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

Prepared in cooperation with
Unified Sewerage Agency of Washington County, Oregon

Effects of Hypothetical Management Scenarios on Simulated Water Temperatures in the Tualatin River, Oregon

Water-Resources Investigations Report 00–4071
Supplement to Water-Resources Investigations Report 97–4071

science for a changing world

Cover photograph. Stafford Bridge on the Tualatin River, Oregon. (Photograph courtesey of Tirian Mink, Portland, Oregon.)

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By JOHN C. RISLEY

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Portland, Oregon
2000

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CONVERSION FACTORS

Multiply	By	To obtain
acre	0.001562	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.646317	millions of gallons per day (Mgal/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

Temperature in degrees Celsius (^oC) as follows: $^oC = (^oF - 32)/1.8$.

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called Mean Sea Level of 1929.

ACKNOWLEDGMENTS

The author gratefully acknowledges several agencies and individuals for providing assistance and data used in the analyses for this report. The Unified Sewerage Agency of Washington County, Oregon, provided effluent flow and temperature data in addition to financial assistance. Jerry Rodgers, Oregon Water Resources Department, provided stage and discharge data, which were used to define boundary conditions for model simulations. The Lake Oswego Corporation provided operation data for the Oswego diversion dam at river mile 3.4. The Oregon State Climate Service provided meteorological data collected at Hillsboro Airport. Finally, the U.S. Geological Survey extends its appreciation to landowners who provided river access for data collection.

Effects of Hypothetical Management Scenarios on Simulated Water Temperatures in the Tualatin River, Oregon

By **John C. Risley**

SIGNIFICANT FINDINGS

Water temperature is one of the most important factors determining the health of fish and other aquatic organisms. If water temperatures warm beyond a critical threshold, particularly during the sensitive life stages of fish, survival can markedly decrease. In 1996, the State of Oregon adopted a revised maximum water temperature standard of 17.8°C (degrees Celsius) (64°F [degrees Fahrenheit]) for most waterways, including the Tualatin River in northwestern Oregon. To assess water temperature conditions in the Tualatin River, a recent cooperative study between the U.S. Geological Survey and the Unified Sewerage Agency of Washington County, Oregon, used two dynamic-flow heat-transport models, DAFLOW-BLTM (river mile [RM] 63.9-RM 38.4) and CE-QUAL-W2 (RM 3 8.4-RM 3.4). After the models were calibrated with data collected during the 1994 low-flow season, they were used to simulate various hypothetical water-management scenarios. Results from the first 10 scenarios were published in an earlier report. This report presents the results of an additional 16 scenarios for both 1994 and 1995 conditions. In all 16 scenarios, the State's temperature standard (17.8°C) was exceeded in much of the lower reaches of the Tualatin River during the warmer months in both years.

* The effect of diverting 1.33 ft^3/s (cubic feet per second) of Rock Creek Wastewater-Treatment plant (WWTP) effluent for irrigation was evaluated. Temperatures downstream of that facility (RM 38.1) for most months decreased about 0.05°C or less. Farther downstream, near RM 10, the effect was almost negligible. The effect of the diversion is slightly more apparent in the 1994 simulation than in the 1995 simulation. In a similar follow-up scenario, a constant flow of 1.33 ft^3/s was withdrawn from the river at RM 37.3 and an additional constant flow of 2.0 ft^3/s was released from Henry Hagg Lake to compensate. The effect of this diversion/augmentation on the river system was also fairly minimal for both 1994 and 1995. Temperatures generally decreased from RM 60.0 to RM 3.4 by about 0.05 to 0.1°C. For most months, the overall cooling resulting from this scenario was slightly greater than the cooling resulting from the former scenario.

* In another set of scenarios, the effect of piping and then releasing Rock Creek WWTP effluent at two upstream locations (RM 43.8 and RM 55.2) was evaluated. A constant flow of 5 Mgal/d (million gallons per day) was released at each upstream location, in addition to a constant release of either 10, 20, or 30 Mgal/d of effluent at RM 38.1. Temperatures increased between RM 55.2 and RM 38.1 by about 1.0°C or less, but were still within compliance with the water-quality standard. Downstream of RM 38.1 the river temperature decreased (generally 0.6°C or less) if the release from Rock Creek WWTP was only 10 Mgal/d. If the release from Rock Creek WWTP was 20 or 30 Mgal/d, tem-

peratures downstream of RM 38.1 generally increased. However, the magnitude of the increase was generally less than 1.0°C.

* The temperature effect resulting from constant 25, 45, or 65 Mgal/d effluent releases from the Rock Creek (RM 38.1) and Durham (RM 9.3) WWTPs was evaluated. Temperatures throughout the reach downstream of Rock Creek WWTP and, to a lesser extent downstream of Durham WWTP, increased proportionately. The magnitude of the increases was as much as 0.6, 1.5, and 2.2°C for the three scenarios, respectively.

* In another scenario, a cooler water-temperature data set, representing more shaded "natural" background conditions, was used as input to the model upper boundary at Gaston (RM 63.9). Water temperatures decreased substantially between RM 63.9 and the confluence with Scoggins Creek (RM 60.0) by as much as 4.0°C. However, the effect of the temperature decrease was dampened by the large volume of colder water flowing from Scoggins Creek as a result of releases from Henry Hagg Lake. For most of the reach downstream of RM 60.0, the overall cooling effect of this scenario was less than 0.5°C. In a follow-up scenario, the same model upper boundary condition was used in conjunction with the "natural" background conditions scenario from an earlier study. Water temperatures again decreased substantially between RM 63.9 and the confluence with Scoggins Creek (RM 60.0). However, between Scoggins Creek and the Dairy Creek confluence (RM 44.8), water temperatures gradually increased because the unnaturally cool water released from Henry Hagg Lake was not present. However, almost all of the reach above Rood Bridge (RM 38.4) was still in compliance with the water-quality standard. Below RM 38.4 temperatures increased (1.0°C or less) for July and August and decreased for other months.

* The effect of setting the temperature of effluent released at RM 38.1 and RM 9.3 equal to the temperature of the river was evaluated. Temperatures downstream of RM 38.1 decreased by as much as 2.4°C. The reduction then tapered off to 0.5°C upstream of RM 9.3. Downstream of RM 9.3, temperatures decreased by as much as 1.2°C.

* Another scenario was used to evaluate the effect of releasing a purchased allotment of Scoggins Dam flow (up to, but not exceeding 10 Mgal/d) at RM 38.1 instead of into Scoggins Creek. Observed Scoggins Dam temperature data were used for the allotted flow. Temperatures increased for all months except October from RM 60.0 to RM 38.1 by as much as 0.6°C. However, downstream of RM 38.1, temperatures decreased from as much as 0.7°C for all months except October. However, the effect of the supplemental release became less pronounced farther downstream.

* The effect of constant effluent releases of 20, 25, 45, and 65 Mgal/d at two WWTPs (RM 38.1 and RM 9.3) was evaluated. The 1994 and 1995 measured effluent temperature data from the WWTPs were used, except that the temperatures were not permitted to be greater than 17.8°C. For most months, the temperature in the reach downstream of both WWTPs decreased in all four scenarios. From RM 38.1 to RM 9.3, the temperature decrease was less than 1.0°C. Downstream of the Durham WWTP (RM 9.3), temperatures decreased almost by 2.0°C.

INTRODUCTION

In 1994, the U.S. Geological Survey (USGS) and the Unified Sewerage Agency of Washington County, Oregon (USA) began a cooperative study to better understand water-temperature variations in the Tualatin River and to assess mitigative water-management solutions. Continuous water-temperature data were collected at locations along the main stem of the river and along the major tributaries during the low-flow periods of 1994 and 1995. The 1994 data were used to develop and calibrate flow and water-temperature models characterizing conditions in the main stem. The models were used to simulate 10 hypothetical water-management scenarios, which would enable water managers to understand the effects of various human activities on water temperatures. Modeling results from the study are presented in Risley (1997); the data collected are presented in Risley and Doyle (1997). This report presents the water-temperature model simulation results of 16 additional hypothetical water-management scenarios using the 1994 and 1995 data. The additional modeling was funded by the USGS and the USA under a cooperative agreement. For a comprehensive description of the water-temperature models and their underlying assumptions, refer to Risley (1997).

Background

Water temperature is one of the most important factors determining the overall health of fish and other aquatic organisms. If water temperatures warm beyond a critical threshold, particularly during sensitive life stages of fish, survival can markedly decrease (Mullane and others, 1995). In the Tualatin River and many other Oregon streams, the critical water-temperature threshold for many cold-water species is reached and surpassed during the low-flow periods from May to October. Under State of Oregon regulations revised in 1996, for waterways like the main-stem of the Tualatin River, where salmonoid rearing and migration has been declared a beneficial use, an activity is not permitted to raise the temperature of the receiving water body if the receiving water body already has exceeded 17.8^{o}C (degrees Celsius) (64^{o}F [degrees Fahrenheit]) (Oregon Administrative Rules [OAR] 340-041-0445 (2) (b) (A) (i)) on the basis of a 7-day moving average of daily maximum temperatures (OAR 340-41-006 (54), January 11, 1996). In waters and periods of the year designated by the State to support “native salmonid spawning, egg incubation, and fry emergence from the egg and from the gravels” a more stringent criterion of 12.8^{o}C (55.0^{o}F) can apply (OAR 340-041-0445 (2) (b) (A) (iv)).

Oregon Department of Fish and Wildlife (ODFW) surveys have identified streams in the Tualatin Basin as spawning, rearing, and migration habitat for winter steelhead, coho salmon, and cutthroat trout (Oregon Department of Environmental Quality, unpub. data, 1999). (Although the coho salmon are not native in the Tualatin Basin, they are now resident there as a result of the fish ladder at Willamette Falls). Some streams in the basin also could be rearing and migration (but not spawning) habitat for spring chinook. The spawning periods (which includes incubation and fry emergence) for the winter steelhead, coho salmon, and cutthroat trout are from mid-December to the end of May, mid-October to the end of February, and April to the end of June, respectively. Most, but not all, of the stream reaches included in this modeling study are along the main stem and have been identified as rearing and migration habitat. Exceedance of the State temperature standards could occur in most of this reach if temperatures exceed 17.8^{o}C (64.0^{o}F). However, Scoggins Creek from the Henry Hagg Lake to the Tualatin River, also within the study area, is spawning habitat for the three fish species mentioned. Exceedance of the State standards could occur in this reach if temperatures exceed 12.8^{o}C (55.0^{o}F) from mid-October to the end of June. A reach on the Tualatin River from Gaston (RM 63.9) to Wapato Creek (RM 61.9) is spawning habitat for the coho salmon and the winter steelhead. Exceedance of the State standards could occur in this reach if temperatures exceed 12.8^{o}C (55.0^{o}F) from mid-October to the end of May.

The Oregon Department of Environmental Quality (ODEQ) and the ODFW are in the process of determining for which streams in the basin spawning and rearing/migration will be designated as beneficial uses. The ODEQ is using this information to develop total maximum daily loads (TMDLs) for temperature. In compliance with the Federal Clean Water Act, the ODEQ listed the Tualatin River as “water-quality limited” for temperature in 1998. Once a waterway has been designated as water-quality limited, TMDLs must be developed for that water body to meet the established water-quality standard. Aside from State regulations, agencies like the ODEQ, ODFW, and USA also are concerned about the relationship between water temperature and fish survival because winter steelhead and spring chinook were listed as “threatened” under the Endangered Species Act in 1999 by the U.S. National Marine Fisheries Service. Cutthroat trout also may be listed as “threatened” in the near future.

From May through October, the mean temperature of wastewater-treatment-plants effluent on the Tualatin River is approximately 20^{o}C. During June through September, water temperatures in the lower part of the Tualatin River downstream of Rood Bridge (river mile [RM] 38.4 to RM 0.0) typically exceed the 17.8^{o}C criterion. Most point-source discharges in the

Tualatin River are effluent and urban runoff. Other human-caused water-temperature modifications include removal of riparian vegetation (resulting in a decrease in shading) and reduction of natural base-flows caused by timber harvesting, agriculture, and urban development. During some months of the year, flow releases from Scoggins Dam can decrease the temperature in the main river body. However, only after the separate impacts of these human-caused factors have been more clearly quantified and characterized will it be possible to develop cost-effective remedial measures to the problem.

Purpose and Scope

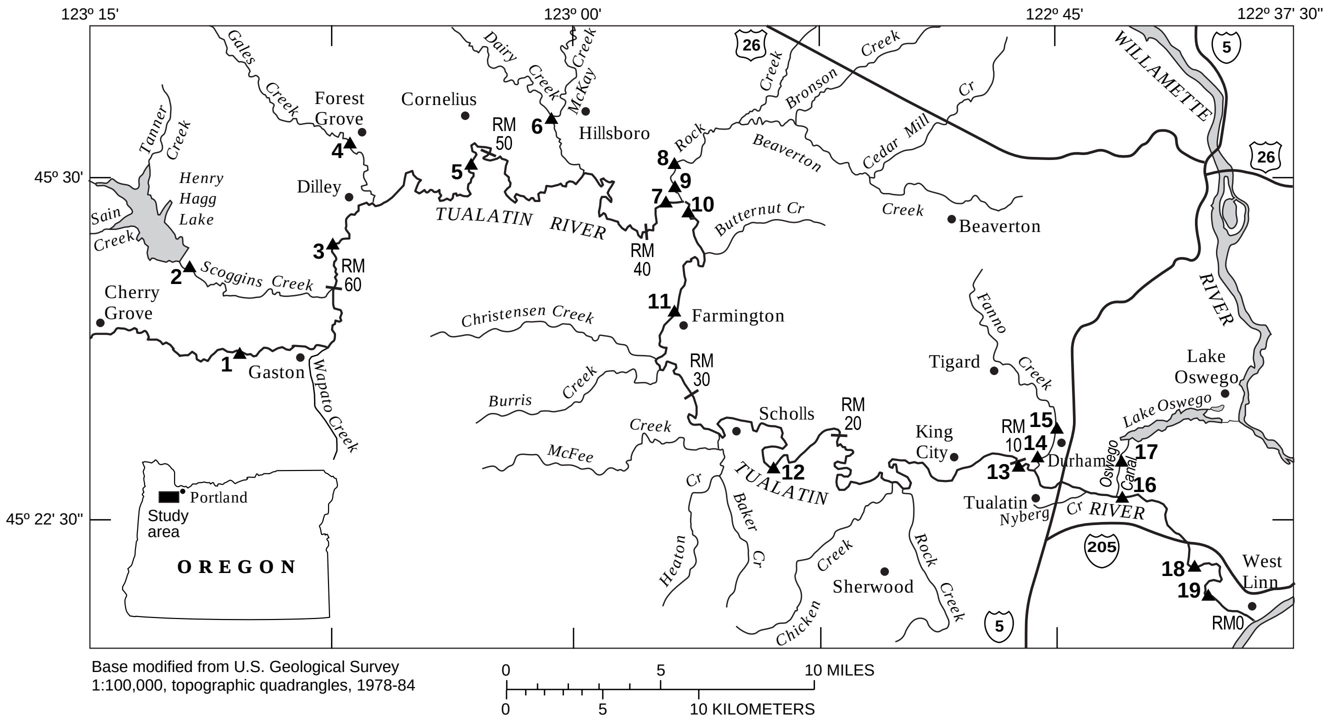
The objectives of the USGS-USA cooperative water-temperature study were to (1) quantify the temporal and spatial patterns of water temperature in the main stem of the Tualatin River and the mouths of its major tributaries, (2) determine the relation of water temperature in the Tualatin River and its major tributaries to climatic conditions, seasonal and daily variations, and human-caused factors, and (3) assess the effects of various flow-management practices on water temperature during the low-flow season (May through October).

This report provides a brief description of the data-collection network and the simulation models used in the study, a description of the 1995 model simulation (not included in the initial study report [Risley, 1997]), and the results of additional simulations of hypothetical water-management scenarios (also not included in the initial study report). The current USGS Tualatin water-temperature-modeling activities are a component of a broader, ongoing USGS-USA cooperative water-quality study of the Tualatin River. Additional information about these studies and their publications can be found at http://oregon.usgs.gov/projs_dir/pn356/.

