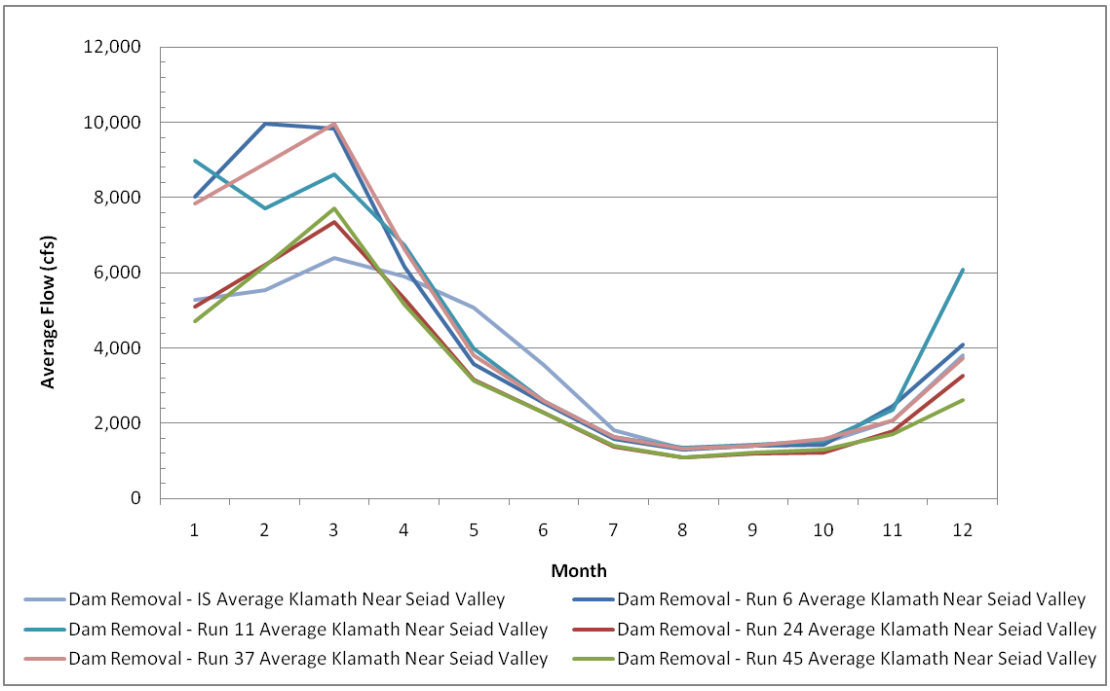

Figure 11-4. Average flows in the Klamath River near Seiad Valley for Dam Removal Alternative.

