

# Simulated Effects of Dam Removal on Water Temperatures along the Klamath River, Oregon and California, Using 2010 Biological Opinion Flow Requirements

By John C. Risley, Scott J. Brewer, and Russell W. Perry



Prepared in cooperation with the Bureau of Reclamation

Open-File Report 2011–1311

U.S. Department of the Interior  
U.S. Geological Survey

Cover: Iron Gate Reservoir on the Klamath River in California (Photograph by John Risley, U.S. Geological Survey, October 2005.)

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**U.S. Department of the Interior**  
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## Conversion Factors and Datums

### Conversion Factors

#### Inch/Pound to SI

	Multiply	By	To obtain
inches (in.)		2.54	centimeter (cm)
feet (ft)		0.3048	meter (m)
mile (mi)		1.609	kilometer (km)
square mile (mi <sup>2</sup> )		2.590	square kilometer (km <sup>2</sup> )

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C=(°F-32)/1.8

### Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

# Simulated Effects of Dam Removal on Water Temperatures along the Klamath River, Oregon and California, Using 2010 Biological Opinion Flow Requirements

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## Summary

Computer model simulations were run to determine the effects of dam removal on water temperatures along the Klamath River, located in south-central Oregon and northern California, using flow requirements defined in the 2010 Biological Opinion of the National Marine Fisheries Service. A one-dimensional, daily averaged water temperature model (River Basin Model-10) developed by the U.S. Environmental Protection Agency Region 10, Seattle, Washington, was used in the analysis. This model had earlier been configured and calibrated for the Klamath River by the U.S. Geological Survey for the U.S. Department of the Interior, Klamath Secretarial Determination to simulate the effects of dam removal on water temperatures for current (2011) and future climate change scenarios. The analysis for this report was performed outside of the scope of the Klamath Secretarial Determination process at the request of the Bureau of Reclamation Technical Services Office, Denver, Colorado.

For this analysis, two dam scenarios were simulated: “dams in” and “dams out.” In the “dams in” scenario, existing dams in the Klamath River were kept in place. In the “dams out” scenario, the river was modeled as a natural stream, without the J.C. Boyle, Copco1, Copco2, and Iron Gate Dams, for the entire simulation period. Output from the two dam scenario simulations included daily water temperatures simulated at 29 locations for a 50-year period along the Klamath

River between river mile 253 (downstream of Link River Dam) and the Pacific Ocean. Both simulations used identical flow requirements, formulated in the 2010 Biological Opinion, and identical climate conditions based on the period 1961–2009.

Simulated water temperatures from January through June at almost all locations between J.C. Boyle Reservoir and the Pacific Ocean were higher for the “dams out” scenario than for the “dams in” scenario. The simulated mean monthly water temperature increase was highest [1.7–2.2 degrees Celsius (°C)] in May downstream of Iron Gate Dam. However, from August to December, dam removal generally cooled water temperatures. During these months, water temperatures decreased 1°C or more between Copco Lake and locations 50 miles or more downstream. The greatest mean monthly temperature decrease was 4°C in October just downstream of Iron Gate Dam. Near the ocean, the effects of dam removal were small (less than 0.2°C) for most months. However, the mean November temperature near the ocean was almost 0.5°C cooler with dam removal.

The simulated streamflow and water temperature values for the “dams in” and “dams out” scenarios from the RBM10 model created for the Klamath River application are available at <http://pubs.usgs.gov/of/2011/1311/>.

# Introduction

In 2010, the Secretary of the Interior was tasked with deciding whether the removal of the lower four dams (J.C. Boyle, Copco1, Copco2, and Iron Gate) on the Klamath River in south-central Oregon and northern California (fig. 1), as called for by the Klamath Hydroelectric Settle-

ment Agreement (KHSA) ( 2010), would improve salmonid fisheries and be in the public interest. As part of the Klamath Secretarial Determination process, environmental impact studies were conducted by various Federal agencies and private firms to evaluate the physical, social, and economic consequences associated with dam removal.

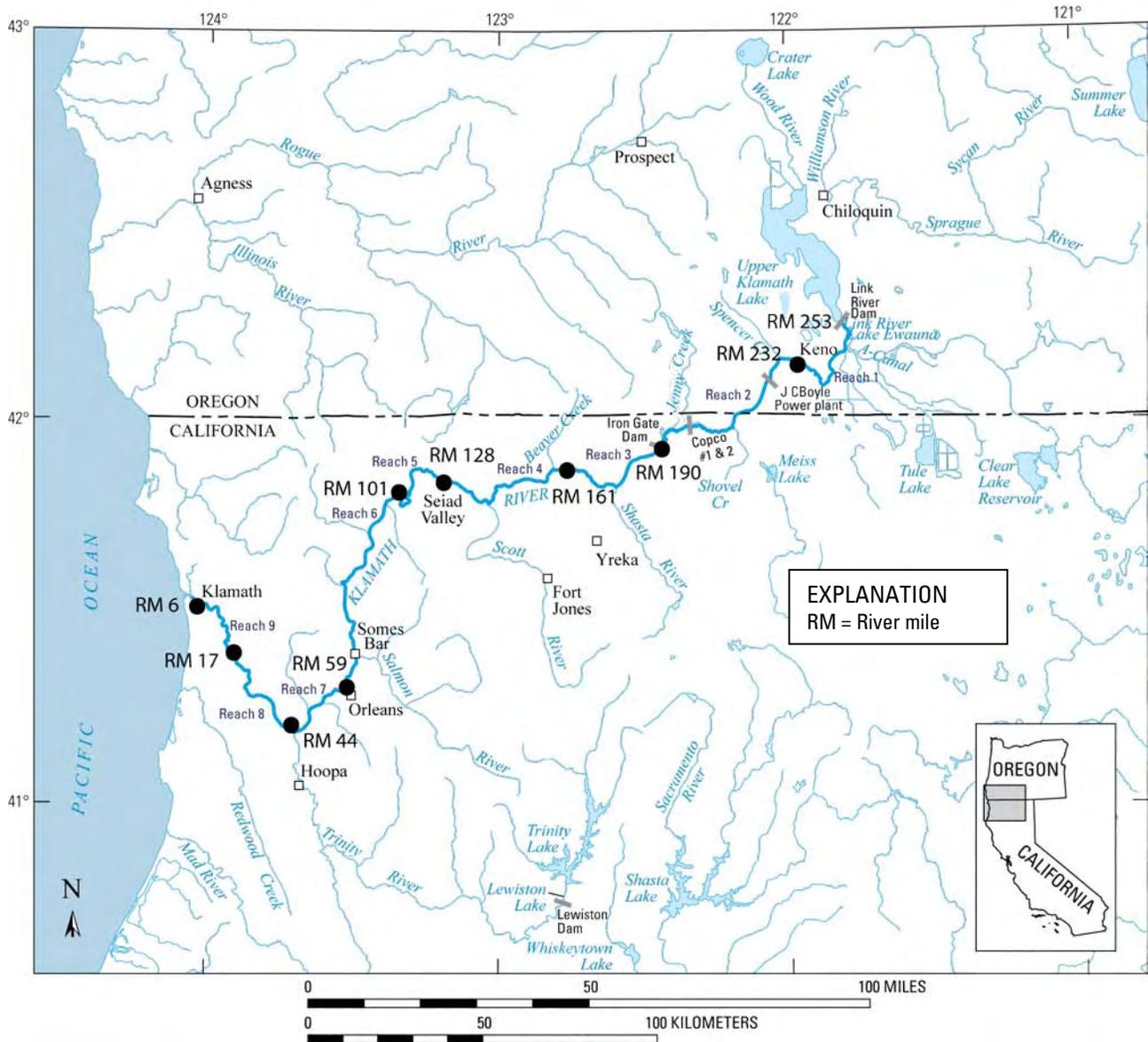


Figure 1. Map of the Klamath River showing the study area from Link River Dam to the Pacific Ocean (from Perry and others, 2011).

To evaluate the effects of dam removal on water temperatures under historical and future climate scenarios, the U.S. Geological Survey (USGS) developed and calibrated a one-dimensional, daily averaged water temperature model, based on the U.S. Environmental Protection Agency River Basin Model-10, for the lower 253 mi of the Klamath River (Perry and others, 2011). After the completion of that study, the Bureau of Reclamation (Reclamation) Technical Services Center, Denver, Colorado, asked the USGS to simulate the effects of dam removal on water temperatures in the Klamath River using flow requirements in the Biological Opinion of the National Marine Fisheries Service (2010). This request and the scenario simulations described herein were not related to the Klamath Secretarial Determination process.

## Purpose and Scope

This report presents simulated daily water temperature output from the U.S. Environmental Protection Agency River Basin Model-10 (RBM10) river basin model (Yearsley and others, 2001; Yearsley, 2003) for a 50-year period at 29 locations along the Klamath River between Link River Dam (river mile [RM] 253) and the Pacific Ocean (Perry and others, 2011). The output includes two simulations: one with the six existing dams on the Klamath River in place and another with the lower four dams (J.C. Boyle, Copco1, Copco2, and Iron Gate) removed. Flow requirements used in both simulations were defined by the National Marine Fisheries Service, 2010 Biological Opinion (National Marine Fisheries Service, 2010).