Description of the Study Area

The Tualatin River, a major tributary to the Willamette River, is located in northwestern Oregon west of Portland (fig. 1). The 712-square-mile (mi^2) basin is bounded by the Coast Range on the west and northwest, the Tualatin Mountains on the east and northeast, and the Chehalem Mountains on the south. The study reach extended from Gaston (RM 63.9) to the Oswego diversion dam (RM 3.4) and had an approximate 80-foot change in elevation. The study reach is a regulated system. Completion of Scoggins Dam, on Scoggins Creek, in the early 1970s created Henry Hagg Lake. With the exception of the reach 2 to 3 miles below RM 63.9, most of the study reach is slow and meandering. Major tributaries to the Tualatin River include Scoggins, Gales, Dairy, Rock, and Fanno Creeks. The study area has a modified-maritime climate, with annual precipitation averaging about 45 inches per year; minimum and maximum air temperatures average between 0 and 17^{o}C (32 and 62^{o}F) during the winter and between 5 and 28^{o}C (42 and 82^{o} F) during the summer. Approximately 50 percent of the drainage basin is forestland, 35 percent is used for agriculture, and 15 percent is urbanized. Urban development is expanding in the eastern and central regions of the basin. Vegetation along the study reach is dominated by white oak, ash, and cottonwood, with an understory of grass and shrubs. Some coniferous trees, mostly Douglas firs, border the river in the lower section of the study reach. Most soils in the study area can be characterized as silt loams and loams that are moderately well-drained and generally contain naturally high concentrations of phosphorus.

As agriculture and urban development grew during the 20th century, the Tualatin River came under increasing flow regulation. In addition to the flow augmentation provided by Henry Hagg Lake, flows in the headwaters of the Tualatin River are augmented by a diversion from the Trask River Basin, which is located on the western side of the Coast Range Mountains. At the Springhill Pumping Plant (RM 56.1), withdrawals are made for both irrigation by the Tualatin Valley Irrigation District and municipal and industrial water use by the Joint Water Supply Commission. Additional irrigation withdrawals are taken directly from the river by users at numerous locations along the main stem. Flows from Gales Creek and Dairy Creek are unregulated and predominately from farmland and forest drainage. Rock Creek flow is from a mixture of agricultural and urban drainage. Most of Fanno Creek flow is from urban drainage. During the summers of 1994 and 1995, the two principal USA-operated WWTPs, at Rock Creek (RM 38.1) and Durham (RM 9.3), each discharged an average of approximately 28 ft^3/s (18 million gallons per day [Mgal/d]) of treated effluent into the river. At RM 6.7, a gravity flow canal (Oswego Canal) diverts approximately 60 ft^3/s of water from the Tualatin River to Lake Oswego. The flow through the canal is enabled by the Oswego



EXPLANATION

12▲ **Sampling site and map number —**See table 1

1 Tualatin River near Gaston
2 Scoggins Creek below Henry Hagg Lake, near Gaston
3 Tualatin River near Dilley
4 Gales Creek at Route 47 at Forest Grove
5 Tualatin River at Golf Course Road near Cornelius
6 Dairy Creek at Route 8 near Hillsboro
7 Tualatin River at Rood Bridge at Hillsboro
8 Rock Creek near Hillsboro
9 Rock Creek Wastewater-Treatment Plant near Hillsboro
10 Tualatin River at irrigation pumphouse at Meriwether Golf Course
11 Tualatin River at Farmington
12 Tualatin River near Scholls
13 Tualatin River near Tualatin
14 Durham Wastewater-Treatment Plant near Durham
15 Fanno Creek at Durham
16 Tualatin River at Oswego Canal at Tualatin
17 Oswego Canal near Lake Oswego
18 Tualatin River at Oswego diversion dam near West Linn
19 Tualatin River at West Linn

Figure 1. The Tualatin River Basin, Oregon. (RM, river mile)

diversion dam on the Tualatin River near West Linn at RM 3.4.

DATA COLLECTION

Continuous water-temperature and streamflow data were collected in 1994 and 1995 from May 1 to November 30 at 19 fixed-station continuous-monitoring sites established by the USGS, Oregon Water Resources Department (OWRD), and other agencies (fig. 2 and table 1). Meteorological data used as input to the models included air temperature, wind speed, and solar radiation collected at three locations in the study reach. Additional input data included dewpoint temperature, wind direction, and precipitation collected at the Hillsboro Airport. Data used for configuring the model parameters included bathymetric, channel cross-section, and riparian shading measurements. Risley and Doyle (1997) described the data - collection equipment, data-collection protocols, and quality-assurance protocols used in the study.

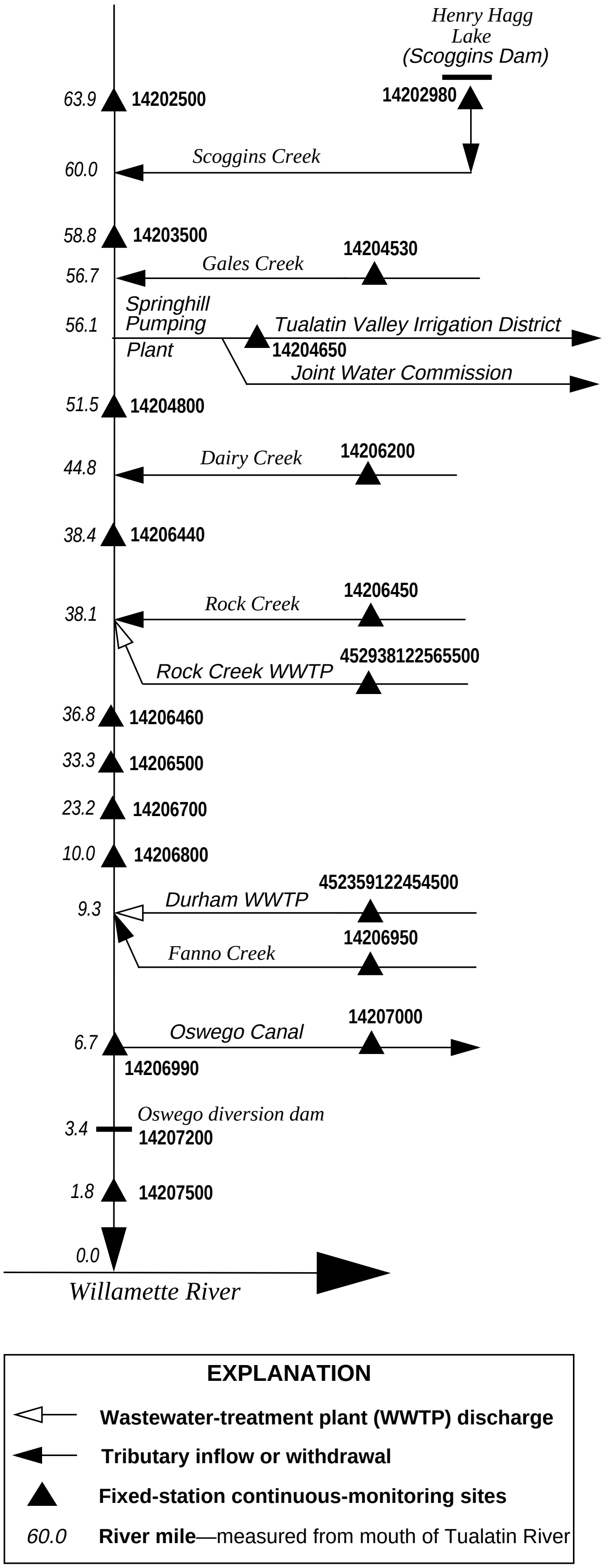


Figure 2. Relative positions of selected tributaries, fixed-station continuous-monitoring sites, and wastewater-treatment plants, Tualatin River Basin, Oregon, 1994–95.

Water Temperature

Continuous water-temperature measurements were recorded half hourly by the USGS at 13 locations on the main stem of the Tualatin River (RM 63.9 to RM 3.4) and on major tributaries near their mouths. USA also measured and recorded half hourly effluent temperature data at the Rock Creek and Durham WWTPs. Temperature probes used by the USA at both WWTPs were checked by the USGS with certified temperature probes during both seasons. Correction shifts were applied to the USA data before they were used in the modeling.

Streamflow

Streamflow data were collected by the USGS and OWRD at locations in the Tualatin River Basin for this and other studies. Flow data collected at nine stream-gaging stations were used as upstream boundaries to the models. Data from six other stations, on the main stem within the study reach, were used to calibrate the flow models. The data were collected by USGS and OWRD according to standardized techniques of the USGS (Rantz and others, 1982). The USGS-operated streamflow-gaging stations included Scoggins Creek below Henry Hagg Lake near Gaston (14202980), Tualatin River near Dilley (14203500), Fanno Creek at Durham (14206950), and Tualatin River at West Linn (14207500). The remaining stations used in the simulations were operated by OWRD. In addition to the streamflow-gaging stations, stage data were recorded by OWRD on the Tualatin River at the Oswego Canal (14206990). Although flow computations were not made for this station, the stage data were used in determining the approximate water level of the river during the calibration simulations. Hourly effluent flow measurements from both the Rock Creek and Durham WWTPs were made and recorded by the USA. These data also were used as boundary conditions for the simulations.

Riparian Shading

Riparian shading data were compiled from field cross-section surveys, aerial photography, and topographic maps. Because of the high level of variability in riparian shading along stream reaches, established field techniques (Bartholow, 1989) were used to opti-

Table 1. U.S. Geological Survey fixed-station continuous-monitoring sites in the Tualatin River Basin, Oregon, 1994–95

[D, Discharge; WT, water temperature; AT, air temperature; WS, wind speed; SR, solar radiation; ---, data not collected]

Site number	Station name	Station number	Station location Latitude	Station location Longitude	River mile	Data collected D	WT	AT	WS	SR
1	Tualatin River near Gaston	14202500	45°26’15"	123°10’05"	63.9	X	X	---	---	---
2	Scoggins Creek below Henry Hagg Lake, near Gaston	14202980	45°28’10"	123°11’56"	4.3	X	X	---	X	X
3	Tualatin River near Dilley	14203500	45°28’30"	123°07’23"	58.8	X	X	---	---	---
4	Gales Creek at Route 47 at Forest Grove	14204530	45°30’39"	123°06’52"	1.5	X	X	---	---	---
5	Tualatin River at Golf Course Road near Cornelius	14204800	45°30’08"	123°03’18"	51.5	X	X	X	---	---
6	Dairy Creek at Route 8 near Hillsboro	14206200	45°31’12"	123°00’34"	2.1	X	X	---	---	---
7	Tualatin River at Rood Bridge at Hillsboro	14206440	45°29’25"	122°57’01"	38.4	X	X	---	---	---
8	Rock Creek near Hillsboro	14206450	45°30’09"	122°56’48"	1.2	X	X	X	---	---
9	Rock Creek Wastewater-Treatment Plant near Hillsboro	45293812-2565500	45°29’38"	122°56’55"	38.1	X	X	---	X	X
10	Tualatin River at irrigation pumphouse at Meriwether Golf Course near Hillsboro	14206460	45°28’42"	122°56’24"	36.8	---	X[1]	X[1]	---	---
11	Tualatin River at Farmington	14206500	45°27’00"	122°57’00"	33.3	X	X[2]	---	---	---
12	Tualatin River near Scholls	14206700	45°23’39"	122°53’51"	23.2	---	X	X[1]	---	---
13	Tualatin River near Tualatin	14206800	45°23’28"	122°46’22"	10.0	---	X	---	---	---
14	Durham Wastewater-Treatment Plant near Durham	45235912-2454500	45°23’59"	122°45’45"	9.3	X	X	X[2]	X	X
15	Fanno Creek at Durham	14206950	45°24’13"	122°45’13 "	1.1	X	X	---	---	---
16	Tualatin River at Oswego Canal at Tualatin	14206990	45°22’57”	122°43’12"	6.7	X[3]	---	---	---	---
17	Oswego Canal near Lake Oswego	14207000	45°23’20 "	122°43’10"	.4	X	---	---	---	---
18	Tualatin River at Oswego diversion dam near West Linn	14207200	45°21’24"	122°41’02"	3.4	---	X	X	---	---
19	Tualatin River at West Linn	14207500	45°21’03"	122°40’30"	1.8	X	--	---	---	---

[1]Data collected in 1995 only.
[2]Data collected in 1994 only.
[3]Stage-recording station only.

mize data collection, assuring that sufficient data were collected within project resources. Field equipment included a hand held clinometer, a distance range finder, a light meter, and measuring tapes. Collected shading parameters included average vegetation height, crown measurement (average tree width), average vegetation offset, vegetation density, stream width, and bank height. The most significant obstruction of solar radiation on the water surface of the Tualatin River is vegetation. Because of the flatness of the Tualatin Valley, topographic blockage of radiation in the study area was generally limited to the height of the stream bank.

Aerial photography was used to determine the approximate canopy thickness and vegetation density of both banks of each stream segment. The canopy thickness of each segment was categorized as (1) no vegetation, (2) single row vegetation with approximately 50 percent crown closure, (3) single row vegetation with approximately 100 percent crown closure, (4) thick double row vegetation, and (5) completely wooded areas. Additional details regarding the riparian shading field surveying are documented in Risley (1997).

COMPUTER MODELS

The Stream Network Temperature (SNTEMP) model estimated riparian shading coefficients for the full study reach (RM 63.9 to RM 3.4) (Theurer and others, 1984); the Diffusion Analogy Flow (DAFLOW) model and the Branched Lagrangian Transport Model (BLTM) simulated flow and heat transport in the upper river section (RM 63.9 to RM 38.4) Jobson and Keefer, 1979; Jobson, 1981; Jobson and Schoellhamer, 1987; Jobson, 1989 and Jobson, 1997; and the CE-QUAL-W2 model simulated flow and heat transport in the lower river section (RM 38.4 to RM 3.4) (Cole and Buchak, 1995). Riparian shading coefficients estimated by the SNTEMP model were used as input data for the flow and heat-transport models used in both the upper and lower river sections. The full study reach (RM 63.9 to RM 3.4) was divided into an upper and a lower river section, because flow conditions in each section warranted using different models. Streamflow in the upper river section above Rood Bridge (RM 38.4) is vertically well mixed throughout the year. However, the river at pool locations below Scholls Bridge (RM 26.9) can become thermally stratified during low-flow periods. A one-dimensional flow and heat-transport model was selected for the upper river section, and a two-dimensional laterally averaged flow and heat-transport model was selected for the lower river section. For more information on the computer models used in the study, refer to Risley (1997).

Shading Coefficients

The shading algorithms in the SNTEMP model (Theurer and others, 1984) were used in this study to estimate solar-radiation-weighted riparian shading resulting from both topography and vegetation. Monthly mean shading coefficients (from May through October) were estimated for approximately 270 stream segments within the full study reach (RM 63.9 to RM 3.4).

Variations in topography and vegetation on each side of the stream are taken into account in the model's computations. Although the algorithms took into account variations in solar radiation for each calender day, the model output was lumped into monthly mean values. Required input data, which were collected in the field, for the shading model include (1) Julian calendar date, (2) site latitude, (3) stream segment azimuth (general orientation of the stream segment with respect to due south), (4) topographic altitude at (both sides), (5) vegetation height (both sides), (6) crown measurement (both sides), (7) vegetation offset (both sides), (8) vegetation density (both sides), and (9) stream width.

Upper River Section

DAFLOW and BLTM, used for the Gaston (RM 63.9) to Rood Bridge (RM 38.4) river reach, are flow and heat-transport models, respectively, developed and maintained by the USGS (fig. 3). The models have been used in various surface-water and water-quality studies (Jobson and Keefer, 1979; Jobson, 1981; Jobson, 1989). The two models are typically used conjunctively. The output file from DAFLOW contained half-hourly flow (for this study), cross-sectional area, width, and tributary flows and was used as input to BLTM.