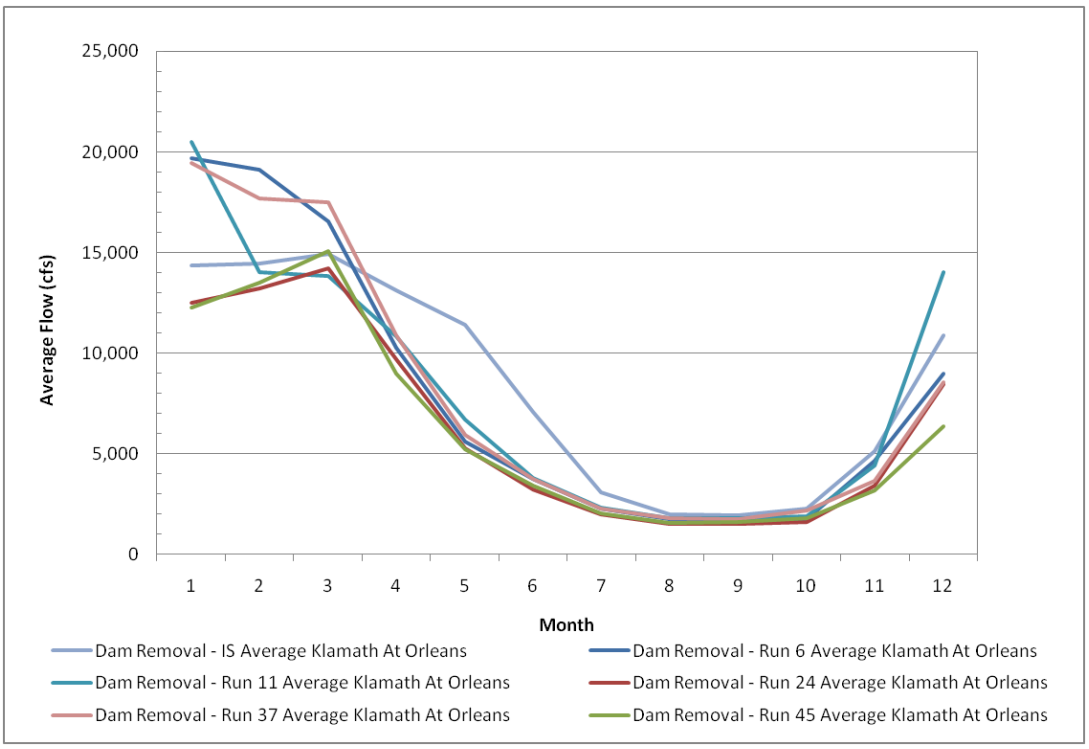

Figure 11-5. Average flows in the Klamath River at Orleans for Dam Removal Alternative

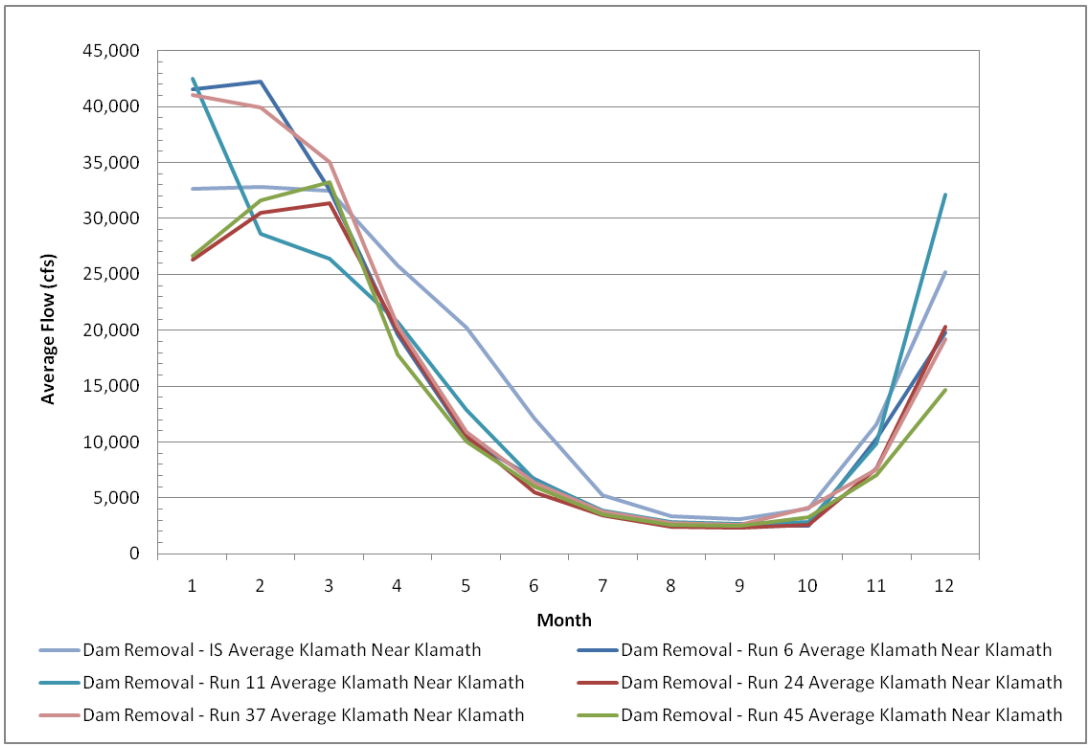

Figure 11-6. Average flows in the Klamath River at Klamath for Dam Removal Alternative.

These results are consistent with the findings of Reclamation (2011c, 2011d), which are reports intended to assess the effect of, and risk resulting from, global climate change with respect to the quantity of water resources located in each major Reclamation river basin. Some of the key findings of the Reclamation (2011c, 2011d) study are summarized in Figure 11-7 and Figure 11-8.

The technical assessment provided: (1) an analysis of changes in hydroclimate variables—namely, precipitation, temperature, snow water equivalent, and streamflow across the major Reclamation river basins—and the technical foundation for the SECURE report and (2) documentation for this new hydrologic projections dataset that will be made publicly available over the Western United States. The analysis involves developing hydrologic projections associated with World Climate Research Programme Coupled Model Intercomparison Project3 (WCRP CMIP3) climate projections that have been bias-corrected and spatially downscaled and served at the following Web site: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections. In total, 112 hydrologic projections were developed, relying on watershed applications of the Variable Infiltration Capacity macroscale hydrology model. From these time-series climate and hydrologic projections (or hydroclimate projections), changes in hydroclimate variables were computed for three future decades: 2020s (water years 2020–2029), 2050s (water years 2050–2059) and 2070 (water years 2070–2079) from the reference 1990s' decade (water years 1990–1999). The reference 1990s are from the ensemble of simulated historical hydroclimates, not from the observed 1990s.