## Description of Study Area

The Klamath River basin of southern Oregon and northern California covers more than 12,000 mi<sup>2</sup> (fig. 1) and can be divided into upper and lower subbasins at Iron Gate Dam (RM 190). The upper basin is bounded by the Cascade Range on the west, the Deschutes River basin on the north, the Great Basin on the east, and the Pit River ba-

sin on the south. The upper basin is in the rain-shadow of the Cascades and consists of mostly agricultural and range lands with areas of pine forest and semi-arid high desert plateaus. It is characterized primarily by low-relief volcanic terrain punctuated by volcanic buttes. The average annual precipitation for the upper basin is about 35 in. (California Rivers Assessment, 2011), but ranges widely, from about 67 in. at Crater Lake, Oregon, to about 11 in. at Tule Lake, California (National Climatic Data Center, 2004). The lower Klamath River basin is mostly forested except for areas of agriculture and rangeland in the drainages of the Scott and Shasta Rivers. The lower basin is dominated by a steep, rugged, complex terrain and alluvial reaches. Average annual precipitation for the lower basin is about 80 in. (California Rivers Assessment, 2011), increasing from east to west and with elevation.

The modeled reach for this analysis begins near Link River Dam and continues 253 mi downstream to the Pacific Ocean. At the upstream boundary, the water level in Upper Klamath Lake is controlled by Link River Dam. Constructed in 1921, the dam is operated to provide hydropower, Bureau of Reclamation Project irrigation water, fish habitat within the lake, and downstream fish habitat. Additional information about the study area is provided in Perry and others (2011).

## Water Temperature Model

The model used in the analysis was the River Basin Model-10 (RBM10) created by the U.S. Environmental Protection Agency Region 10 office in Seattle, Washington (Yearsley and others, 2001; Yearsley, 2003). RBM10 is a one-dimensional water temperature model that uses an energy budget method to simulate daily water temperatures along the longitudinal profile of a river. Boundary conditions are specified as daily inputs of discharge and water temperature at the headwater and all significant tributaries. Daily mean meteorological data (net shortwave solar

radiation, net longwave atmospheric radiation, air temperature, wind speed, and vapor pressure) also are required to simulate the air–water heat flux. Additional details about the model configuration and calibration for the Klamath River are in Perry and others (2011). The eight reaches used in the Klamath River RBM10 configuration from Link River Dam to the Pacific Ocean and their downstream river mile locations are shown in figure 1.

## Simulations

### Assumptions

For this analysis, two water temperature scenarios (“dams in” and “dams out”) were simulated for a 50-year period starting on January 1 and ending on September 30. (It was not possible to start the simulation at the beginning of a water year [October 1] because the RBM10 model can start a simulation only on January 1.) For the “dams in” scenario, existing dams in the Klamath River modeling reach (Link River, Keno, J.C. Boyle, Copco1, Copco2, and Iron Gate) were kept in place for the entire simulation period. In the “dams out” scenario, the RBM10 channel geometry was configured to represent a riverine system without the J.C. Boyle, Copco1, Copco2, and Iron Gate Dams for the entire simulation period. For both simulations, water temperature and meteorological data inputs for the upstream and all tributary boundaries were the same that were used in the “Index Sequential” simulations that were created for the Klamath Secretarial Determination and described in Greimann and others (2011) and Perry and others (2011). In those studies, the Index Sequential method was created to simulate flow operation conditions using historical hydrological and meteorological data, which

could then be compared with simulations using future climate data created from global circulation models. However, data from the global circulation models were not used in this study because analyzing climate change effects was not an objective. The 50-year record for the Index Sequential simulations and for the simulations used in this study was constructed using 1961–2009 meteorological data for the first 49 years. The 1961 data were then repeated for the 50th year in the record.

Both the “dams in” and “dams out” simulations in this analysis used the flow requirement plan developed in the 2010 Biological Opinion of the National Marine Fisheries Service (2010). The flow requirement plan would control Link River dam releases and available water for the Bureau of Reclamation Klamath Project, in-lake fish habitat, and in-river fish habitat for 2010–18. Proposed instantaneous minimum Klamath River flows at Iron Gate Dam, minimum Upper Klamath Lake elevations, and Upper Klamath Lake refill target elevations are shown in table 1. In the 2010 Biological Opinion (National Marine Fisheries Service, 2010, p. 9), the priorities for these operational rules are (1) meet or exceed the minimum IGD flows; (2) meet or exceed the minimum UKL elevations; (3) sustain water diversions to meet contractual agreements between Reclamation and water users, including the National Wildlife Refuges; and (4) meet the UKL Refill Targets. Remaining water is identified as surplus water, also referred to as potential IM Water.

Additional details about the flow requirement plan are provided in the 2010 Biological Opinion (National Marine Fisheries Service, 2010).

**Table 1.** Proposed instantaneous minimum Klamath River flows at Iron Gate Dam, minimum Upper Klamath Lake elevations, and Upper Klamath Lake refill targets. Source: National Marine Fisheries Service (2010).

[Elevations in feet above North American Vertical Datum of 1988. NA, not applicable for month.]

Month	Klamath River	Upper Klamath Lake	
	Proposed minimum flows below Iron Gate Dam (cubic feet per second)	Proposed minimum lake elevations (feet)	Proposed lake refill target elevations (feet)
October	1,300	NA	4,139.1
November	1,300	NA	4,139.9
December	1,300	NA	4,140.8
January	1,300	NA	4,141.7
February	1,300	4,141.5	4,142.5
March	1,450	4,142.2	4,143.0
April	1,500	4,142.2	NA
May	1,500	4,141.6	NA
June	1,400	4,140.5	NA
July	1,000	4,139.3	NA
August	1,000	4,138.1	NA
September	1,000	4,137.5	NA

### Results of Water Temperature Simulations

Simulated mean monthly water temperatures at 29 locations along the modeling reach for both dam scenarios during the 50-year simulation period are shown in figures 2–13. Table 2 shows the mean differences (“dams in” minus “dams out”) for these months at the 29 locations. Simulated daily water temperatures for a single year (the 13th year of the simulation based on 1973 meteorology and water availability) J.C. Boyle Reservoir (RM 226.8), downstream of Iron Gate

Dam (RM 190), near Seiad Valley, California (RM 130.7), and near the river mouth (RM 2.7), respectively, are shown in figures 14–17. The 13th year of the 50-year record was selected because the imposed annual mean streamflow downstream of Link River Dam for that year was closest to the median of all annual mean streamflows for the record. Although negligible for some dates, the effects of dam removal on temperatures can be seen in all four locations. The largest effects are apparent just downstream of Iron Gate Dam (fig. 15).

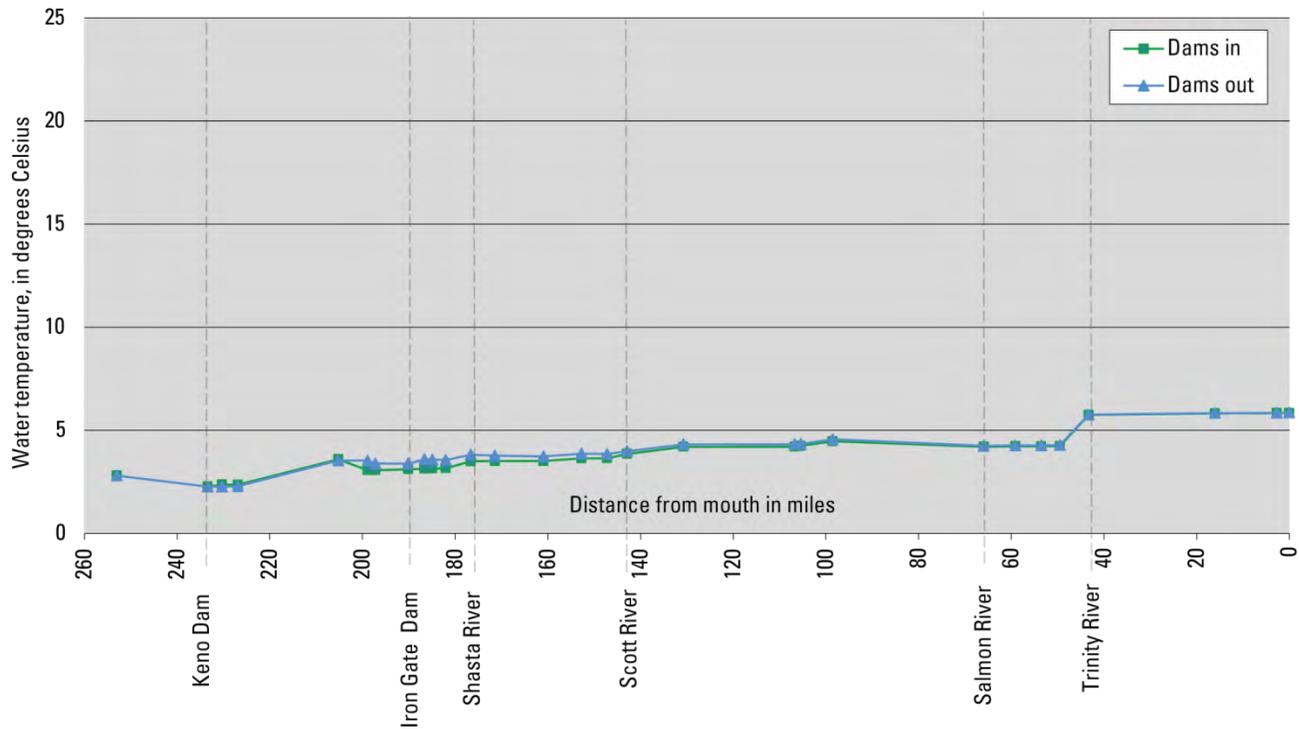


Figure 2. Graph showing simulated Klamath River mean January water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