DAFLOW is an unsteady-state (dynamic), one-dimensional (longitudinal), streamflow-routing model based on a simplified version of the momentum equation. DAFLOW uses a Lagrangian solution scheme;

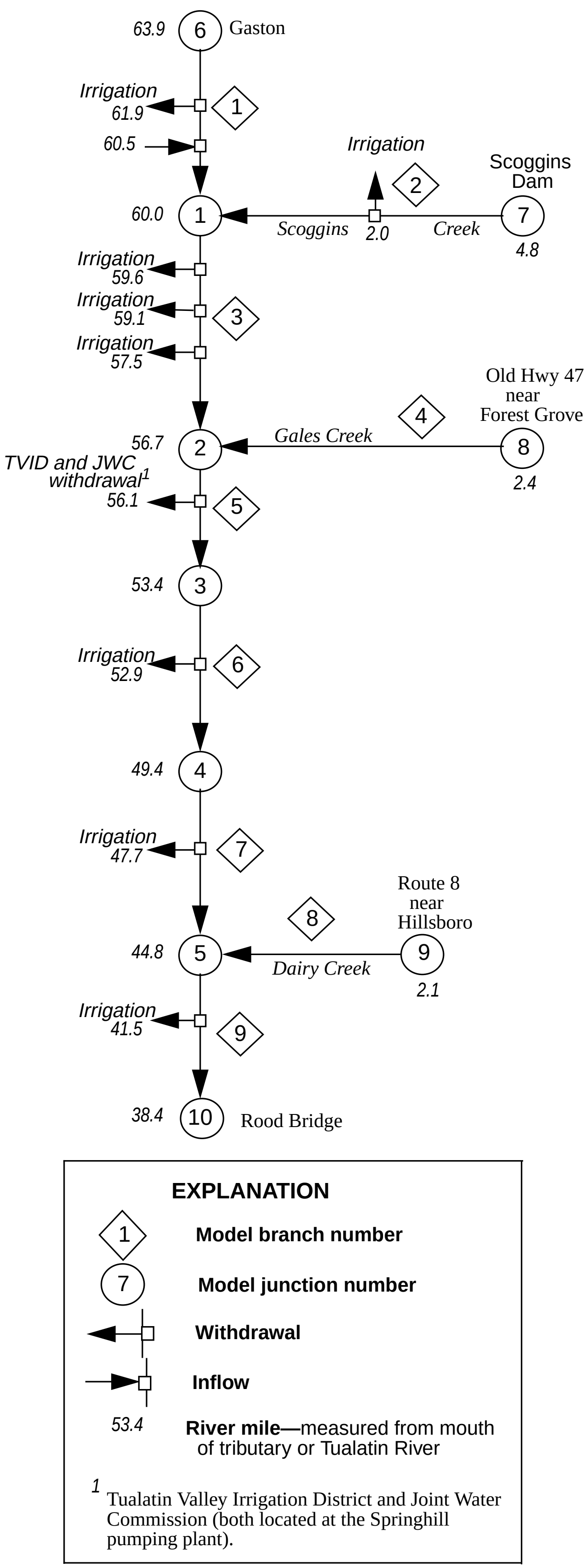


Figure 3. Diffusion Analogy Flow/Branched Lagrangian Transport Model configuration for the Tualatin River from river mile 63.9 to river mile 38.4.

such a scheme uses a computational x-coordinate reference frame that moves with the flow rather than remaining at a fixed grid location. Further details of the numerical methods have been described by Jobson (1989).

BLTM is a one-dimensional transport (water-quality) model capable of simulating the transport of solutes and/or heat in branched river systems. BLTM solves the convective-dispersion equation using a Lagrangian reference frame in which the computational nodes move with the flow. One-dimensional transport theory is explained in more detail in the BLTM's user's manual (Jobson and Schoellhamer, 1987; Jobson, 1997).

In this study the river main stem between Gaston (RM 63.9) to Rood Bridge (RM 38.4) was divided into 89 stream segments. Additional stream segments were used to define the adjoining reaches of Scoggins, Gales, and Dairy Creeks. The net heat-transfer rate through the water surface was simulated for every stream segment on a half-hourly basis. This is defined in BLTM as:

$$H_n = -K\,(T - T_e), \qquad (1)$$

where

H_n is the net heat-transfer rate,

K is the heat-exchange coefficient,

T is the water temperature, and

T_e is the equilibrium temperature.

Half-hourly incoming shortwave solar radiation, wind speed, air temperature, and dewpoint-temperature data were used to compute the heat-exchange coefficient and equilibrium temperatures at each stream segment for every half-hour time step. To account for variations in riparian shading along the stream, the incoming shortwave solar radiation for a given stream segment was reduced by the monthly riparian shading coefficient estimated by the SNTEMP model for that stream segment by using the following equation:

$$S = \mathrm{S_m}(1 - RS), \qquad (2)$$

where

S is incoming shortwave solar radiation reduced for riparian shading,

S_m is measured incoming shortwave solar radiation, and

RS is the monthly riparian shading coefficient.

Output from DAFLOW and BLTM includes simulated half-hourly Rood Bridge flow and water-temperature data files, respectively. These files are used as upper boundary input data to the lower river section model.

Lower River Section

CE-QUAL-W2 is a two-dimensional, laterally averaged, hydrodynamic water-quality model used for the Rood Bridge (RM 38.4) to Oswego diversion dam (RM 3.4) reach, developed and maintained by the Waterways Experiment Station of the U.S. Army Corps of Engineers in Vicksburg, Mississippi (fig. 4; Cole and Buchak, 1995). The version of CE-QUAL-W2 used in this study contains modifications made for another USGS Tualatin River water-quality modeling study (Rounds and others, 1998). Some additional modifications specific to the water-temperature study have been documented in Risley (1997).

CE-QUAL-W2 is a dynamic model capable of simulating water flow, heat flow, and water quality. Both hydrodynamics and water quality are simulated within the same model. CE-QUAL-W2 uses the laterally averaged equations of fluid motion derived from three-dimensional governing equations. Because of the complexity of the governing equations, it is necessary to use advanced numerical-solution techniques. The model uses a variable time-step algorithm that is designed to ensure the mathematical stability of the numerical methods. The time steps were generally less than 30 minutes.

The two dimensions simulated are longitudinal (along the length of the water body) and vertical. The model is well suited for narrow lakes and reservoirs that have minimal variation from side to side but tend to stratify. During low-flow periods the main stem reach from Rood Bridge (RM 38.4) to the Oswego diversion dam (RM 3.4) can be characterized as a reservoir. Using CE-QUAL-W2, the main stem was configured as a single model branch and subdivided into 153 stream segments. The number of layers varied with each segment. Although the user can select simulated temperature output from any layer, all simulated temperatures presented in this report were based on a volume-weighted 10-foot vertical average. The 10-foot water column, rather than the entire water column, was used to avoid possible distortions caused by occasional deep pools (containing cooler waters) in the river.

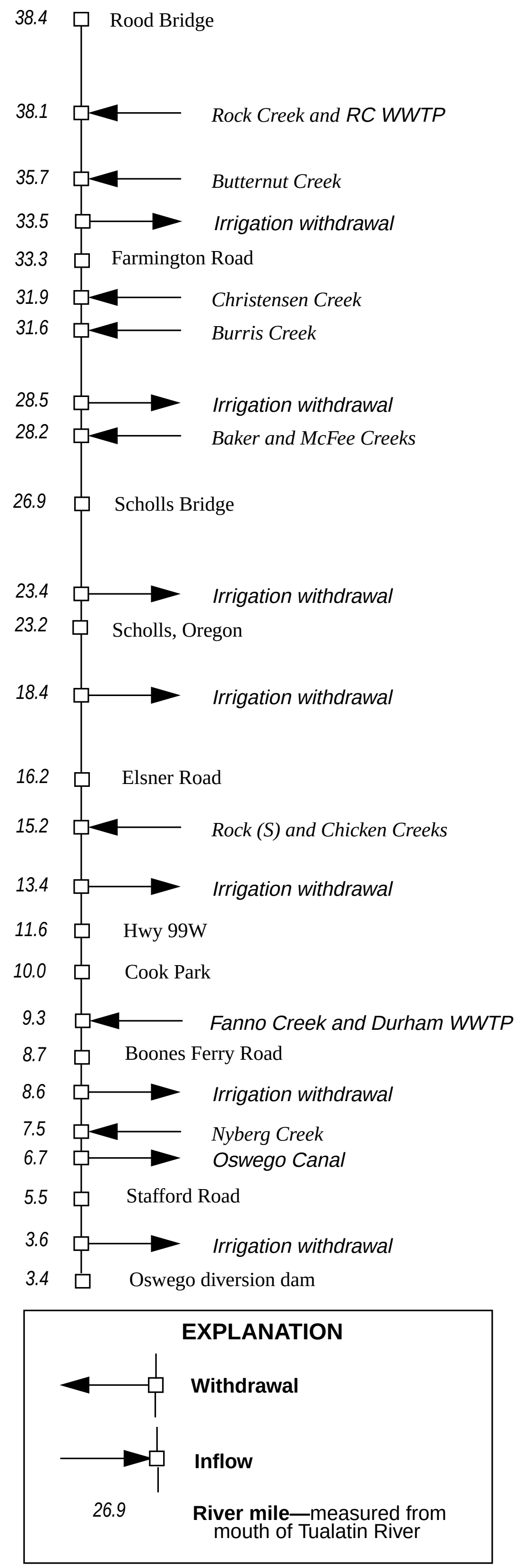


Figure 4. CE-QUAL-W2 model configuration for the Tualatin River from river mile 38.4 to river mile 3.4.

For the temperature study, the CE-QUAL-W2 heat budget subroutine was modified to compute the net heat-transfer rate through the water surface for every stream segment and every time step using the term-by-term energy equation. The equation is defined in the following:

$$H_n = H_s + H_a + H_e + H_c - (H_{sr} + H_{ar} + H_{br}), \quad (3)$$

where

H_n is the net heat-transfer rate through the water surface,

H_s is incoming shortwave solar radiation,

H_a is incoming long-wave (atmospheric) solar radiation,

H_e is evaporative heat loss,

H_c is air/water surface heat conduction

H_{sr} is reflected shortwave solar radiation,

H_{ar} is reflected long-wave solar radiation, and

H_{br} is long-wave back radiation of the water surface.

Time-varying input data required for the model included flow, water temperature, shortwave solar radiation, wind speed, wind direction, air temperature, and dewpoint temperature. The time-varying flow and water-temperature data were assigned as boundary conditions for the main branch and each of the tributaries. To account for variations in riparian shading along the stream, the incoming shortwave solar radiation for a given stream segment was reduced by the riparian shading coefficient estimated by the SNTEMP model (equation 2).

MANAGEMENT SCENARIO SIMULATIONS

The focus of the water-temperature study was a better understanding of spatial and temporal water-temperature variations in the Tualatin River. The development and calibration of water-temperature models, and the simulation of 10 initial hypothetical water-management scenarios using flow and water-temperature data collected from May to November 1994 were reported in Risley (1997). The scenarios enable water managers to understand the effects of various human activities on water temperatures. After completion of the study, the calibrated models were used to simulate 16 additional management scenarios using both 1994 and 1995 data.

1995 Model Simulation

In the 1995 simulation, all model parameters, channel hydraulic coefficients, and riparian shading coefficients were set to the same values as those used for the 1994 calibration. Comparisons of observed and simulated hydrographs from May through October 1995 at Dilley (RM 58.8), Golf Course Road (RM 51.5), and Rood Bridge (RM 38.4) are shown in figure 5. Comparisons of observed and simulated water temperatures for the same time period at Dilley (RM 58.8), Golf Course Road (RM 51.5), Rood Bridge (RM 38.4), Meriwether Golf Course (RM 36.8), Scholls (RM 23.2), Cook Park (RM 10.0), and the Oswego diversion dam (RM 3.4) are shown in figure 6. Because 1995 was climatically different from 1994, its simulated water temperatures were not expected to match its 1995 observed water-temperature data as well as the 1994 calibration. The greatest differences between simulated and observed temperatures were during transition months of May and October. However, the timing of simulated daily maximum and daily minimum temperatures appears to match the timing of the observed data at all seven sites. The root mean square errors (an indication of model accuracy) between the observed and simulated daily mean water temperatures at selected sites for 1994 and 1995 monthly and 6-month periods are shown in table 2. The 1995 simulation errors were larger than the 1994 simulation errors. However, many of the errors were under 0.5^{o}C. This margin of error was considered acceptable (the USGS does not publish temperature data with an accuracy greater than 0.5^{o}C).

Monthly mean water-temperature data collected at the Oswego diversion dam from May to November for the years 1991 to 1998 are shown in table 3. Monthly mean air temperature and monthly precipitation data collected at the Hillsboro Airport for the years 1991 to 1998 are shown in table 4 and 5, respectively. For both water and air temperature, the differences between the 1994 and 1995 monthly mean data are approximately 1^{o}C or less (with the exception of November). The 1994 and 1995 monthly mean values were also close to the 8-year mean of monthly mean values for both water and air temperature. Although the 1994 and 1995 temperatures were close to each other, 1995 was wetter (and thus cloudier) for 5 out of the 7 months (May to November) and had less shortwave solar radiation.

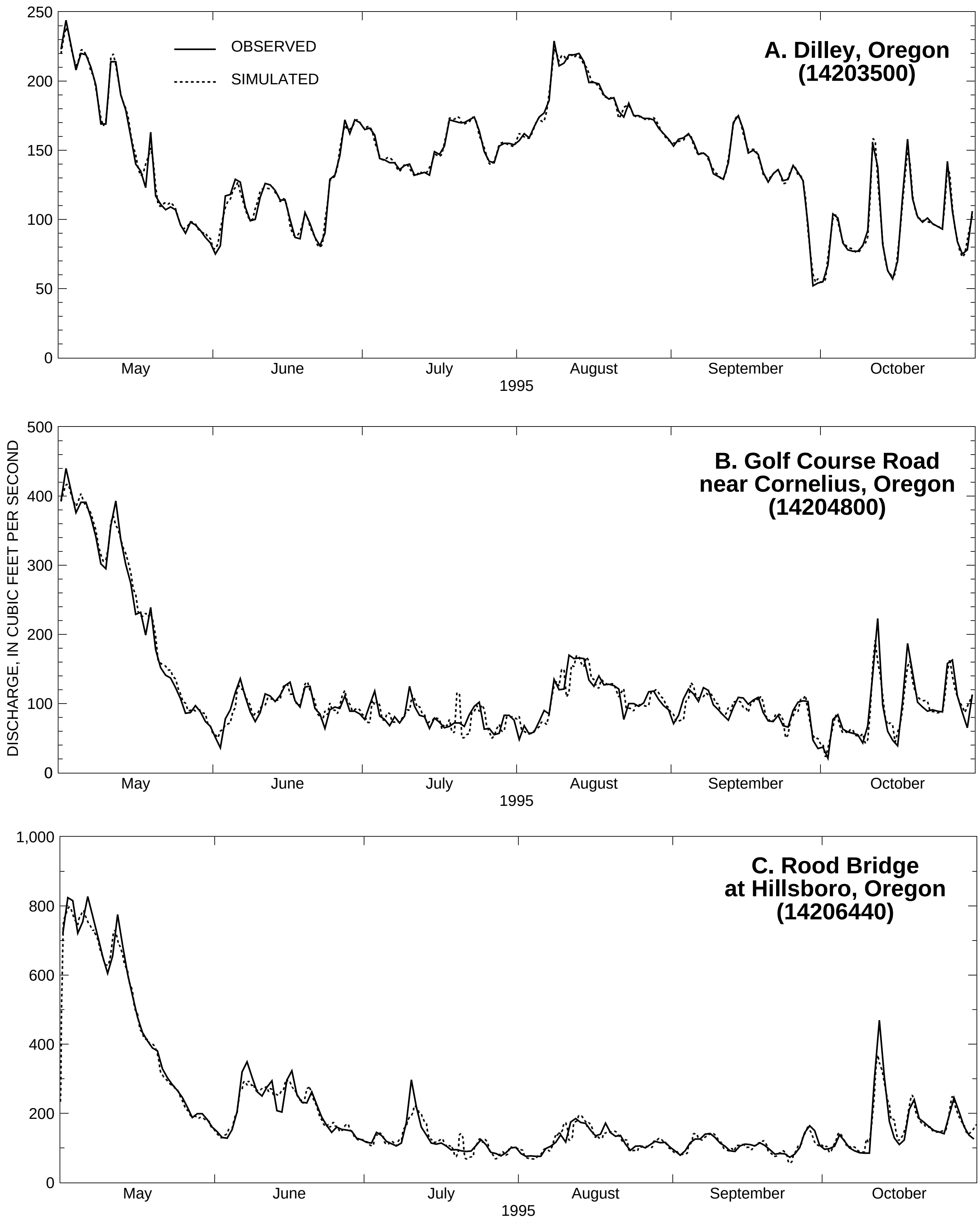


Figure 5. Observed and simulated discharge from May through October 1995 in the Tualatin River, Oregon.