The annual mean temperature in the Upper and Lower basins of the Klamath River are predicted to increase over the next 90 years (Figure 11-7). The annual precipitation demonstrates no major increase or decrease over the next 90 years (Figure 11-7).

Reclamation (2011c) also indicates substantial shifts in the annual runoff from the months of April to July to the months of December to March. Figure 11-8 shows the percent change in runoff for the 2020, 2050, and 2070 decades relative to the 1990s for several points on the Klamath River. For many points within the basin by 2050, there is around a 15 to 50% increase in flow during the months of December to March and approximately a 10 to 20% decrease in flow for the months of April to July. This is consistent with results of this document that show the shift to stream flow late spring and summer months to winter and early spring months.

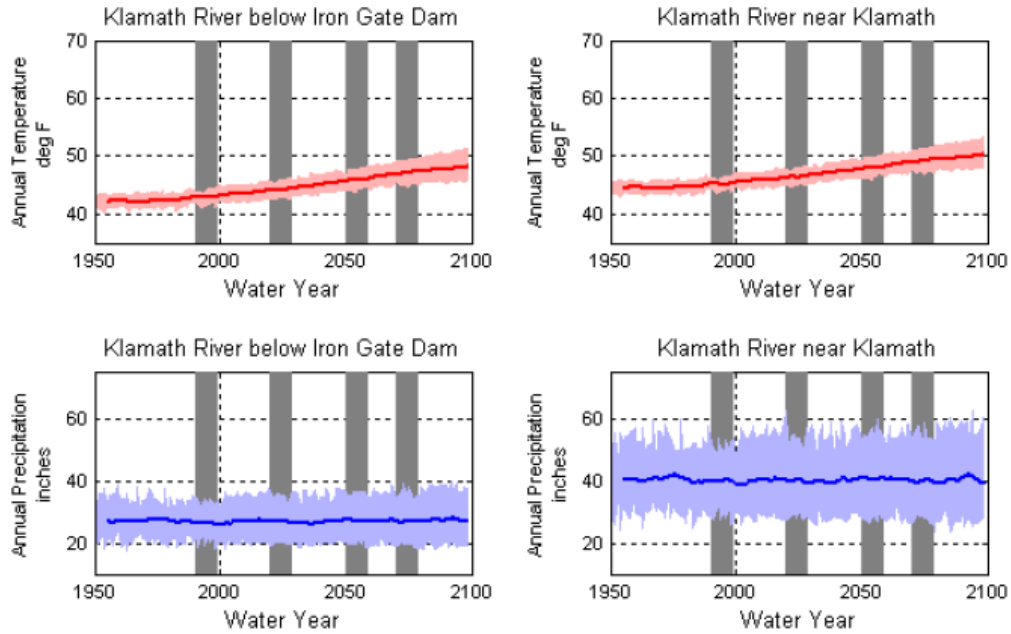

Figure 23. Simulated annual climate averaged over Klamath River subbasins.

Figure 23 displays the ensemble of temperature and precipitation projections from Bias Corrected and Spatially Downscaled WCRP CMIP3 Climate Projections (section 1.5.1). Annual conditions represent spatially averaged results over the basin. Darker colored lines indicate the median-annual condition through time, sampled from the ensemble of 112 climate simulations (section 1.5.1), and then smoothed using a 5-year running average. Lighter-colored areas represent the time-series range of 10th to 90th percentile annual values within the ensemble from simulated 1950 through simulated 2099.

Figure 11-7. Simulated annual climate averaged over Klamath River subbasins. Figure reproduced from Reclamation (2011c).