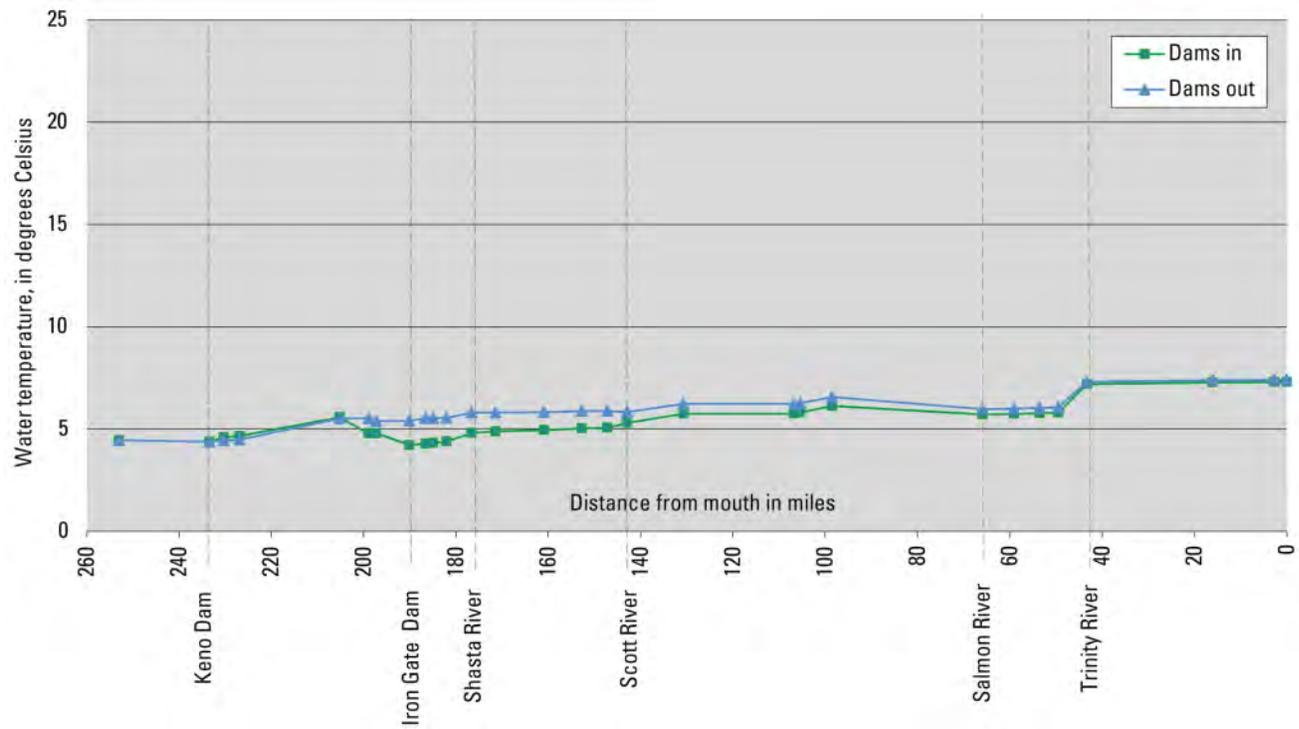


Figure 3. Graph showing simulated Klamath River mean February water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

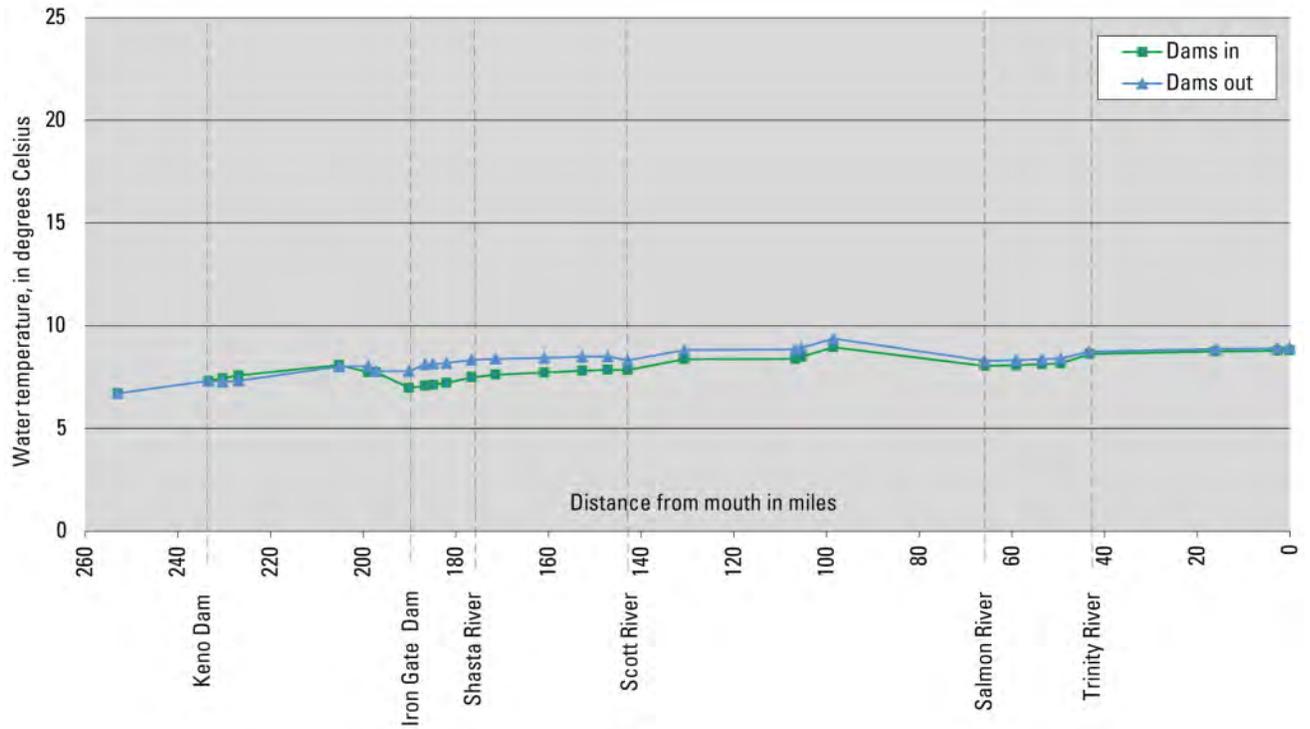


Figure 4. Graph showing simulated Klamath River mean March water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

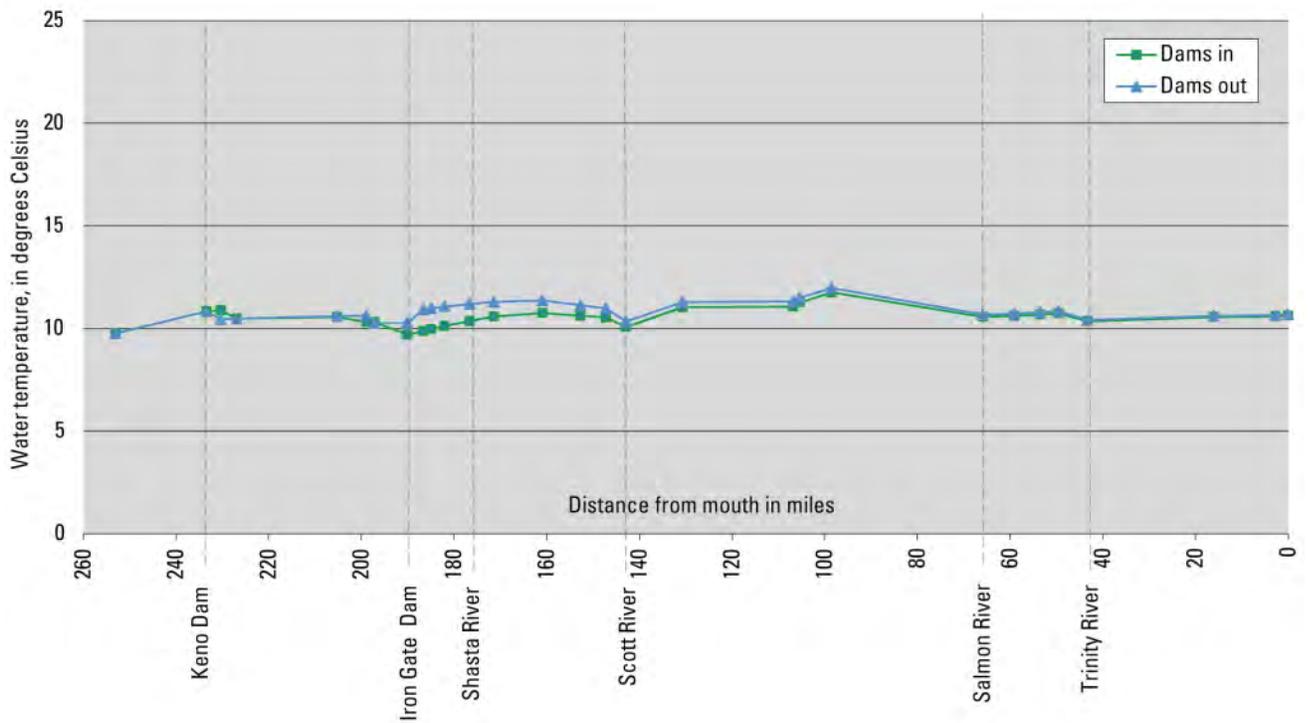


Figure 5. Graph showing simulated Klamath River mean April water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