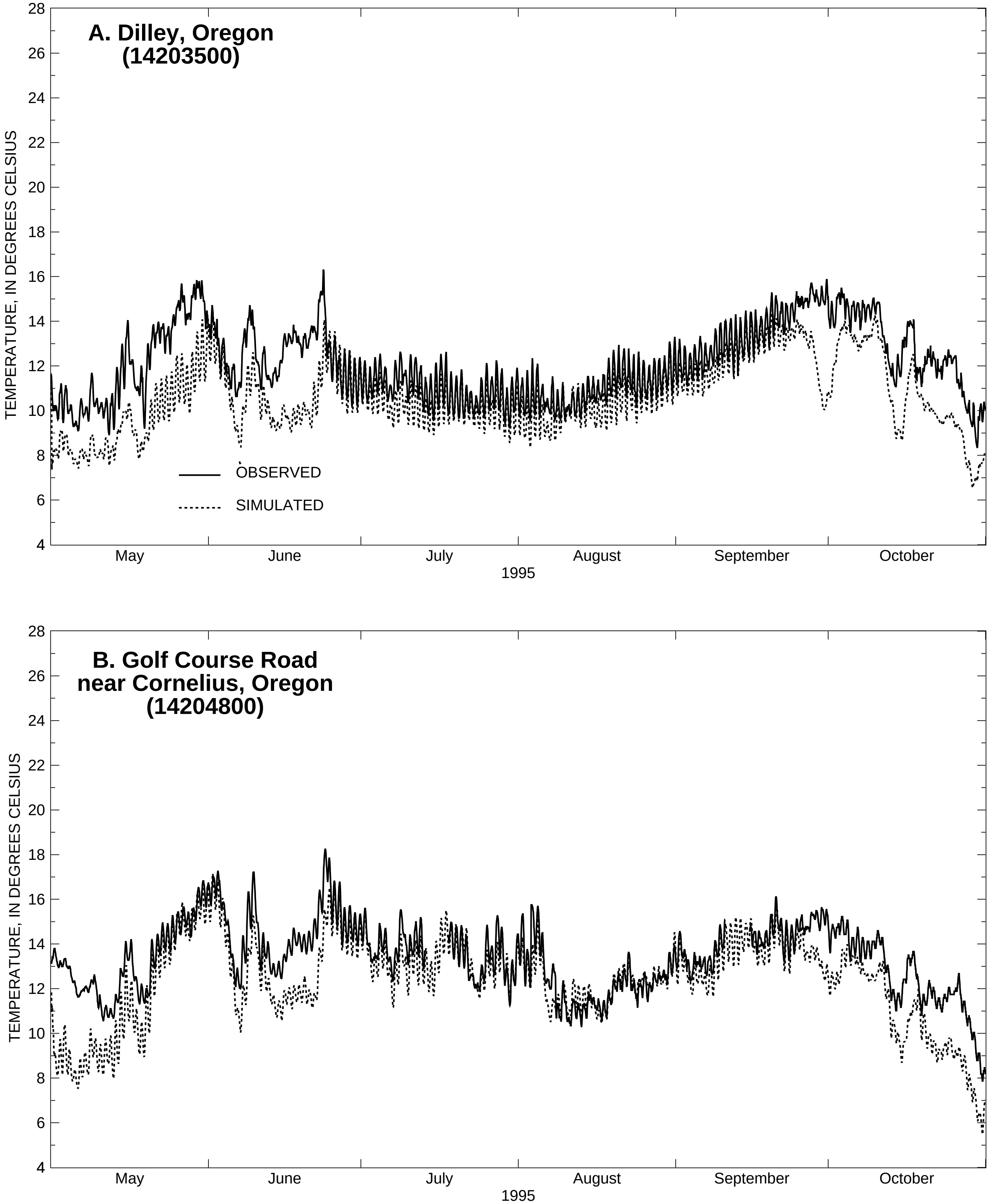
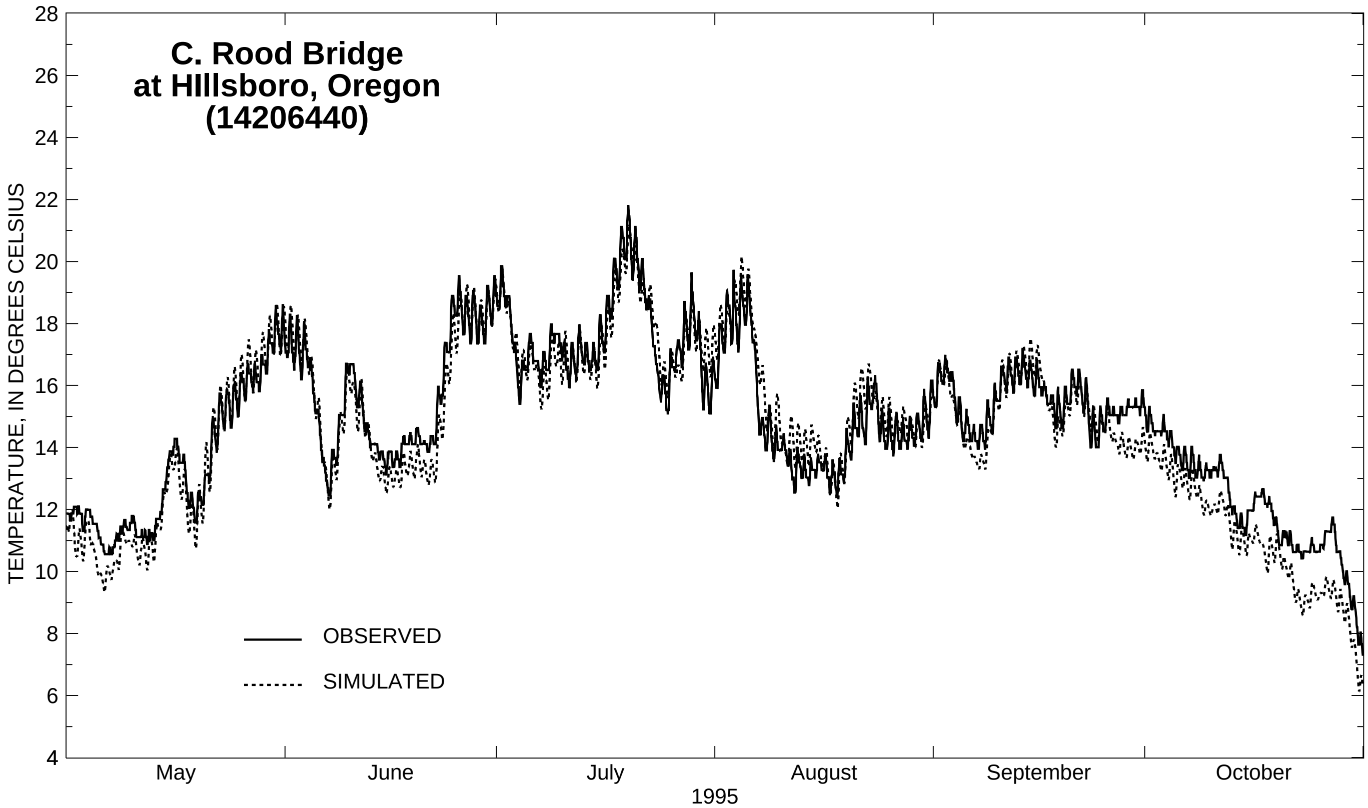


Figure 6. Observed and simulated water temperatures from May through October 1995 in the Tualatin River, Oregon.



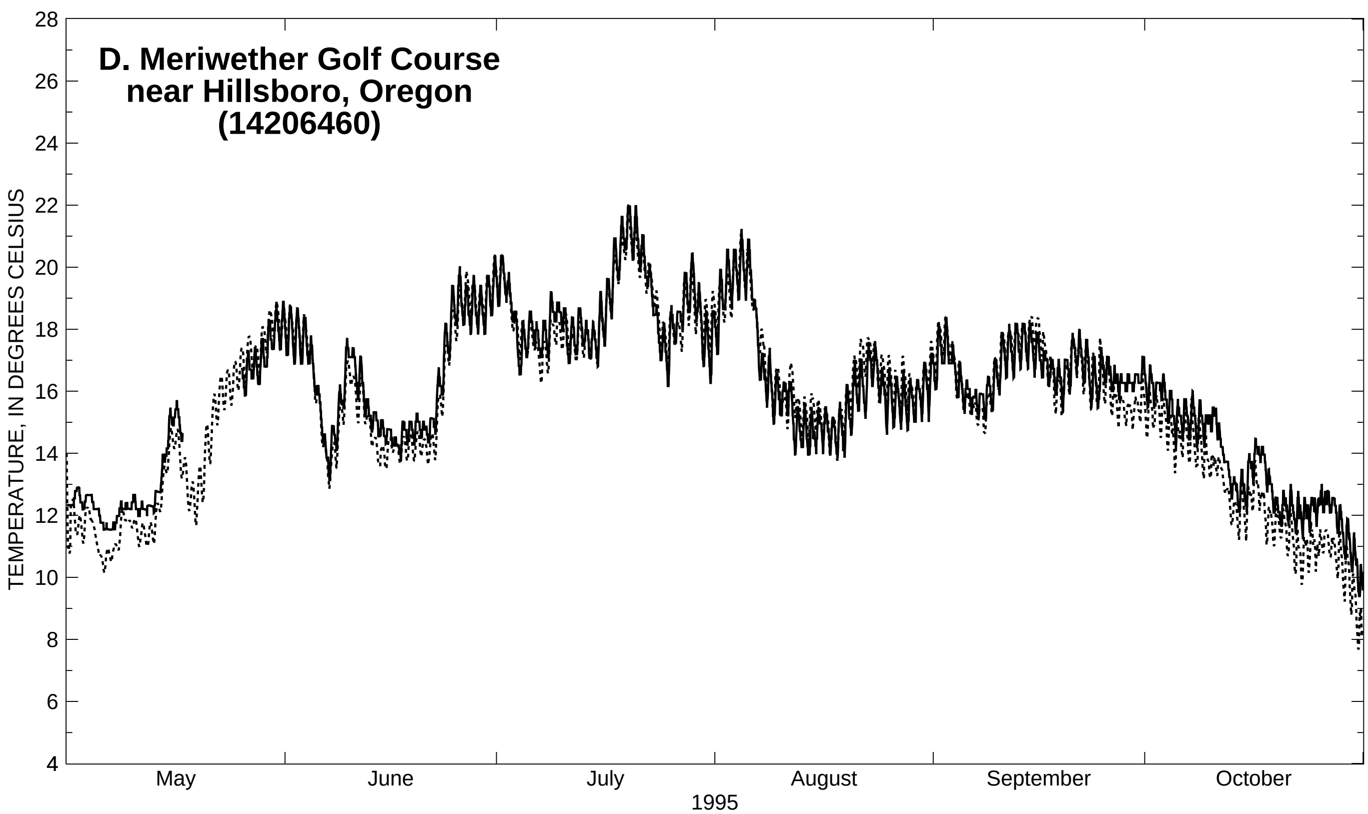
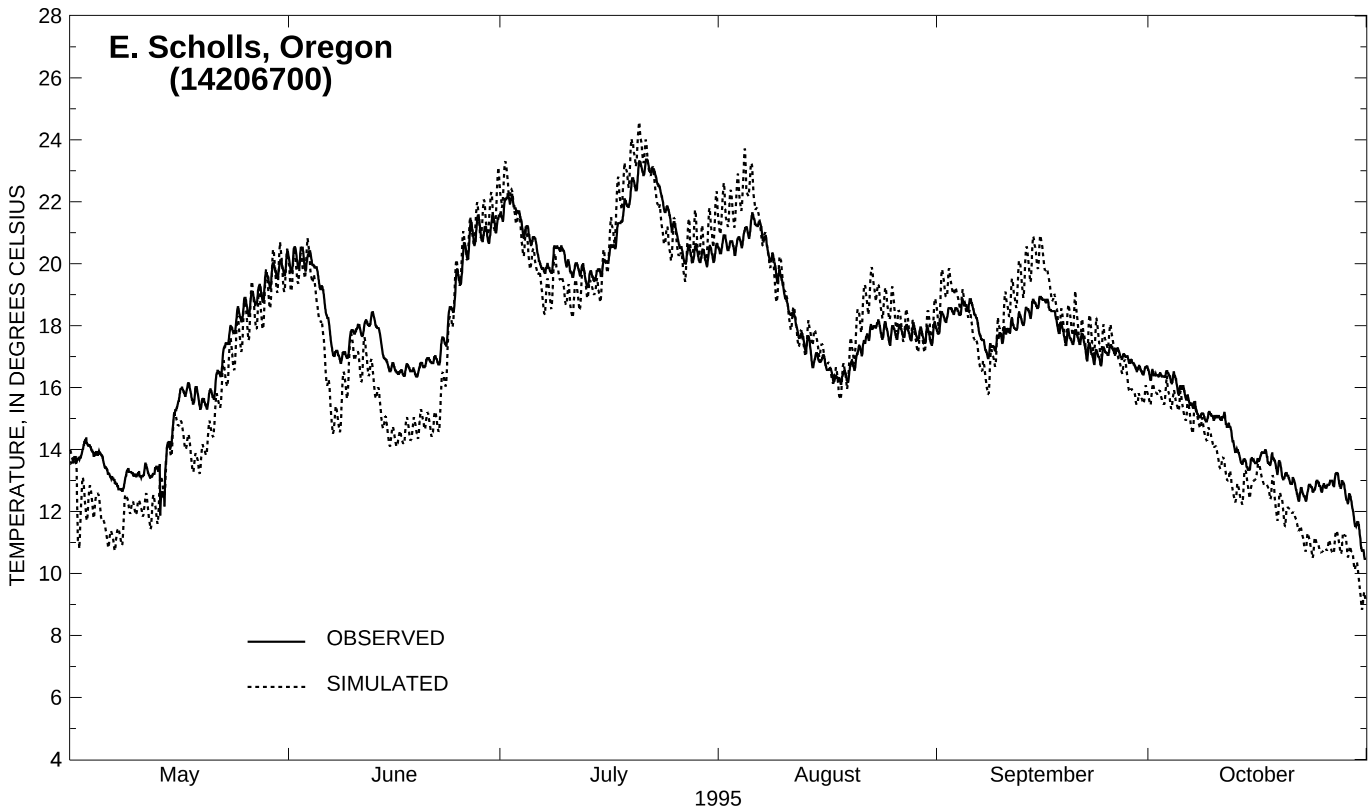


Figure 6. Observed and simulated water temperatures from May through October 1995 in the Tualatin River, Oregon—Continued.