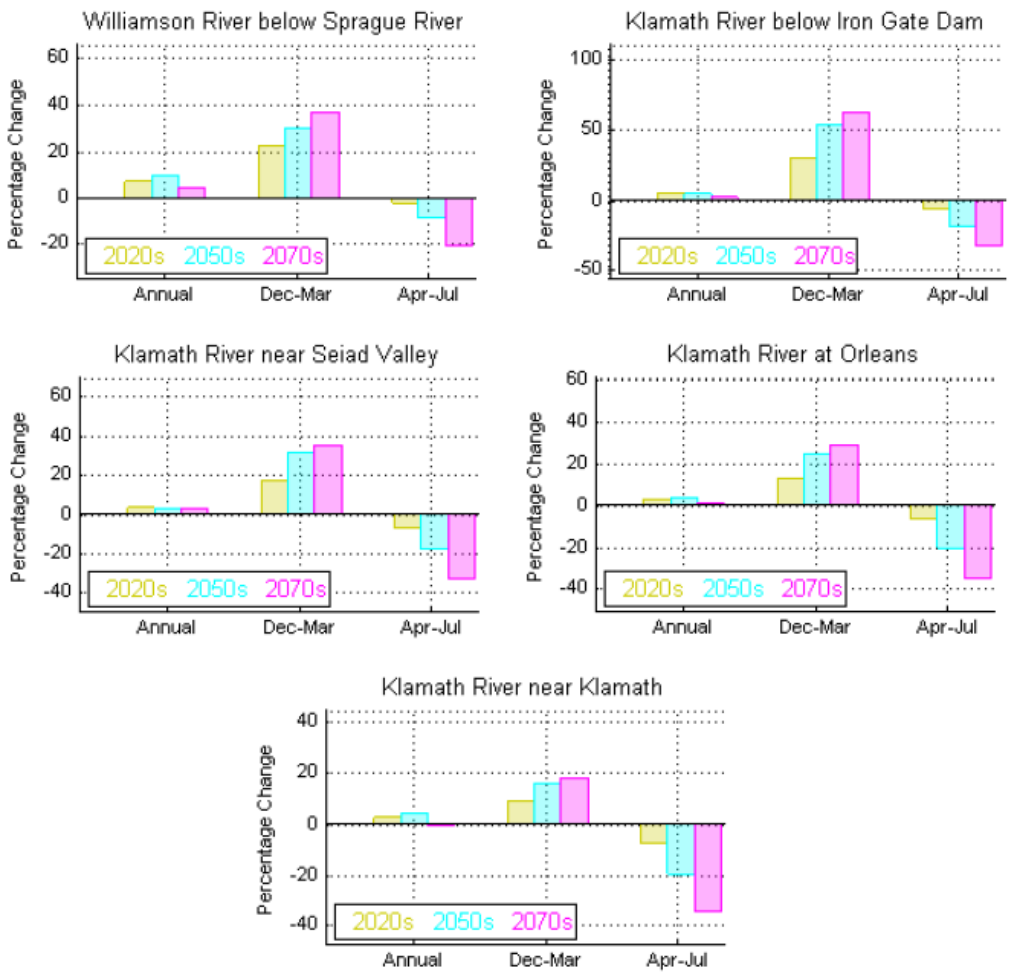

Figure 27. Simulated changes in decade-mean runoff for several subbasins in the Klamath River basin above Klamath, California.

Figure 27 presents Annual, December–March, and April–July runoff impacts for subbasins shown. Each panel shows percentage changes in mean runoff (annual or either season) for three future decades (2020s, 2050s, and 2070s) relative to baseline conditions (1990s). Development of runoff information is described in Reclamation (2011a) based on climate simulations previously discussed (section 1.5.1).

Figure 11-8. Changes in decade-mean runoff for several subbasins in Klamath River. Reproduced from Reclamation (2011c).

11.2. Effect on Hydraulics, Sediment Transport and Geomorphology

The climate change scenarios are not sufficiently refined to determine effects to peak flows. Therefore, it is difficult to determine if climate change will have a significant impact on flood risk, sediment transport, or geomorphology. However, if the future climate is wetter and more precipitation occurs as rainfall and/or there is a faster snowmelt runoff during the spring, then peak flows would likely

increase as well. If the climate is overall drier, the peak flows may not be substantially higher.

If peak flows do indeed increase, higher peak flows will generally create a wider channel and floodplain. Higher flows would also tend to further armor the bed below Iron Gate Dam to Cottonwood Creek under the No Action Alternative, whereas, they would have much less effect on the Dam Removal Alternative because the gravel supply is restored to this reach.

The effect of climate change on geomorphology could be more pronounced if there is a change in riparian vegetation. For example, if the conifer species in the upper Klamath River are replaced by other species, such as willow, the bank properties may be slightly different. The difference in bank properties could translate into different rates of bank erosion and planform change. The quantification of this process is uncertain, however, and would affect both alternatives in a similar manner.