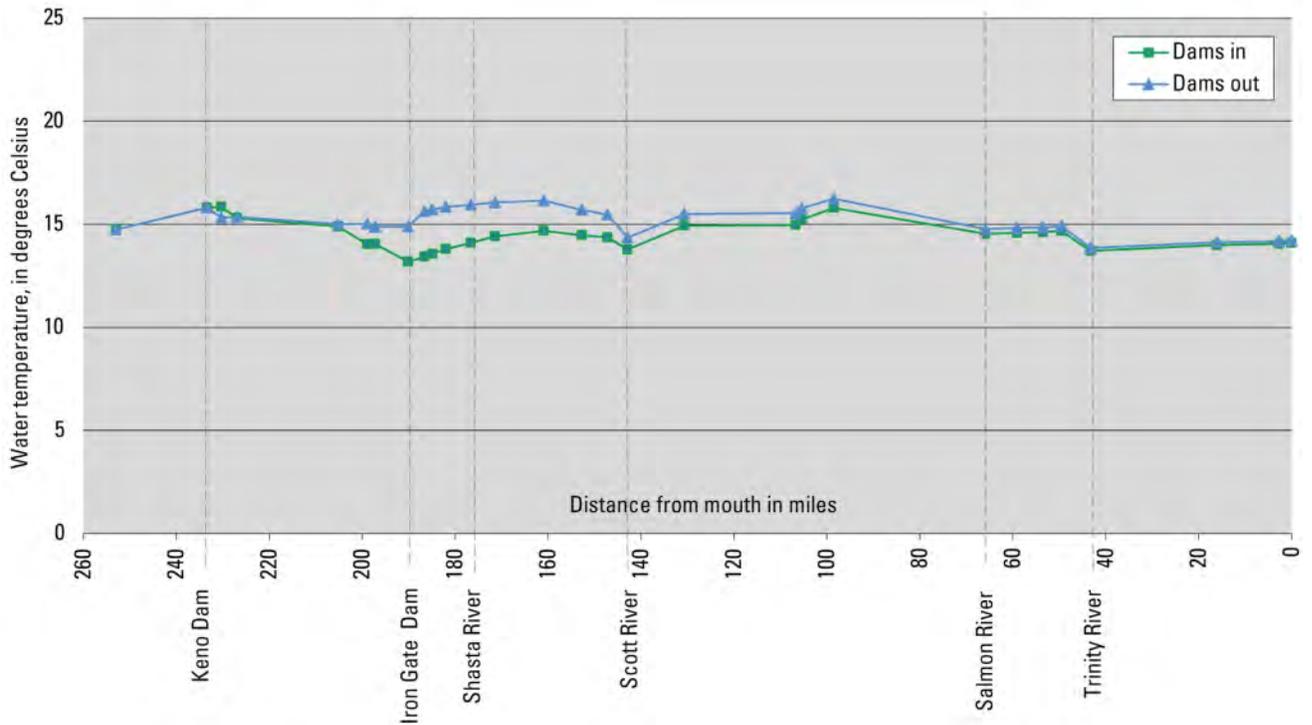


Figure 6. Graph showing simulated Klamath River mean May water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

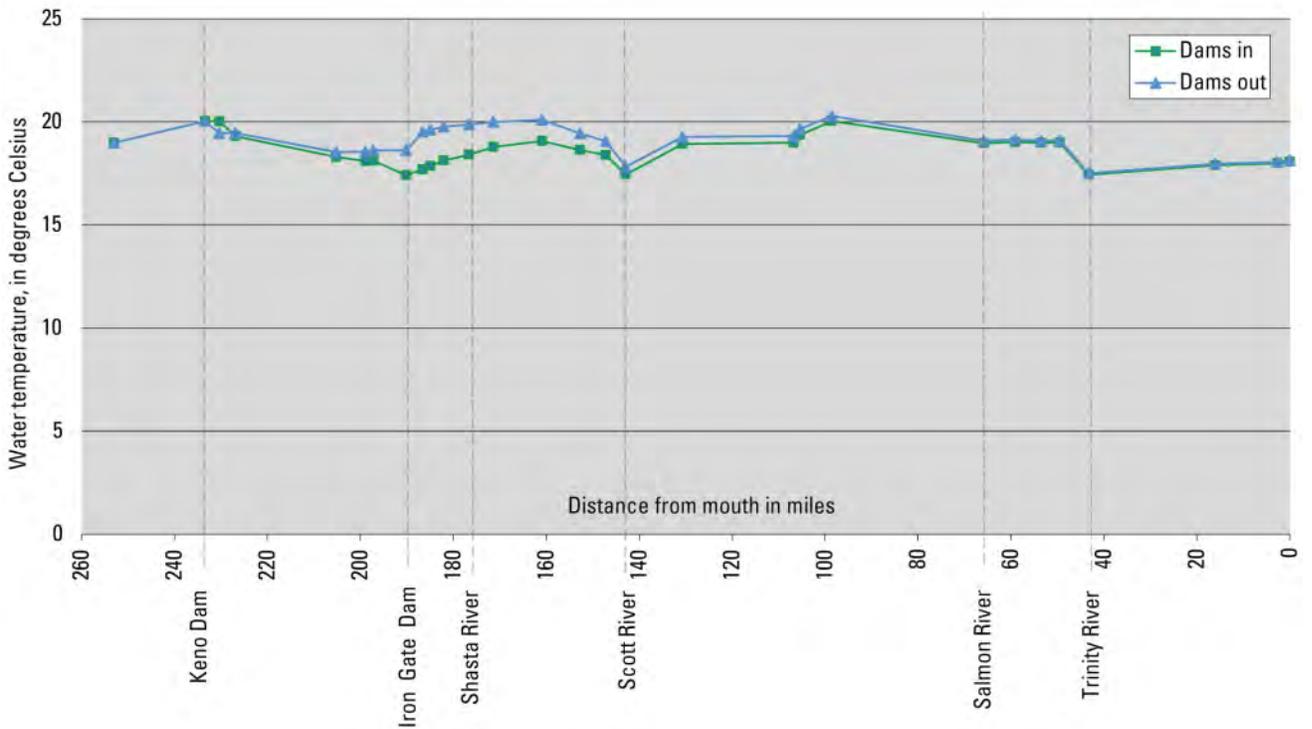


Figure 7. Graph showing simulated Klamath River mean June water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

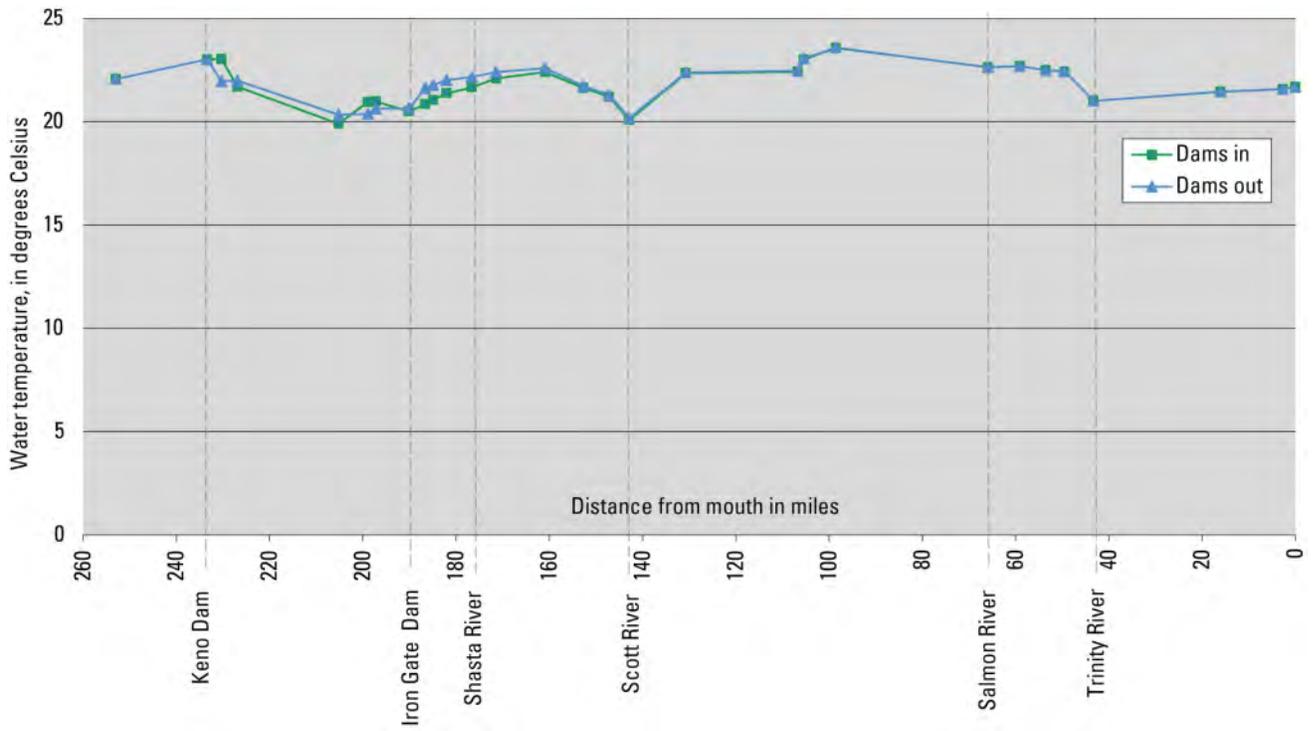


Figure 8. Graph showing simulated Klamath River mean July water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