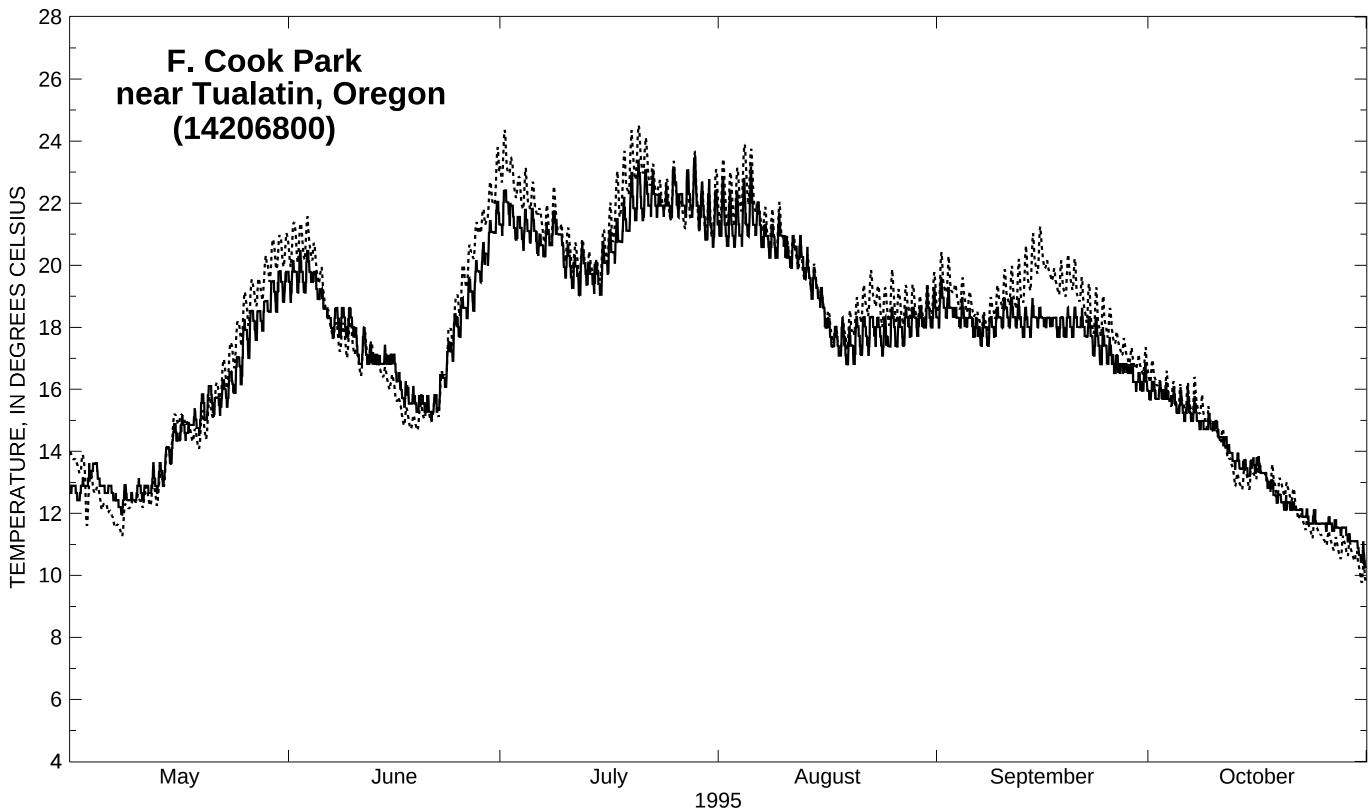


Figure 6. Observed and simulated water temperatures from May through October 1995 in the Tualatin River, Oregon—Continued.

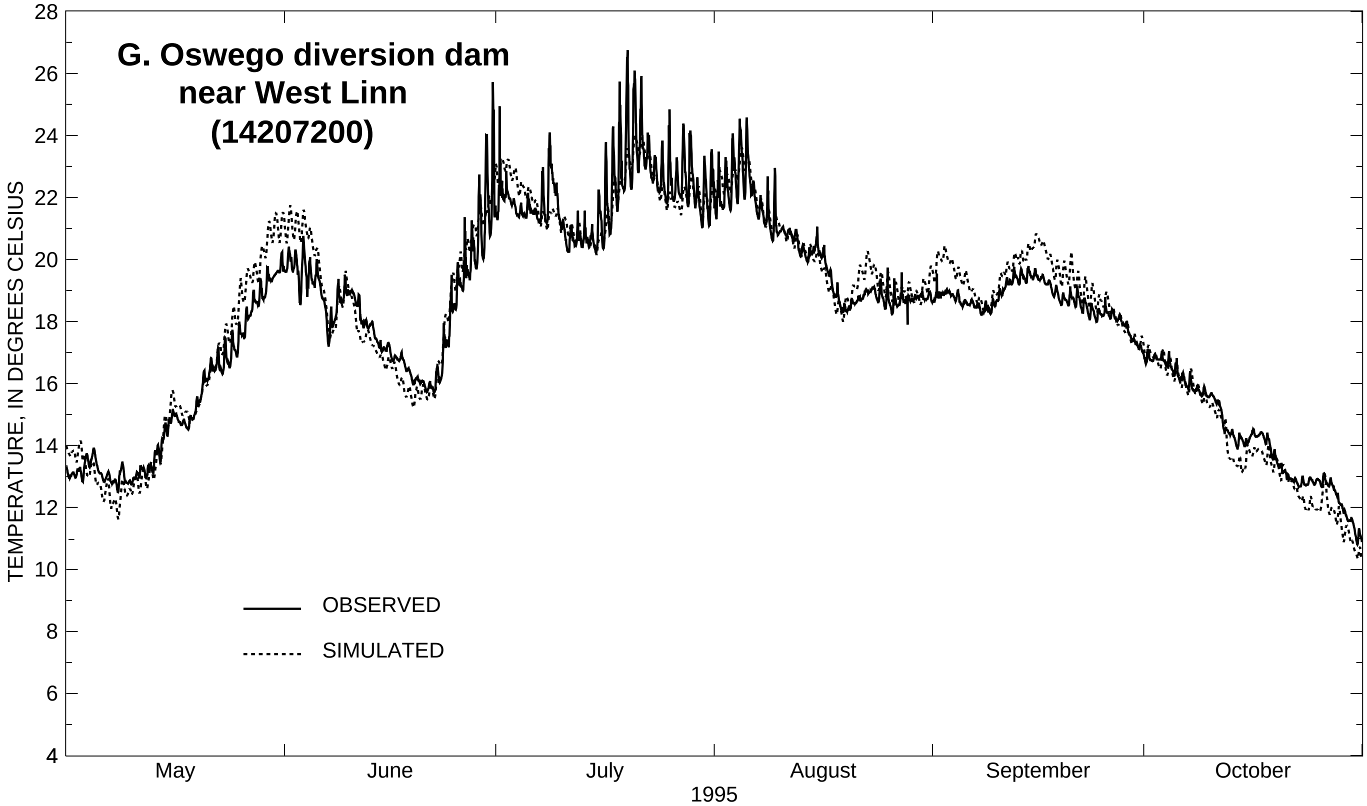


Figure 6. Observed and simulated water temperatures from May through October 1995 in the Tualatin River, Oregon—Continued.

Previous Scenarios

The hypothetical water-management scenarios documented in Risley (1997) are listed in table 6. In addition to existing conditions, the other scenarios included various changes in Henry Hagg Lake operation, riparian shading along the main stem, WWTP operation, and Oswego diversion dam operation. For each scenario, plots showing the monthly mean (May through October) of the 7-day moving average of daily maximum simulated water temperatures along the main-stem of the river were created. The 7-day moving average of daily maximum water temperatures is plotted because it is the statistic used by the 1996 State of Oregon water-temperature standard. Plots showing the monthly mean of the 7-day moving average of daily maximum simulated and observed 1994 and 1995 water temperatures for existing conditions (scenario 1) are shown in figures 7 and 8, respectively.

Both figures 7 and 8 show the usual sudden cooling effect on the river caused by releases from Henry Hagg Lake. (An exception to this was in October 1994 when the lake was drawn down and the temperature of Scoggins Creek was higher than that of the river.) As water moves downstream, there is a general warming trend in most months. The plots also show the pronounced effect of warmer discharge from the main tributaries and the Rock Creek and Durham WWTPs. For most of the months in the plots, there is a noticeable drop in temperature at Rood Bridge (RM 38.4). This apparent temperature decrease is an artifact due to minor instabilities in the numerical solution of the governing equations of CE-QUAL-W2 caused by the inflow of significantly warmer water from Rock Creek WWTP just downstream of RM 38.1. The plots also show erratic temperature fluctuations in the lower river section below RM 27.0. From this location down to the Oswego diversion dam (RM 3.4), the river is more reservoir-like and can become thermally stratified in some locations. Being a two-dimensional model, CE-QUAL-W2 accounts for thermal stratification and channel depth variations in the simulation. Dips in the graphs correlate to known shallow locations in the river. The model simulates the upwelling of cooler waters from the lower layers in the pools just upstream of the shallow sills. Thus, the water flowing over the sills is simulated as cooler than water in the pools. Because flows are better mixed above RM 27.0, the

Table 2. Root mean square error between observed and simulated daily mean water temperatures at sites on the Tualatin River from May through October 1994 and 1995[1].

[RM = river mile; ---, no data collected; Tobs, observed daily mean water temperature; Tsim, simulated daily mean water temperature; and Sept., September; Oct. October. A smaller root mean square error is an indication of more accurate model performance]

Site	1994							1995						
	May	June	July	August	Sep-.	Oct.	6-month period	May	June	July	August	Sept.	Oct.	6-month period
Dilley (RM 8.8)	0.729	0.568	0.300	0.316	0.273	0.416	0.464	2.540	2.159	0.771	0.722	1.509	2017	1.758
Golf Course Road (RM 51.5)	.482	.465	.220	.234	.425	.626	.436	2.316	1.613	.616	.517	.920	1.965	1.529
Rood Bridge (RM 38.4)	.365	.377	.475	.364	.438	.690	.466	.515	.560	.486	.614	.583	1.174	.698
Meriwether Golf Course (RM 36.8)	---	---	---	---	---	---	---	.690	.462	.335	.452	.430	1.029	.610
Farmington (RM 33.3)	.299	.231	.328	.149	.203	.306	.261	---	---	---	---	---	---	---
Scholls (RM 23.2)	.554	.673	.887	.848	.494	.666	.703	1.188	1.395	.657	.752	.806	1.235	1.042
Cook Park (RM 10)	.421	.682	.277	.339	.860	.405	.535	.694	.742	.809	.642	1.010	.362	.734
Oswego diversion dam (RM 3.4)	.334	.612	.425	.612	.477	.449	.476	.713	.651	.574	.353	.664	.461	.582

[1] Root mean square error = $\sqrt{\frac{1}{N}\sum_{n=1}^{N}\langle Tobs - Tsim\rangle^2}$

Table 3. Water temperature data from the Oswego diversion dam (at river mile 3.4) near West Linn, Oregon, for 1991–98

[All values are in degrees Celsius. Values in first eight rows are monthly mean temperatures. Values in the ninth row are means of the first eight rows.; --- = missing data. Shaded cells indicate model simulation periods]

Year	May	June	July	August	September	October	November
1991	---	16.2	21.2	21.4	18.3	14.2	9.8
1992	17.0	20.9	21.5	21.4	17.9	14.5	10.0
1993	15.3	17.3	18.8	20.8	---	14.4	8.5
1994	15.9	18.3	22.0	---	18.7	14.3	---
1995	---	18.4	22.1	20.1	18.6	14.2	10.8
1996	---	17.8	21.2	20.7	16.7	13.9	8.8
1997	16.4	18.0	20.9	21.8	17.8	13.0	10.3
1998	14.5	18.0	21.4	21.7	19.1	14.1	10.7
8-year mean	---	18.1	21.1	---	---	14.1	---

Table 4. Air temperature data from the Hillsboro Airport near Hillsboro, Oregon, 1991–98

[All values are in degrees Celsius. Values in first eight rows are monthly-mean temperatures. Values in the ninth row are means of the first eight rows. Values in the last row are mean-monthly temperatures from 1948 to 1998. Source: Oregon Climate Service. Shaded cells indicate model simulation periods]

Year	May	June	July	August	September	October	November
1991	11.8	14.8	19.3	20.0	18.0	12.0	7.9
1992	15.8	18.7	20.2	19.8	15.7	12.7	7.3
1993	15.6	15.9	16.6	19.2	17.4	13.2	3.7
1994	14.6	15.9	20.2	19.2	18.3	10.5	4.5
1995	15.3	16.7	20.6	18.2	18.4	11.4	10.0
1996	12.4	16.6	21.8	20.1	15.5	11.4	6.7
1997	16.6	16.9	20.2	21.2	17.9	11.7	11.6
1998	14.4	18.7	22.3	21.6	19.6	12.9	10.1
8-year mean	14.6	16.8	20.2	19.9	17.6	12.0	7.7
Long-term mean	13.3	16.5	19.2	19.1	16.5	11.6	7.3

Table 5. Precipitation data from the Hillsboro Airport near Hillsboro, Oregon, 1991–98

[All values are in inches. Values in first eight rows are monthly precipitation. Values in the ninth row are means of the first eight rows. Values in the last row are mean-monthly precipitation from 1930 to 1998. Source: Oregon Climate Service. Shaded cells indicate model simulation periods]

Year	May	June	July	August	September	October	November
1991	2.34	1.70	0.25	0.65	0.39	1.66	5.66
1992	.13	.36	.77	.31	1.21	2.47	4.54
1993	3.52	2.68	1.49	.16	.00	1.08	1.26
1994	1.15	.94	.00	.42	.60	4.52	7.02
1995	1.43	1.80	.98	.39	1.57	2.91	7.74
1996	4.34	.97	.58	.13	2.96	4.22	8.70
1997	1.81	2.30	.29	1.47	3.01	5.52	5.98
1998	4.77	1.49	.07	.00	.90	2.84	11.01
8-year mean	2.44	1.53	.554	.441	1.33	3.15	6.49
Long-term mean	1.82	1.43	.465	.732	1.46	3.05	5.69

Table 6. Hypothetical water-management scenarios from the initial modeling study (Risley, 1997)
[USA, Unified Sewerage Agency; Mgal/d, million gallons per day; WWTP, wastewater-treatment plant]

Scenario number	Title	Description
1	Existing conditions	Observed and simulated 1994 and 1995 meteorologic, flow, shade, and hydraulic data were used as input to the models to determine spatial and temporal temperature variations along the main stem of the river. Mean effluent released from each WWTP from May to October for both years was approximately 18 Mgal/d.
2	Existing conditions without USA allotted flows	Existing conditions used in scenario 1 were simulated except allotted flows for the USA were not released from Henry Hagg Lake reservoir.
3	“Natural” conditions	No flow augmentation from Trask River was provided. Both Henry Hagg Lake reservoir and the low-head diversion dam at RM 3.4 were assumed to not exist. No withdrawals for irrigation, urban water supply, or the Oswego Canal were made. No effluent was released from wastewater-treatment plants. Maximum possible shading along the main stem and tributaries was assumed.
4a	No shading	Existing conditions used in scenario 1 were simulated except no vegetative shading along the main stem and the tributaries was used.
4b	Maximum shading	Existing conditions used in scenario 1 were simulated except maximum possible vegetative shading along the main stem and the tributaries was used.
5	Existing conditions without low-head diversion dam at RM 3.4	Existing conditions used in scenario 1 were simulated except the low-head diversion dam at RM 3.4 was assumed to not exist.
6	Existing conditions with tributary temperature reduction	Existing conditions used in scenario 1 were simulated except the temperatures of all upstream tributary boundaries, except Scoggins Creek, were reduced by 2 degrees Celsius.
7	Existing conditions without WWTPs	Existing conditions used in scenario 1 were simulated except no effluent was released from either the Rock Creek or Durham WWTPs.
8	Existing conditions without USA allotted flows, lower section withdrawals, and WWTPs	Existing conditions used in scenario 1 were simulated except allotted flows for the USA were not released from Henry Hagg Lake reservoir, withdrawals for irrigation and the Oswego Canal were not made in the lower stream section, and no effluent was released from either the Rock Creek or Durham WWTPs.
9	Existing conditions without low-head diversion dam at RM 3.4 and WWTPs	Existing conditions used in scenario 1 were simulated except the low-head diversion dam at RM 3.4 was assumed to not exist and no effluent releases were made from either the Rock Creek or Durham WWTPs.
10	Existing conditions with tributary temperature reduction and without WWTPs	Existing conditions used in scenario 1 were simulated except the temperatures of all upstream tributary boundaries, except Scoggins Creek, were reduced by 2 degrees Celsius and no effluent was released from either the Rock Creek or Durham WWTPs.

plotted lines for each month are smoother for the upper and middle sections of the river’s main stem.

Additional Scenarios

In the current study, the flow and water-temperature models have been used to simulate an additional 16 hypothetical water-management scenarios (Scenarios 11 through 26). Unlike the scenarios published previously (Risley, 1997), the additional scenarios were simulated for the May through October periods of both 1994 and 1995. A brief description of each of the scenarios is provided in table 7. Additional discussion pertaining to the purpose of the scenarios and the simulation results are shown in this section.