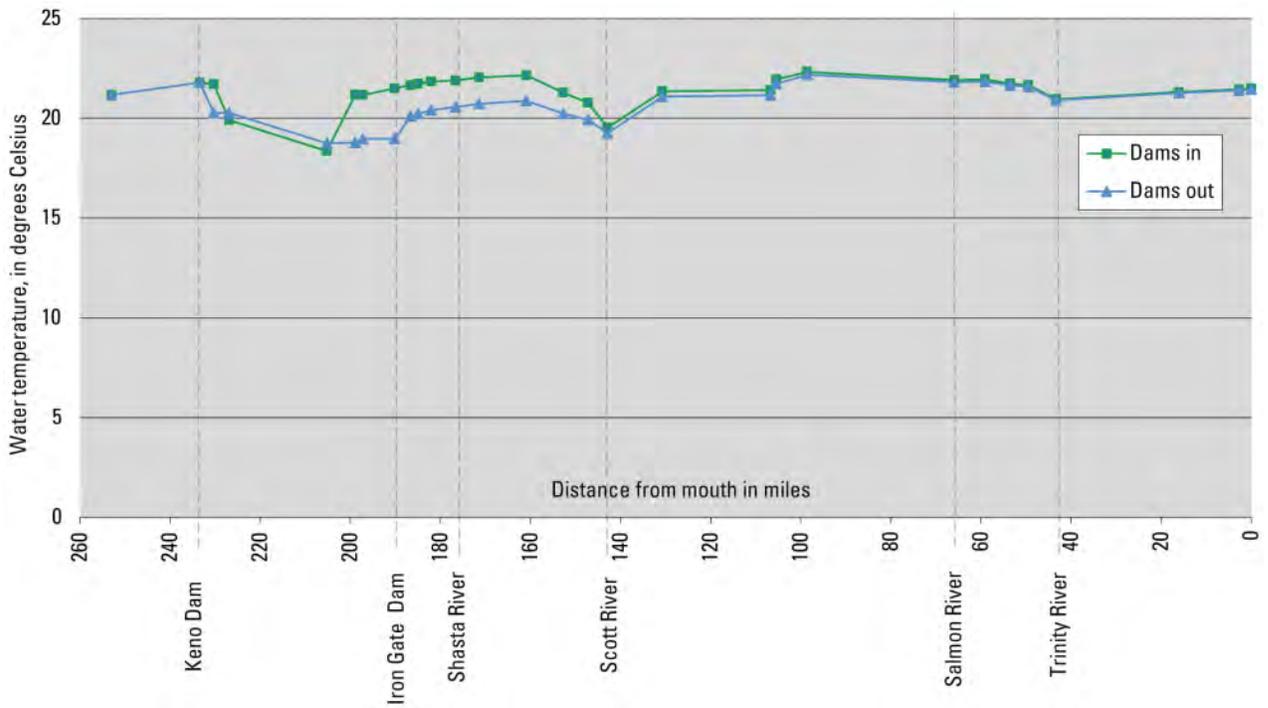


Figure 9. Graph showing simulated Klamath River mean August water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

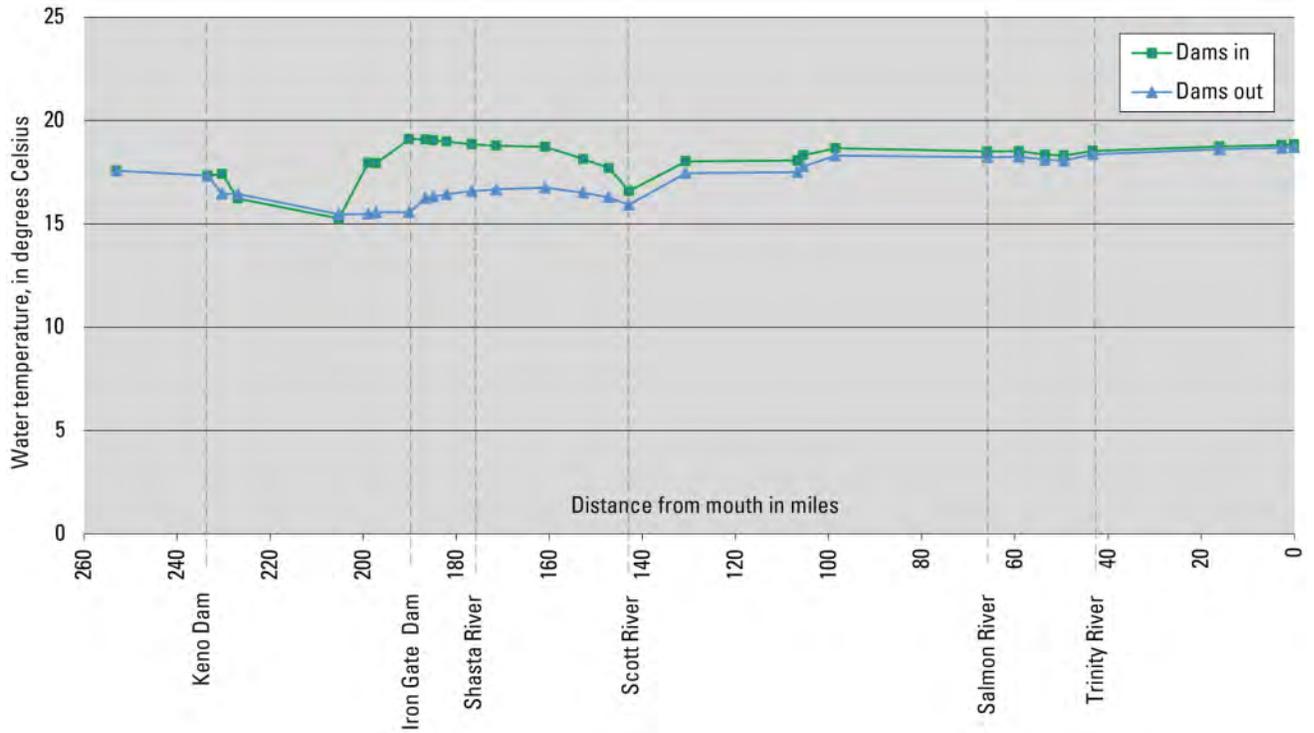


Figure 10. Graph showing simulated Klamath River mean September water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

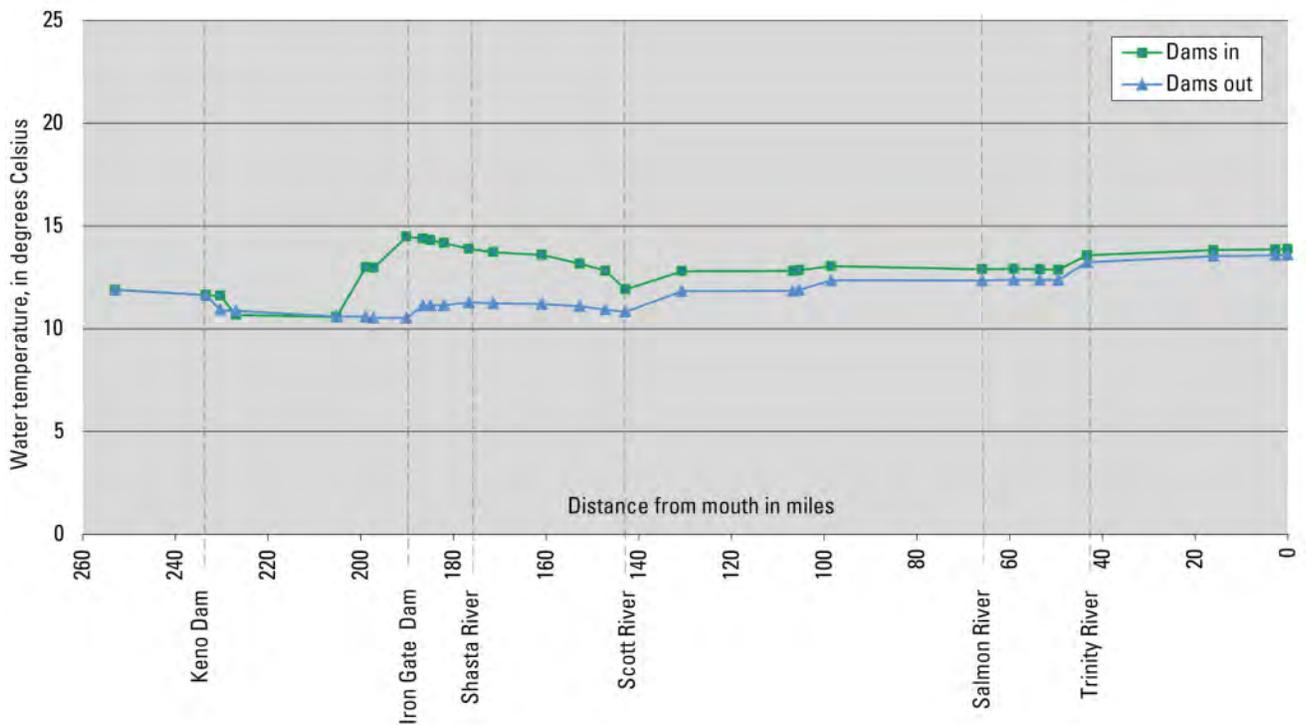


Figure 11. Graph showing simulated Klamath River mean October water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