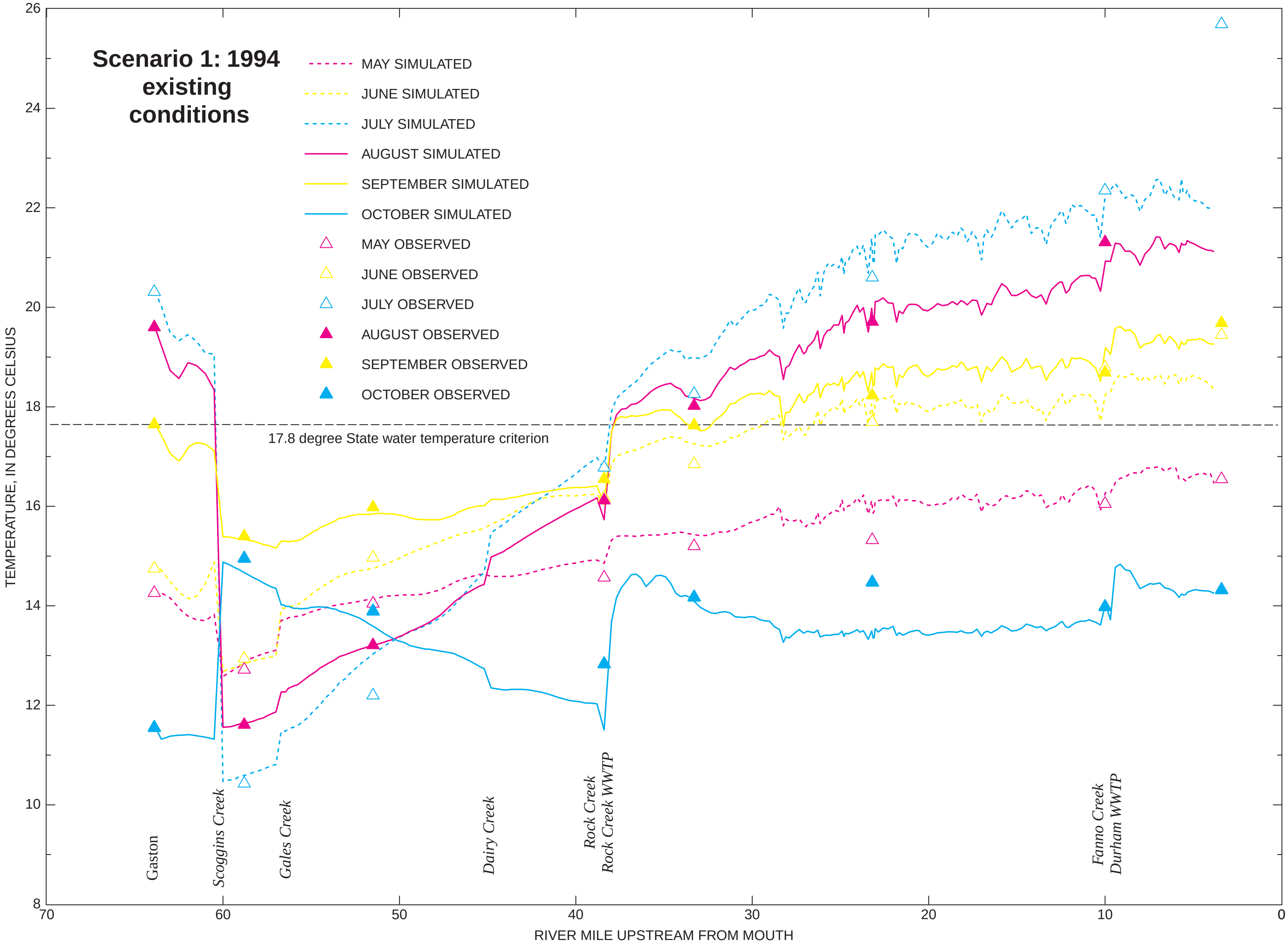


Figure 7. Monthly mean of the 7-day moving average of daily maximum simulated and observed 1994 water temperatures for scenario 1, existing conditions. (WWTP, wastewater-treatment plant.)

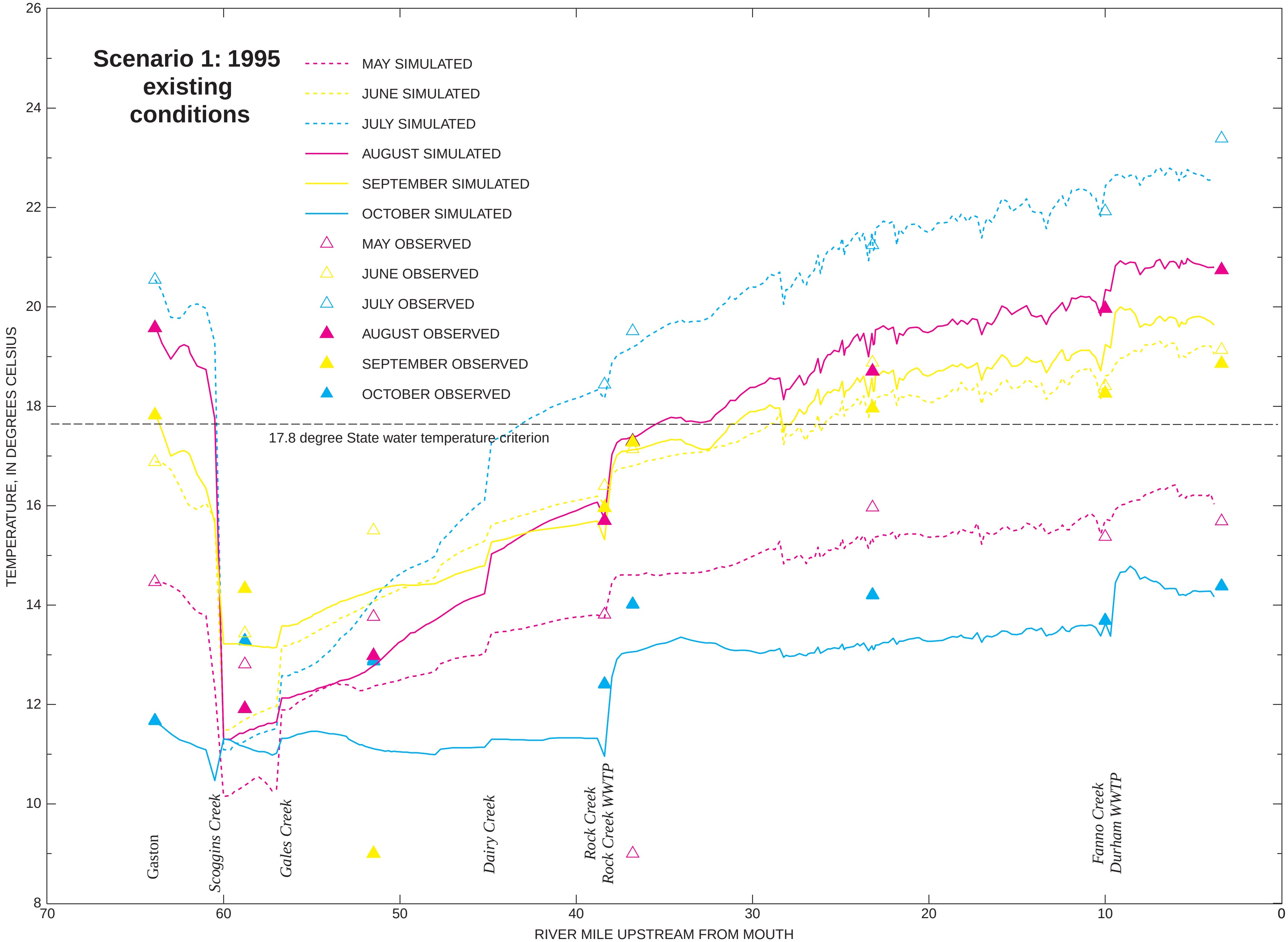


Figure 8. Monthly mean of the 7-day moving average of daily maximum simulated and observed 1995 water temperatures for scenario 1, existing conditions. (WWTP, wastewater-treatment plant.)

Table 7. Additional hypothetical water-management scenarios

[USA, Unified Sewerage Agency; RM, river mile; WWTP, wastewater-treatment plant; ft^3/s, cubic feet per second; Mgal/d, million gallons per day]

Scenario number	Title	Description
11	Existing conditions with 1.33 ft^3/s decrease in Rock Creek WWTP effluent	All existing conditions described in scenario 1 were simulated except effluent from the Rock Creek WWTP was reduced by a constant 1.33 ft^3/s for the entire simulation period.
12	Existing conditions with 1.33 ft^3/s river withdrawal and 2.0 ft^3/s Henry Hagg Lake release	All existing conditions described in scenario 1 were simulated except a constant 1.33 ft^3/s was withdrawn from the river at RM 37.3 and an additional 2.0 ft^3/s was released from Henry Hagg Lake for the entire simulation period.
13	Existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10 Mgal/d at RM 38.1	All existing conditions described in scenario 1 were simulated except constant 5 Mgal/d flows of effluent were released at RM 55.2 and RM 43.8, respectively; and a constant 10 Mgal/d flow of effluent was released at RM 38.1. Rock Creek WWTP 1994 (or 1995) observed effluent-temperature data were used for all three effluent releases.
14	Existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 20 Mgal/d at RM 38.1	All existing conditions described in scenario 1 were simulated except constant 5 Mgal/d flows of effluent were released at RM 55.2 and RM 43.8, respectively; and a constant 20 Mgal/d flow of effluent was released at RM 38.1. Rock Creek WWTP 1994 (or 1995) observed effluent-temperature data were used for all three effluent releases.
15	Existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 30 Mgal/d at RM 38.1	All existing conditions described in scenario 1 were simulated except constant 5 Mgal/d flows of effluent were released at RM 55.2 and RM 43.8, respectively; and a constant 30 Mgal/d flow of effluent was released at RM 38.1. 1994 and 1995 Rock Creek WWTP observed effluent-temperature data were used for all three effluent releases.
16	Existing conditions with 25 Mgal/d of effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 25 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. However, 1994 and 1995 measured effluent-temperature data from the two WWTPs were used.
17	Existing conditions with 45 Mgal/d of effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 45 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. However, 1994 and 1995 measured effluent-temperature data from the two WWTPs were used.
18	Existing conditions with 65 Mgal/d of effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 65 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. However, 1994 and 1995 measured effluent-temperature data from the two WWTPs were used.
19	Existing conditions with Gaston temperature data replaced with Lee Falls data	All existing conditions described in scenario 1 were simulated except 1997 stream-temperature data collected at Lee Falls were used as stream-temperature input at Gaston for both the 1994 and 1995 simulation periods.
20	“Natural” conditions with Gaston temperature data replaced with Lee Falls data	“Natural” conditions described in scenario 3 were simulated except 1997 stream-temperature data collected at Lee Falls were used as stream-temperature input at Gaston for both the 1994 and 1995 simulation periods.

Table 7. Additional hypothetical water-management scenarios—Continued

[USA, Unified Sewerage Agency; RM, river mile; WWTP, wastewater-treatment plant; ft^3/s, cubic feet per second; Mgal/d, million gallons per day]

Scenario number	Title	Description
21	Existing conditions with WWTP effluent temperature equal to receiving river temperature	All existing conditions described in scenario 1 were simulated except the temperature of the effluent from the Rock Creek and Durham WWTPs were approximately equal to the receiving river temperature.
22	Existing conditions with up to 10 Mgal/d of USA allotted flows were released at RM 38.1	All existing conditions described in scenario 1 were simulated except all flow, up to 10 Mgal/d, allotted for USA was released into the Tualatin at River at the Rock Creek WWTP (RM 38.1) instead of from Scoggins Dam. Any remaining USA allotted flow in excess of 10 Mgal/d was still released from Scoggins Dam. The temperature of the allotted flow, regardless of the release point, was not changed from scenario 1.
23	Existing conditions with 20 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 20 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. The temperature of the effluent was also constant at 17.8 degrees Celsius.
24	Existing conditions with 25 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 25 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. The temperature of the effluent was also constant at 17.8 degrees Celsius.
25	Existing conditions with 45 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 45 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. The temperature of the effluent was also constant at 17.8 degrees Celsius.
26	Existing conditions with 65 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3	All existing conditions described in scenario 1 were simulated except constant 65 Mgal/d flows of effluent were released from both the Rock Creek (RM 38.1) and the Durham (RM 9.3) WWTPs for the entire simulation period. The temperature of the effluent was also constant at 17.8 degrees Celsius.

Scenario 11: Existing conditions with 1.33 ft^3/s decrease in Rock Creek WWTP effluent to the main stem

The purpose of scenario 11 was to determine the effect of diverting 1.33 ft^3/s of effluent from the Rock Creek WWTP (RM 38.1) for nearby irrigation. No increase in return flow to the river was assumed. The diversion of 1.33 ft^3/s was held constant throughout the entire simulation period. All other conditions in the models remained unchanged from 1994 and 1995 existing conditions (scenario 1).

The monthly means of the 7-day moving average of daily maximum simulated 1994 temperatures plotted for the main stem of the river are shown in figure 9. Figure 10 shows the difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 11 and scenario 1. Positive values show the warming effect of scenario 11 over existing conditions. Likewise, negative values show the cooling effect of the scenario. A pair of similar plots for 1995 are shown in figures 11 and 12, respectively. (Sets containing these 4 types of plots are presented for each of the other scenarios.)

The effect of scenario 11 on the river system was minimal for both 1994 and 1995. Temperatures downstream of the Rock Creek WWTP (RM 38.1) for most months decreased about 0.05^{o}C or less. The impact gradually tapers off downstream and is negligible

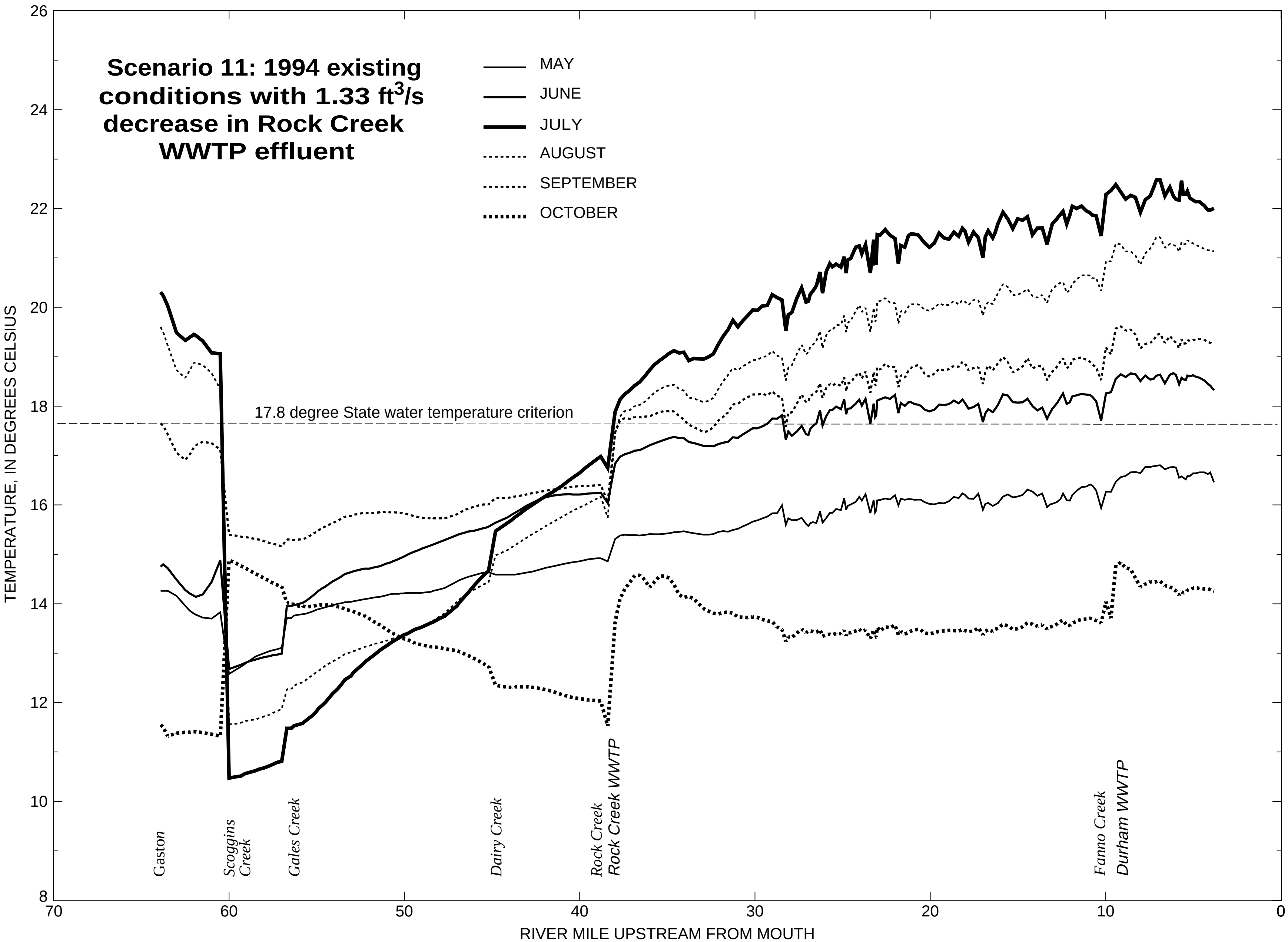


Figure 9. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 11, existing conditions with 1.33 cubic feet per second decrease in Rock Creek WWTP effluent. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