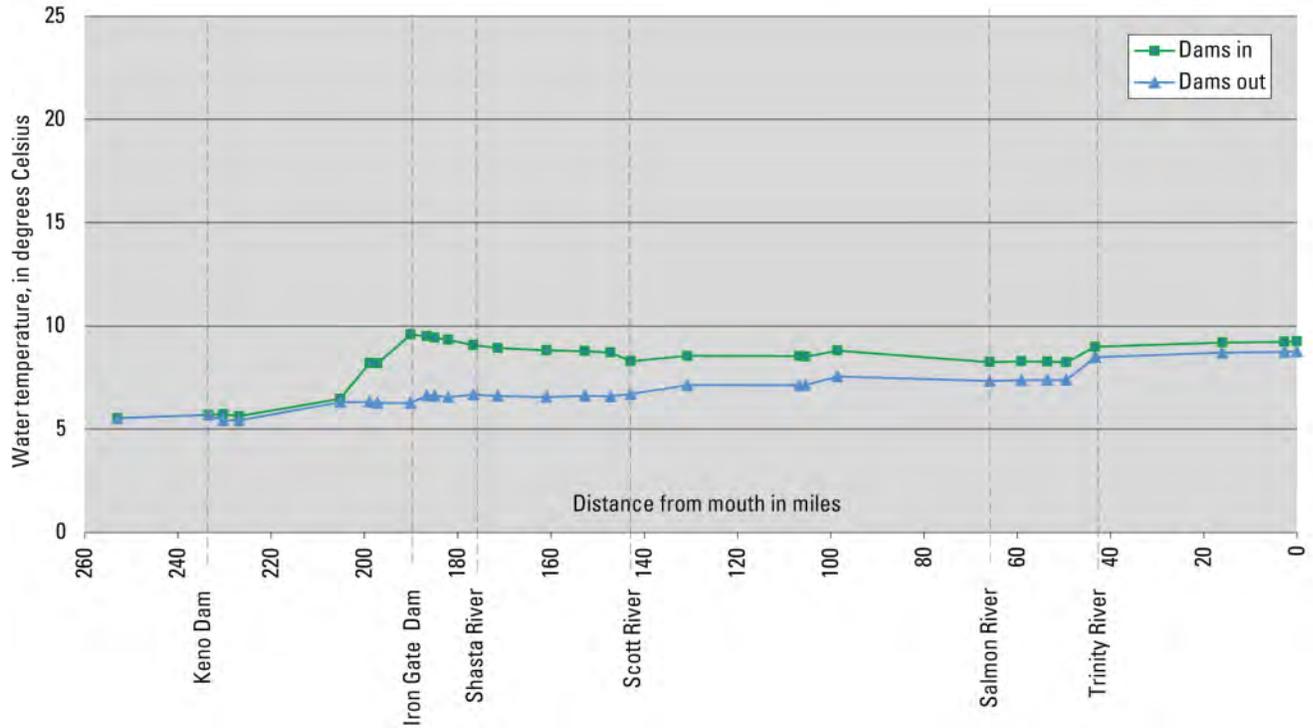


Figure 12. Graph showing simulated Klamath River mean November water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

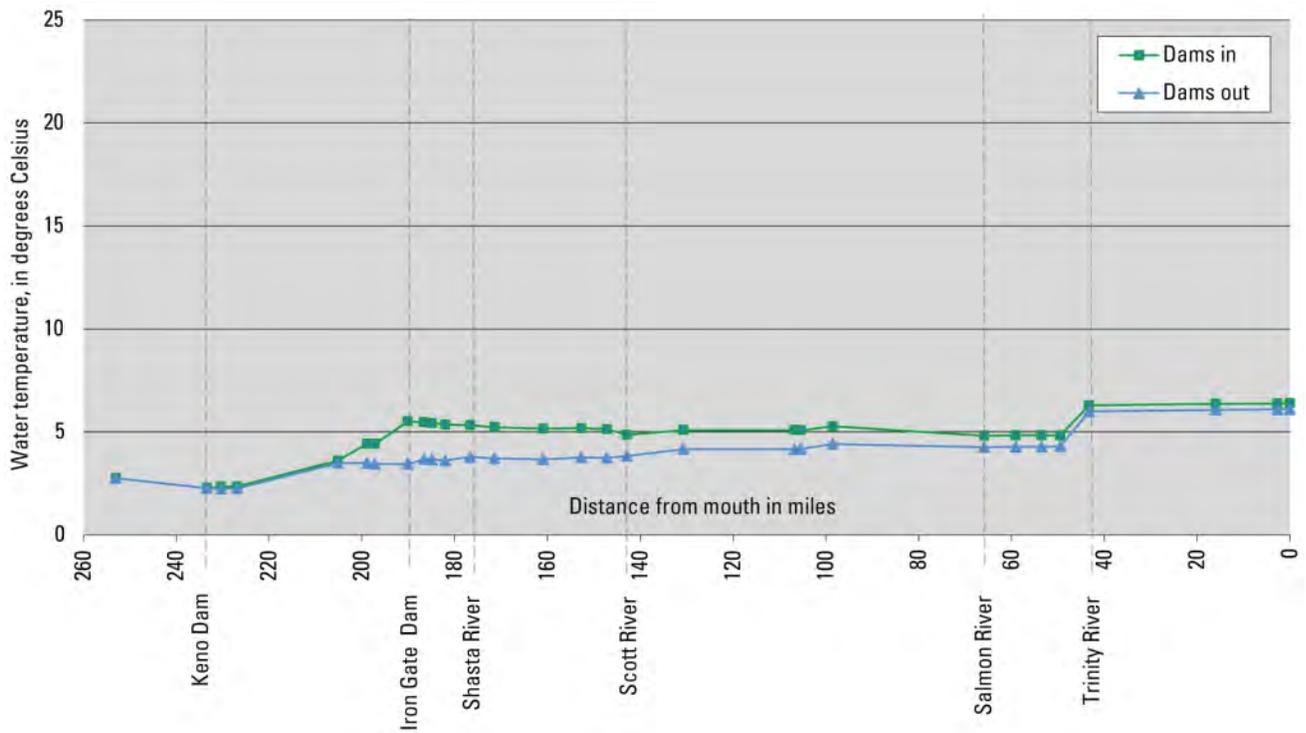
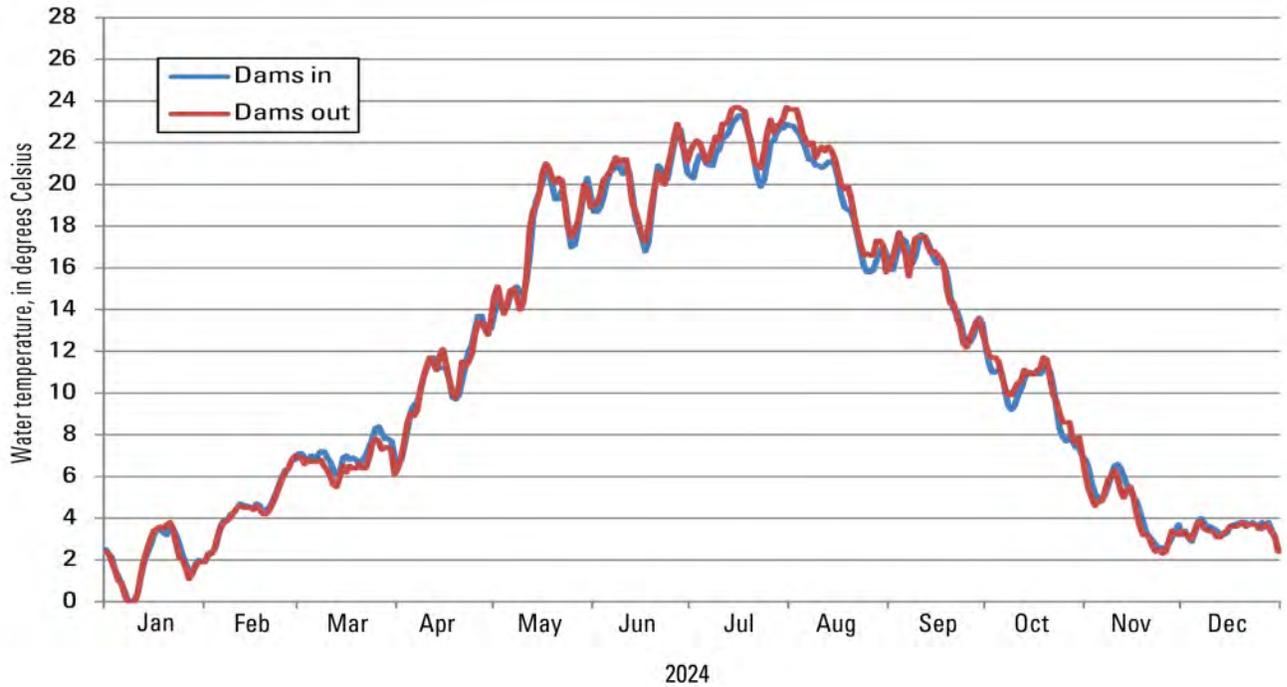
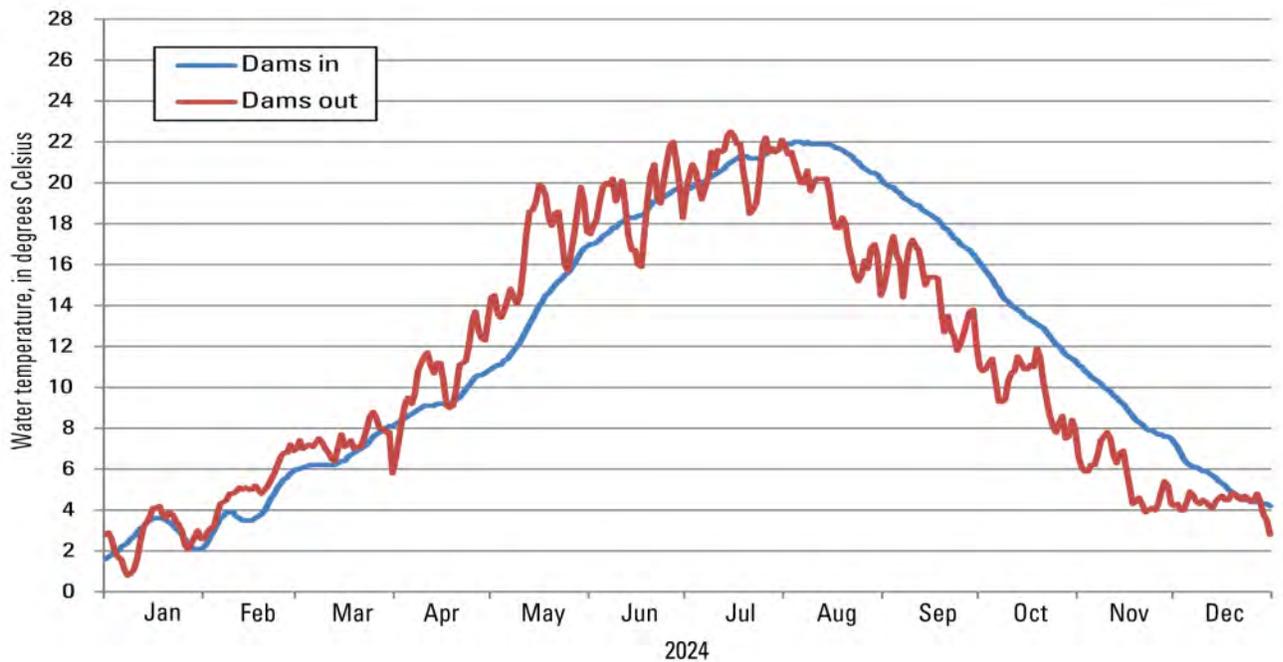


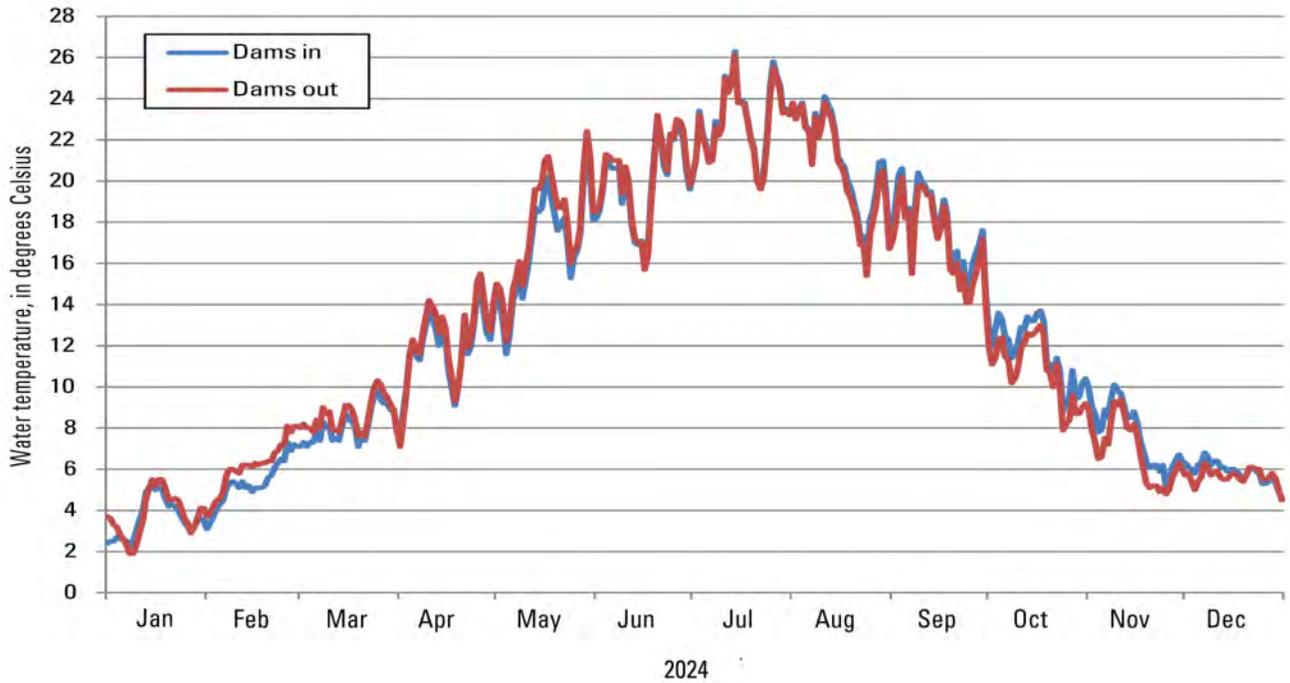
Figure 13. Graph showing simulated Klamath River mean December water temperatures using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.



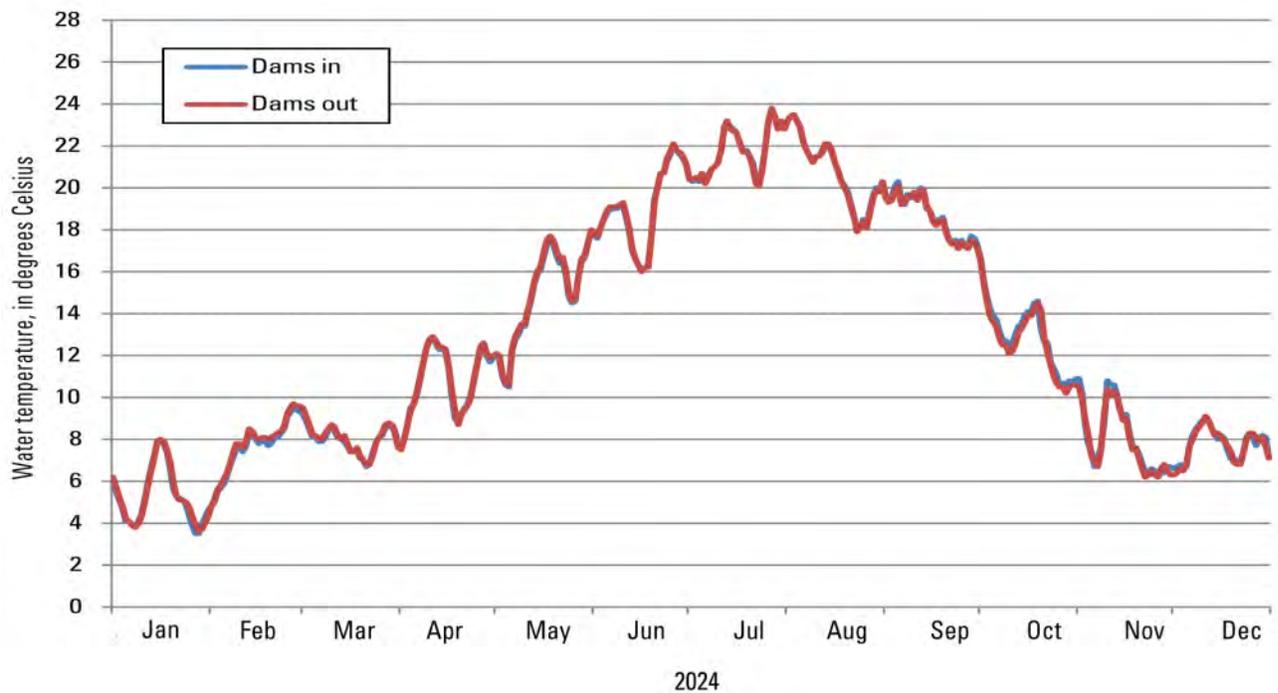
**Figure 14.** Graph showing simulated Klamath River daily mean water temperatures at J.C. Boyle Reservoir (RM 226.8) for a median-flow year using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.



**Figure 15.** Graph showing simulated Klamath River daily mean water temperatures below Iron Gate Dam (RM 190) for a median-flow year using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.



**Figure 16.** Graph showing simulated Klamath River daily mean water temperatures near Seiad Valley, California (RM 130.7) for a median-flow year using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.



**Figure 17.** Graph showing simulated Klamath River daily mean water temperatures near the river mouth (RM 2.7) for a median-flow year using National Marine Fisheries Service 2010 Biological Opinion flow requirements as input values.