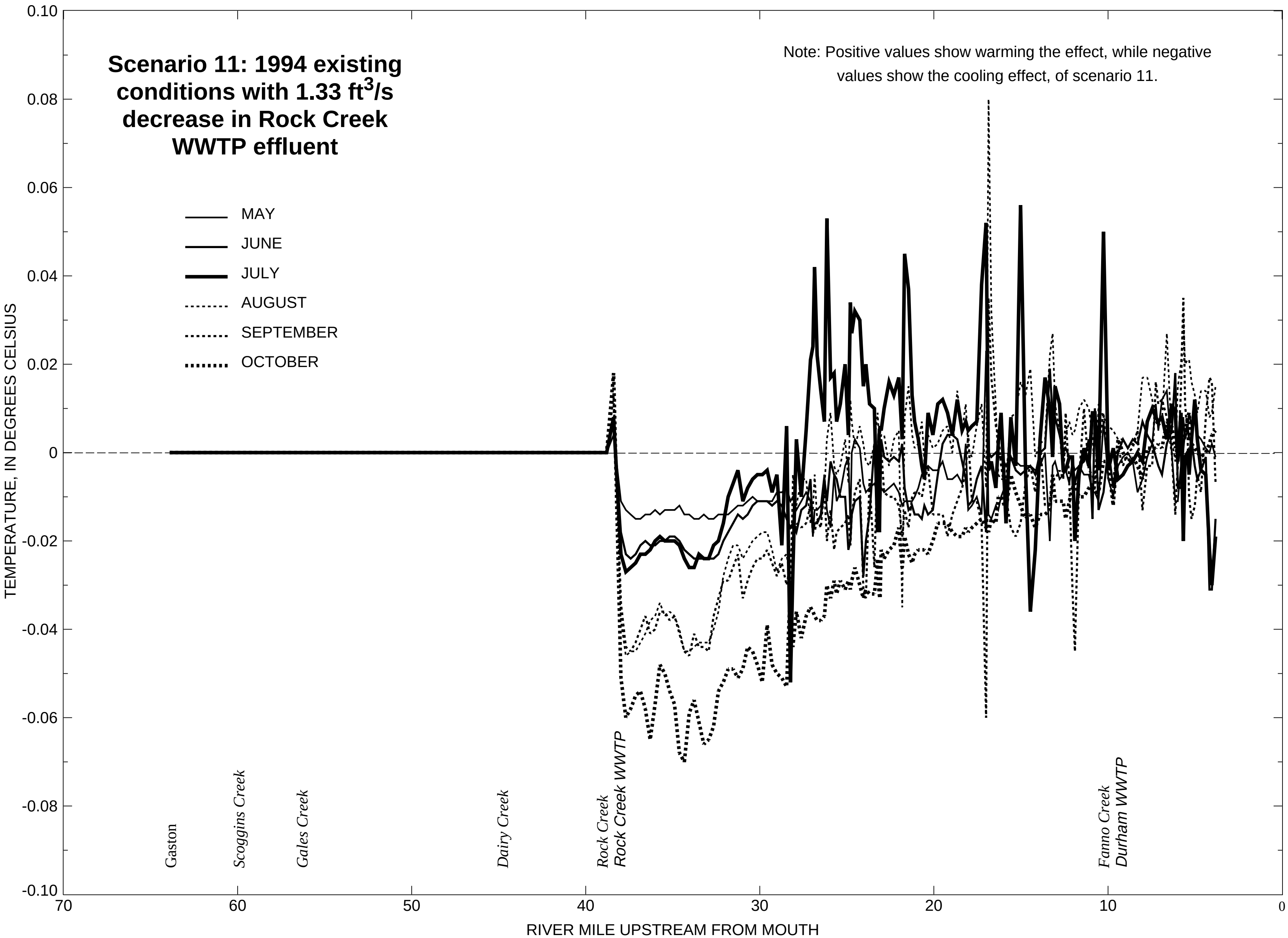


Figure 10. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 11, existing conditions with 1.33 cubic feet per second, decrease in Rock Creek WWTP effluent. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

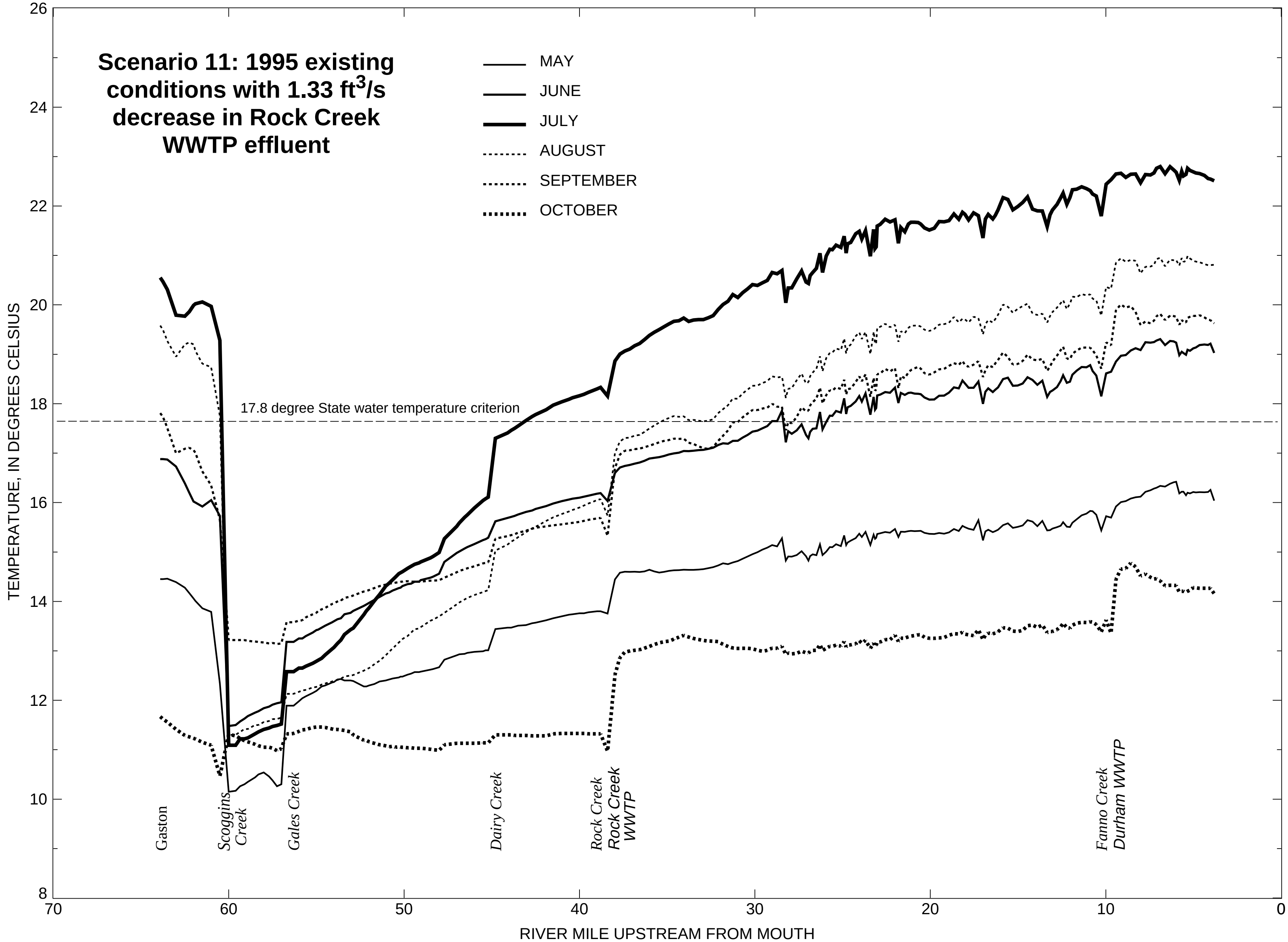


Figure 11. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 11, existing conditions with 1.33 cubic feet per second decrease in Rock Creek WWTP effluent. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

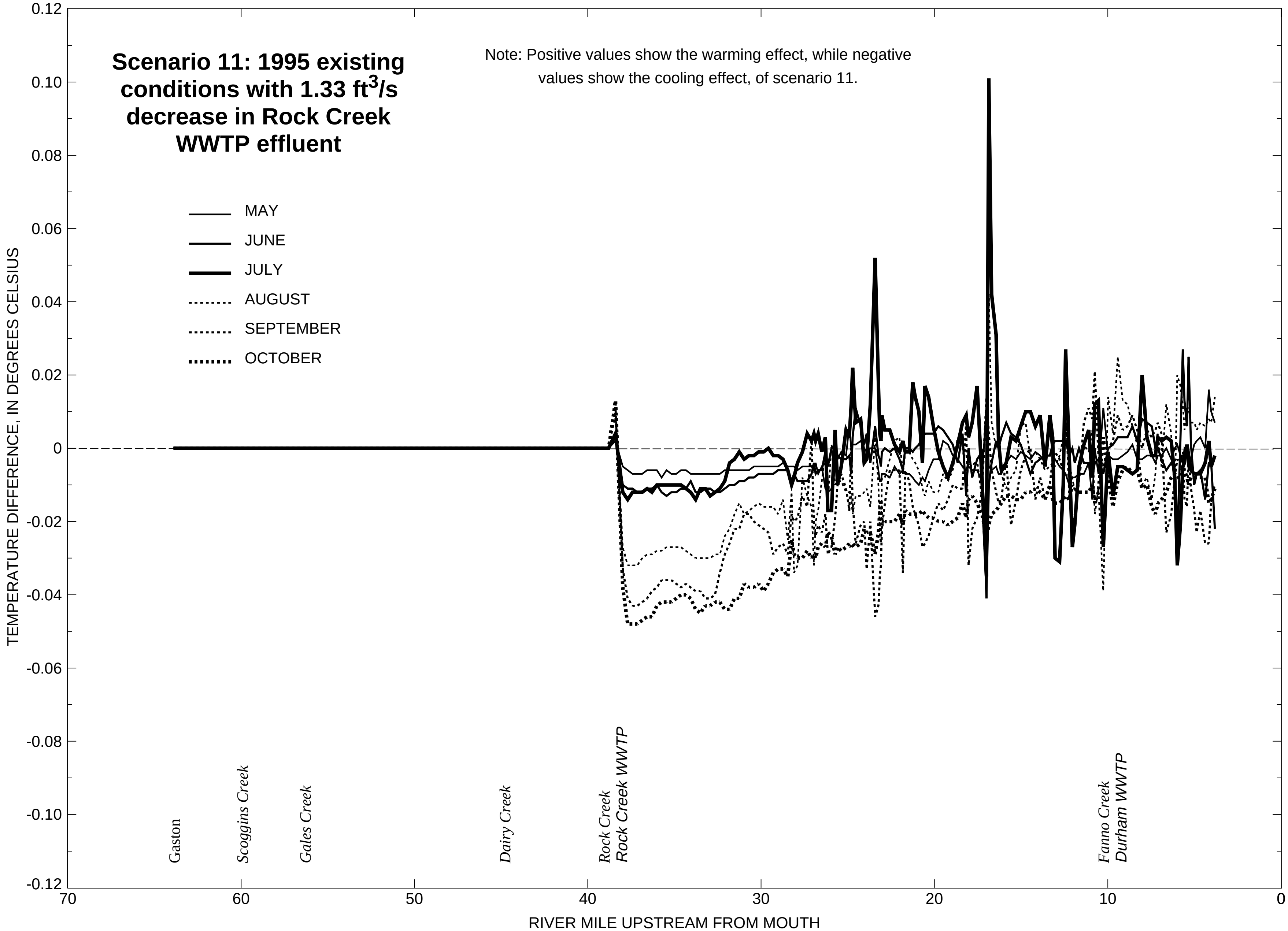


Figure 12. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 11, existing conditions with 1.33 cubic feet per second decrease in Rock Creek WWTP effluent. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

around RM 10.0. The effect of the scenario is slightly more apparent in the 1994 simulation than the 1995 simulation.

Scenario 12: Existing conditions with 1.33 ft^3/s river withdrawal and 2.0 ft^3/s Henry Hagg Lake release

In scenario 12, 1.33 ft^3/s was withdrawn from the river at RM 37.3 for nearby irrigation at a constant rate for the entire simulation period. No increase in return flow to the river was assumed. To compensate for the withdrawal, an additional constant flow of 2.0 ft^3/s was released from Henry Hagg Lake for the entire simulation period. All other conditions in the models were held constant to existing conditions (scenario 1).

The effect of scenario 12 on the river system was also fairly minimal for both 1994 and 1995 (figs. 13–16). Relative to the scenario 1 simulation, temperatures generally decreased over the entire reach between RM 60.0 and RM 3.4 by about 0.05 to 0.1^oC. However, the overall cooling effect of this scenario, particularly during the month of July, was slightly greater than the cooling effect of scenario 11 since an additional 2.0 ft^3/s was released from Henry Hagg Lake. However, October 1995 was an exception because flows released from the lake were warmer than the main stem of the river.

Scenarios 13, 14, and 15: Existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10, 20, and 30 Mgal/d at RM 38.1

In scenarios 13, 14, and 15, the effect on river temperatures of piping some of the effluent produced at the Rock Creek WWTP (RM 38.1) to upstream locations (Hillsboro West WWTP at RM 43.8 and the Forest Grove WWTP at RM 55.2) and releasing it there was examined. In the existing-conditions scenario, the mean flow of effluent from the Rock Creek WWTP was approximately 18 Mgal/d for the 1994 and 1995 May through October periods. For all three of the new scenarios, a constant flow of 5 Mgal/d of effluent was released at both RM 43.8 and RM 55.2 for the entire simulation period. Constant flows of 10, 20, and 30 Mgal/d of effluent at the Rock Creek WWTP (RM 38.1) were simulated for scenarios 13, 14, and 15, respectively. The temperature of the diverted effluent (to RM 43.8 and RM 55.2) was not adjusted for possible cooling that could occur during travel in an underground pipe. 1994 and 1995 measured effluent-temperature data from the Rock Creek WWTP were used in all three scenarios. All other conditions in the simulations were held constant to existing conditions (scenario 1).

For scenario 13, temperature increased between RM 55.2 and the Rock Creek WWTP (RM 38.1) due to the release of effluent at RM 55.2 and RM 43.8 (figs. 17–20). The increase in temperature was generally less than 1.0^oC and did not cause a violation of the State water-quality standard. For the reach downstream of RM 38.1, the river temperature decreased (generally less than 0.6^oC) due to a reduction of effluent released at Rock Creek WWTP. This cooling trend downstream of RM 38.1 was eliminated in scenario 14, in which Rock Creek WWTP effluent production increased to 20 Mgal/d (figs. 21–24). Water temperature generally increased throughout the river system downstream of RM 38.1. In scenario 15, Rock Creek WWTP effluent increased to 30 Mgal/d (figs. 25–28). Water temperatures increased downstream of RM 38.1; however, the magnitude of the increase was generally less than 1.0^oC. Interestingly, some minor cooling of the river is observed in scenario 15 for July, probably due to the decreased travel time resulting from the increase in river discharge.

Scenarios 16, 17, and 18: Existing conditions with 25, 45, and 65 Mgal/d of effluent at RM 38.1 and RM 9.3

In light of the forecast expansion in effluent production at both the Rock Creek and Durham WWTPs due to regional population growth, the purpose of scenarios 16, 17, and 18 was to determine the temperature effect resulting from substantial increases in effluent loading. Constant 25, 45, and 65 Mgal/d flows of effluent were released from both WWTPs for the entire simulation periods for scenarios 16, 17, and 18, respectively; however, 1994 and 1995 measured effluent temperature data from the two WWTPs were still used. All other conditions in the models were held constant to existing conditions (scenario 1).