Removal of the dams increased simulated water temperatures from January through June at almost all locations between J.C. Boyle Reservoir and the mouth of the river. During this period, the reservoirs typically are full, and water released at the hydropower intake level is cooler than water at the surface level. The hydropower intakes for Copco 1 and Iron Gate Dams are 33 and 35 ft below normal pool elevations, respectively (Blair Greimann, Bureau of Reclamation, oral commun., 2011). The highest simulated mean monthly increases in water temperature (1.7–2.2°C) occurred in May downstream of Iron Gate Dam. From August to December, dam removal had the opposite effect and generally cooled water temperatures because the thermal heat that accumulates in the reservoir water over the summer no longer existed under the scenario. During August–December, water temperatures decreased 1°C or more from Copco Lake to locations 50 mi or more downstream. The highest simulated mean monthly temperature decrease was 4°C in October, just downstream of Iron Gate Dam.

The simulated effects of dam removal were evident as far upstream as RM 230.2, which coincides with the upstream boundary of the existing J.C. Boyle Reservoir (table 2). Simulated mean water temperatures for July and August at this location were more than 1°C cooler for the “dams out” scenario than for the “dams in” scenario. Downstream, near the ocean, the simulated effects of dam removal were small (less than 0.2°C) for most months. However, the simulated mean water temperature near the ocean for November was almost 0.5°C cooler for the “dams out” scenario than for the “dams in” scenario.

**Table 2.** Differences in simulated mean monthly water temperatures at various locations in the Klamath River for the 50-year simulation period, computed as the results with dams in place minus the results with the dams removed.

[Negative values indicate warming; positive numbers indicate cooling. Blue and red shaded cells indicate a cooling or warming, respectively, of more than 1 degree Celsius resulting from dam removal; --, unnamed.]

Location	River mile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Link River Dam	252.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Below Keno Dam	233.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
--	230.2	0.1	0.2	0.2	0.4	0.5	0.6	1.1	1.4	1.0	0.7	0.3	0.1
J.C. Boyle Reservoir	226.8	0.1	0.2	0.2	0.0	-0.1	-0.1	-0.3	-0.4	-0.2	-0.2	0.2	0.1
--	205.1	0.1	0.1	0.1	-0.1	-0.1	-0.2	-0.4	-0.4	-0.2	0.0	0.2	0.1
Copco Lake	198.8	-0.5	-0.7	-0.3	-0.3	-1.0	-0.5	0.6	2.4	2.5	2.4	1.9	0.9
--	197.1	-0.3	-0.6	0.0	0.1	-0.8	-0.5	0.3	2.2	2.4	2.4	1.9	1.0
Below Iron Gate Dam	190.0	-0.3	-1.2	-0.8	-0.6	-1.7	-1.2	-0.1	2.5	3.5	4.0	3.3	2.1
--	186.6	-0.5	-1.2	-1.0	-1.0	-2.2	-1.8	-0.8	1.6	2.8	3.3	2.9	1.8
--	184.9	-0.4	-1.2	-1.0	-1.0	-2.2	-1.8	-0.7	1.5	2.7	3.2	2.8	1.8
--	182.0	-0.4	-1.1	-1.0	-0.9	-2.1	-1.6	-0.6	1.4	2.5	3.0	2.8	1.7
Below Shasta River	176.6	-0.3	-1.0	-0.9	-0.8	-1.9	-1.5	-0.5	1.3	2.3	2.6	2.4	1.5
--	171.4	-0.3	-0.9	-0.8	-0.7	-1.6	-1.2	-0.3	1.3	2.1	2.5	2.3	1.5
--	160.9	-0.2	-0.9	-0.7	-0.6	-1.5	-1.0	-0.2	1.3	2.0	2.4	2.3	1.5
--	152.7	-0.2	-0.8	-0.7	-0.5	-1.2	-0.8	-0.1	1.1	1.6	2.1	2.2	1.4
--	147.2	-0.2	-0.8	-0.7	-0.4	-1.1	-0.7	-0.1	0.9	1.4	1.9	2.1	1.4
Below Scott River	142.9	-0.1	-0.5	-0.5	-0.3	-0.6	-0.4	-0.1	0.3	0.7	1.1	1.6	1.0
Near Seiad Valley, CA	130.7	-0.1	-0.5	-0.5	-0.2	-0.6	-0.3	0.0	0.3	0.6	1.0	1.4	0.9
--	106.7	-0.1	-0.5	-0.5	-0.2	-0.6	-0.3	0.0	0.3	0.6	1.0	1.4	0.9
--	105.4	-0.1	-0.5	-0.4	-0.2	-0.5	-0.3	0.0	0.2	0.6	1.0	1.4	0.9
--	98.5	-0.1	-0.4	-0.4	-0.2	-0.5	-0.2	0.0	0.1	0.4	0.7	1.3	0.9
Below Salmon River	65.9	0.0	-0.3	-0.3	-0.1	-0.2	-0.1	0.0	0.1	0.3	0.5	0.9	0.6
Orleans, CA	59.1	0.0	-0.3	-0.3	-0.1	-0.2	-0.1	0.0	0.1	0.3	0.5	0.9	0.6
--	53.5	0.0	-0.3	-0.3	-0.1	-0.2	-0.1	0.0	0.1	0.3	0.5	0.9	0.5
--	49.5	0.0	-0.3	-0.3	-0.1	-0.2	-0.1	0.0	0.1	0.2	0.5	0.9	0.5
Below Trinity River	43.3	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.1	0.2	0.3	0.5	0.3
--	16.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1	0.3	0.5	0.3
Near Klamath, CA	2.7	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1	0.3	0.5	0.3
Pacific Ocean	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.1	0.3	0.5	0.3

Simulated water temperatures downstream of Iron Gate Dam (RM 190) for the median year (fig. 15) were compared with a dry and a wet year (fig. 18). Water temperatures for the dry year were warmer on average than for the median and wet years for both the “dams in” and “dams out” scenarios. Conversely, water temperatures for the wet year were cooler on average than for the median and dry years. The dry and wet years were

determined by selecting the years having mean annual flows just downstream of Link River Dam (RM 252.9) that were nearest the 25th and 75th percentile flows, respectively. The 43rd year in the 50-year period was used as the dry year and was based on 2003 meteorological conditions. The 38th year was used as the wet year and was based on 1998 meteorological conditions.

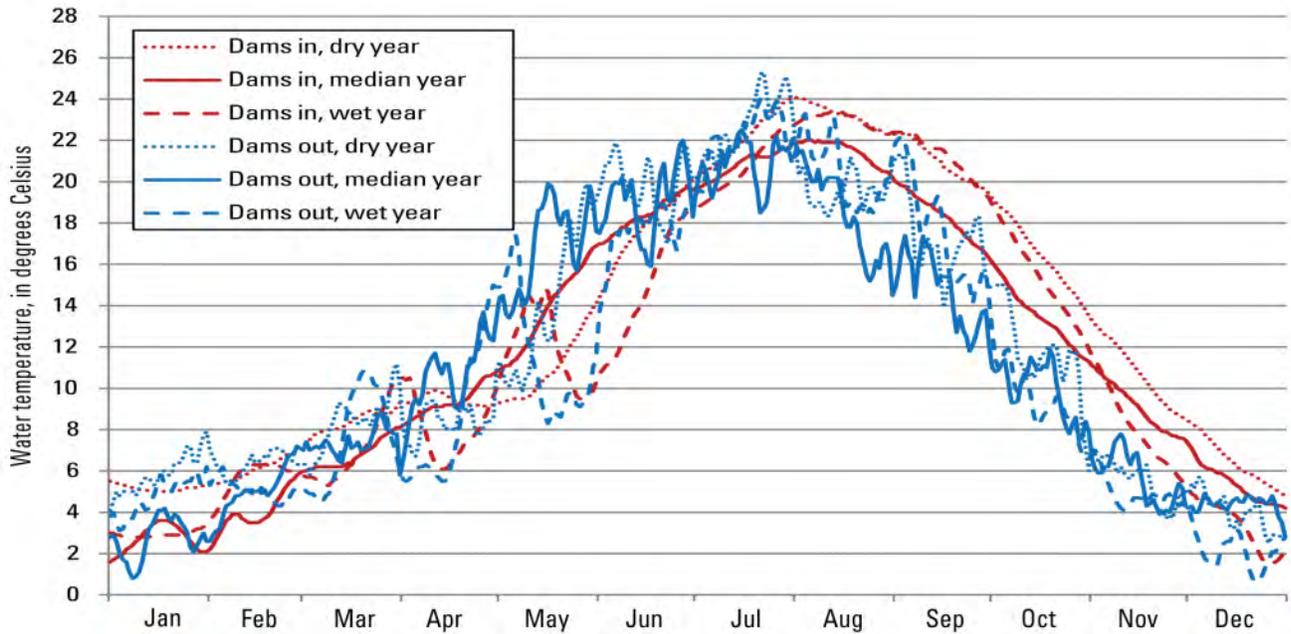


Figure 18. Graph showing simulated dry, median, and wet year Klamath River daily-mean water temperatures downstream of Iron Gate Dam (RM 190) using 2010 Biological Opinion flow requirements as input values.

The simulated streamflow and water temperature values for the "dams in" and "dams out" scenarios from the RBM10 model created for the Klamath River application are available at <http://pubs.usgs.gov/of/2011/1311/>.

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