Because the effluent released from the two WWTPs was substantially above the actual amount of effluent released from these plants in 1994 and 1995, simulated water temperatures throughout the reach downstream of Rock Creek WWTP, and to lesser extent downstream of Durham WWTP, proportionately increased (figs. 29–40). The magnitude of the temperature rise was generally under 0.6, 1.5, and 2.2^oC for effluent releases of 25, 45, and 65 Mgal/d,. respectively.

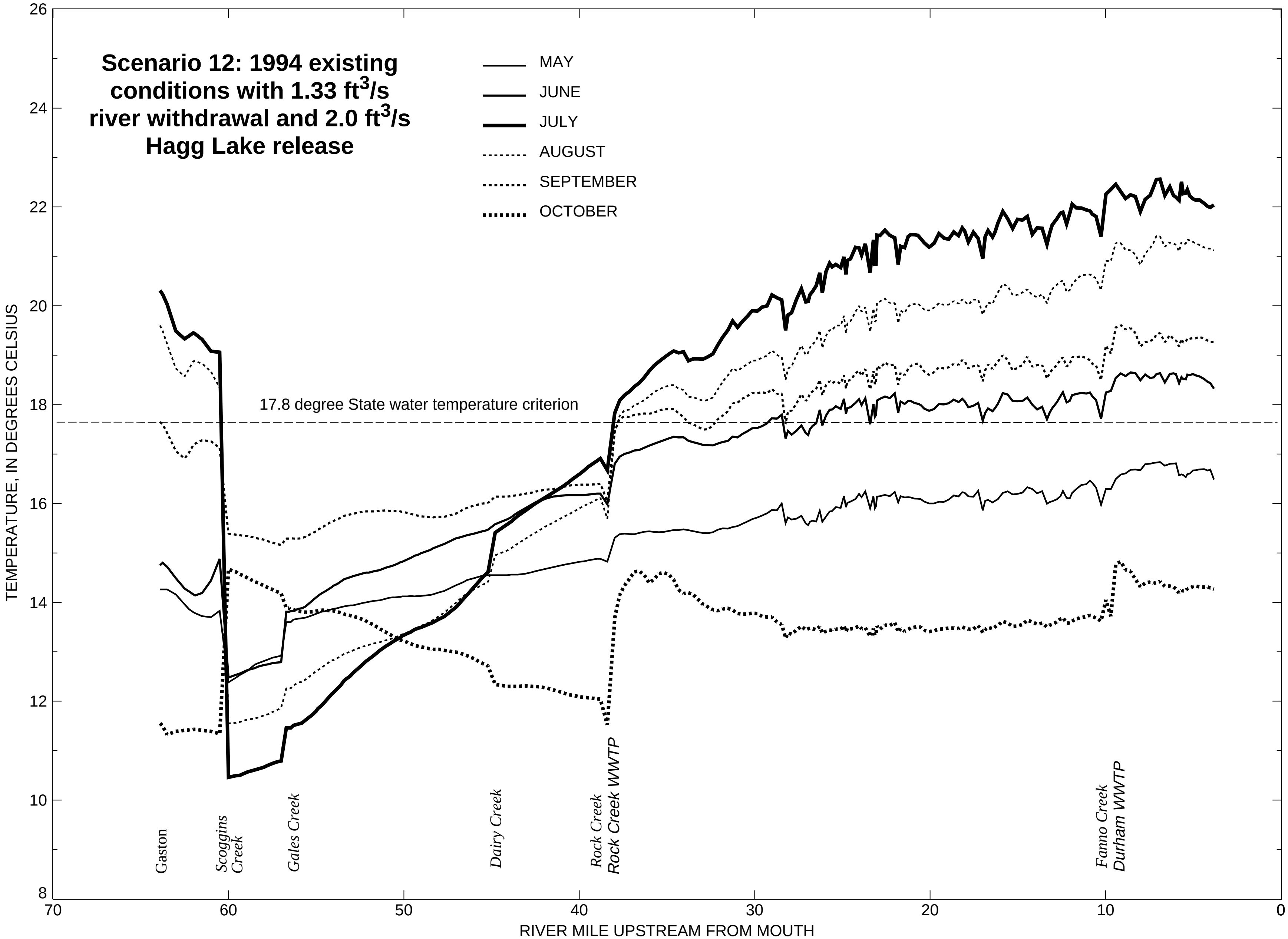


Figure 13. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 12, existing conditions with 1.33 cubic feet per second river withdrawal and 2.0 cubic feet per second Henry Hagg Lake release. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

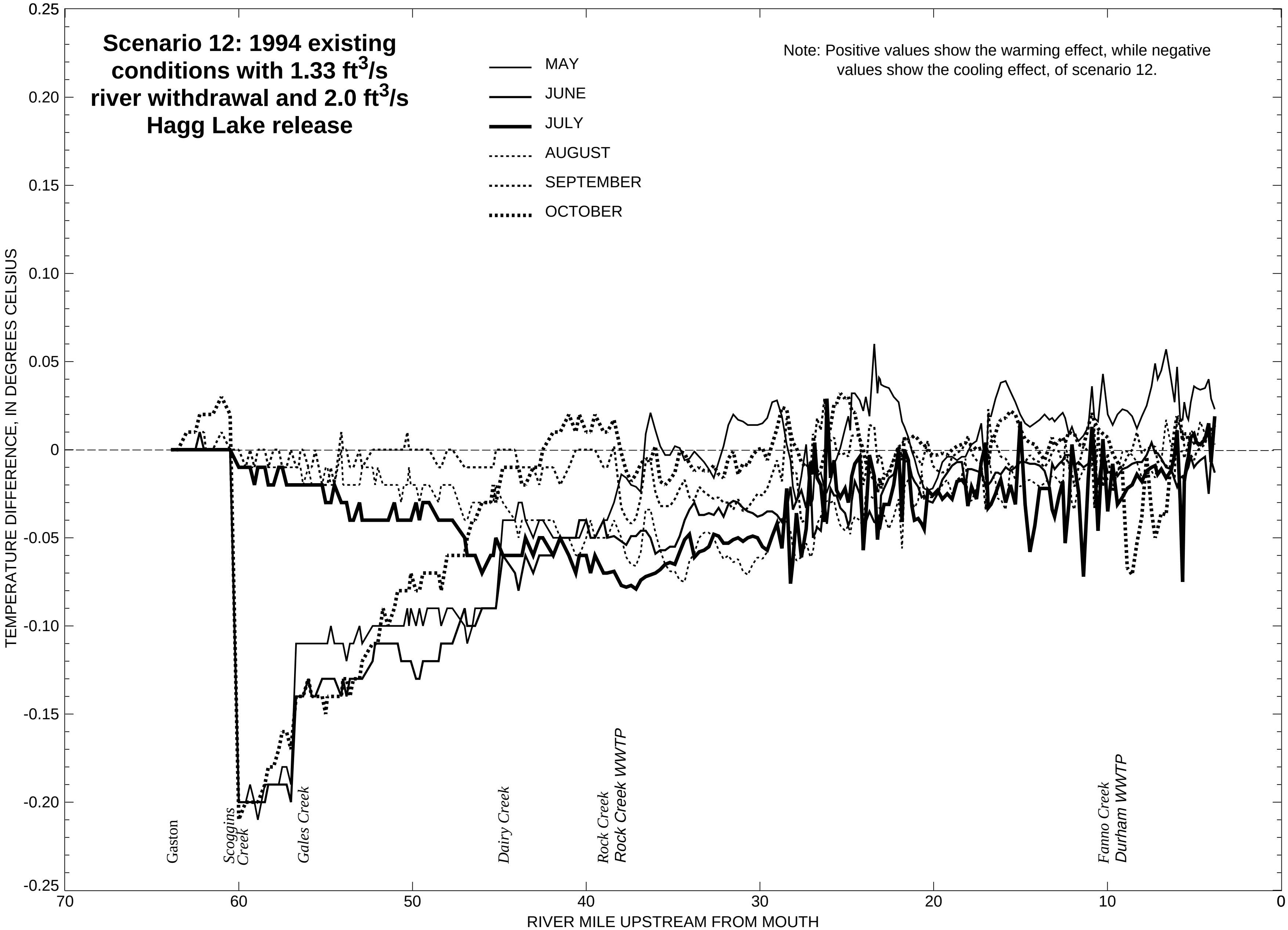


Figure 14. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 12, existing conditions with 1.33 cubic feet per second river withdrawal and 2.0 cubic feet per second Henry Hagg Lake release. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

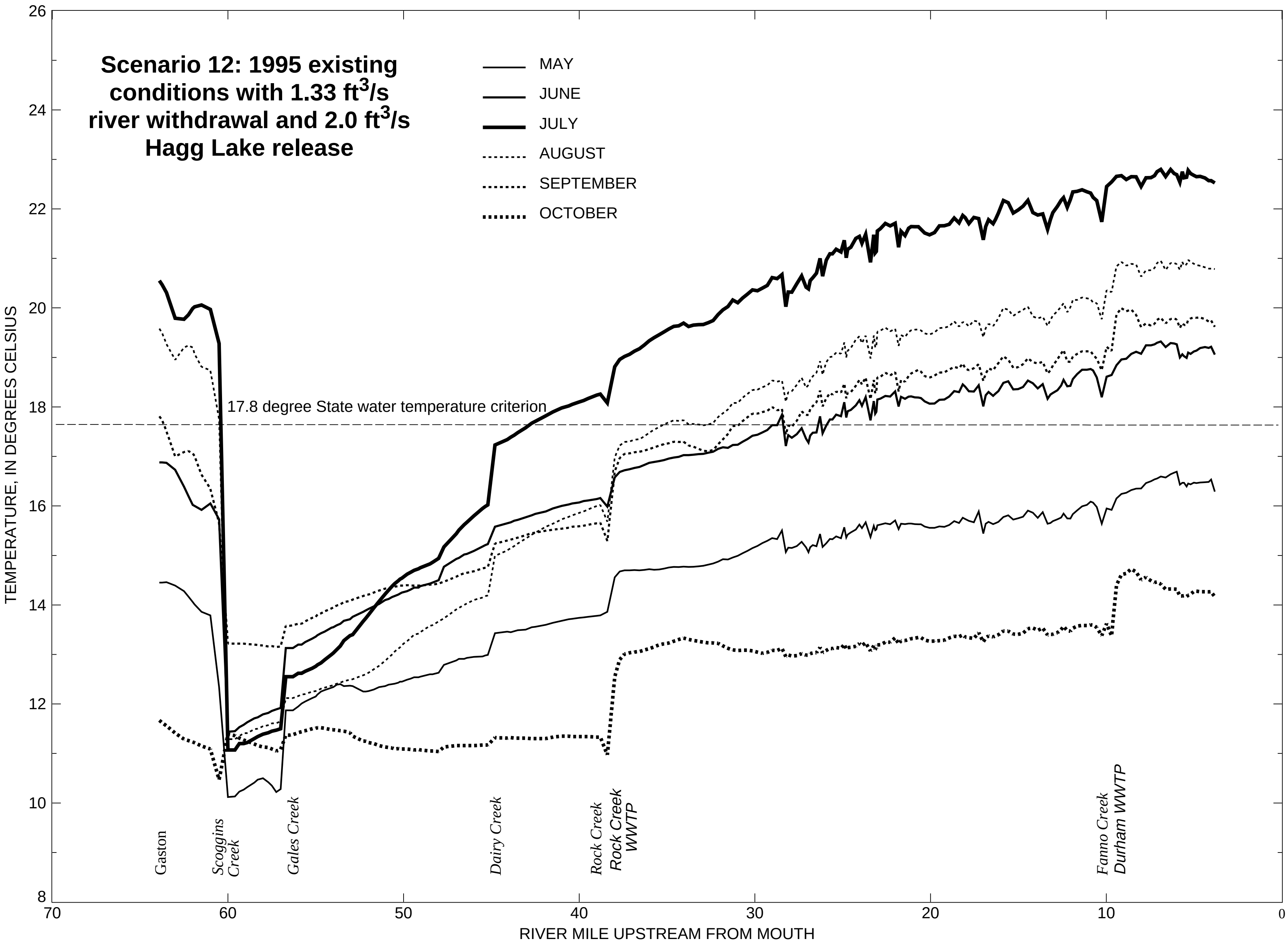


Figure 15. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 12, existing conditions with 1.33 cubic feet per second river withdrawal and 2.0 cubic feet per second Henry Hagg Lake release. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

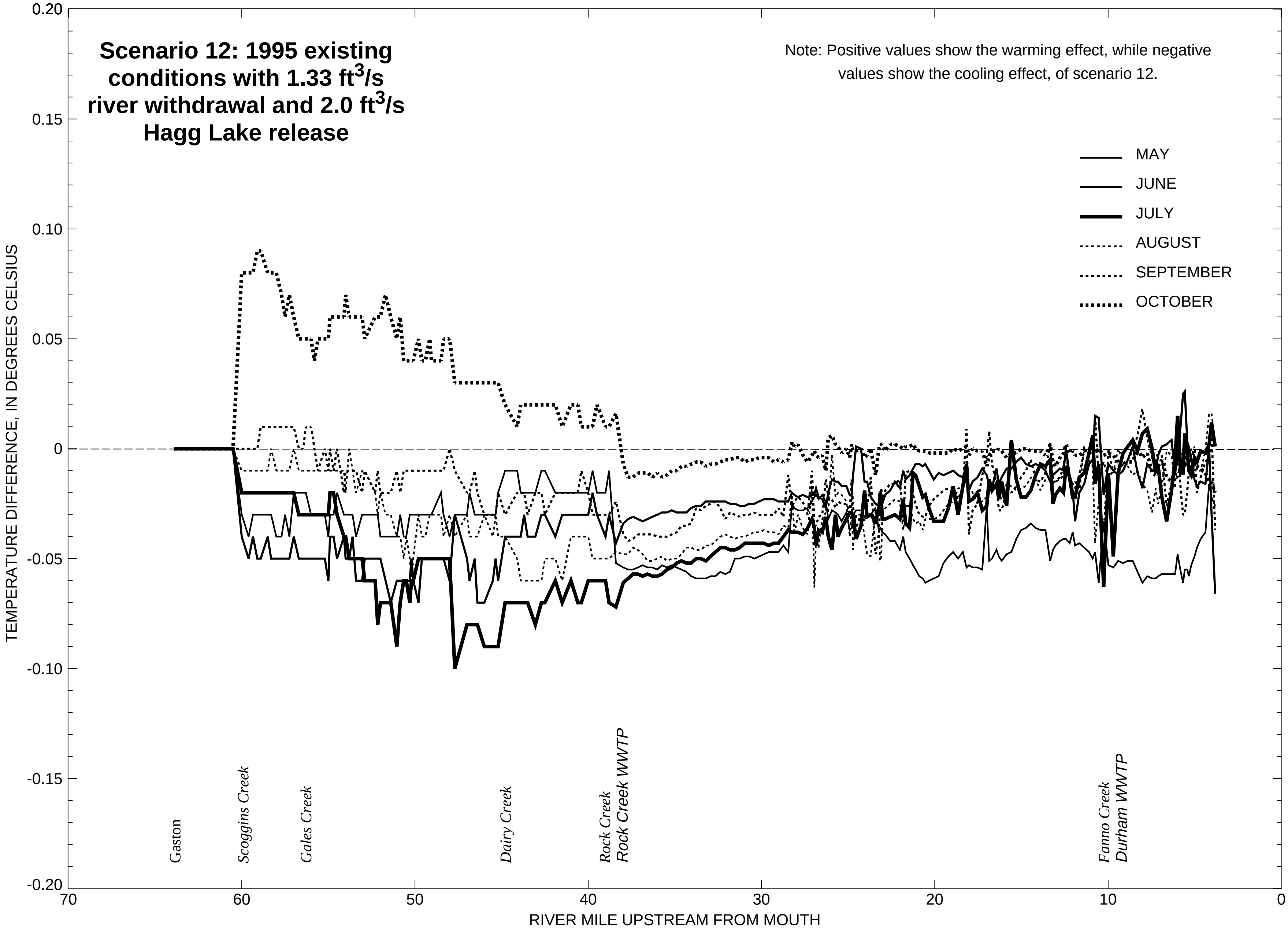


Figure 16. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 12, existing conditions with 1.33 cubic feet per second river withdrawal and 2.0 cubic feet per second Henry Hagg Lake release. (ft^3/s, cubic feet per second; WWTP, wastewater-treatment plant.)

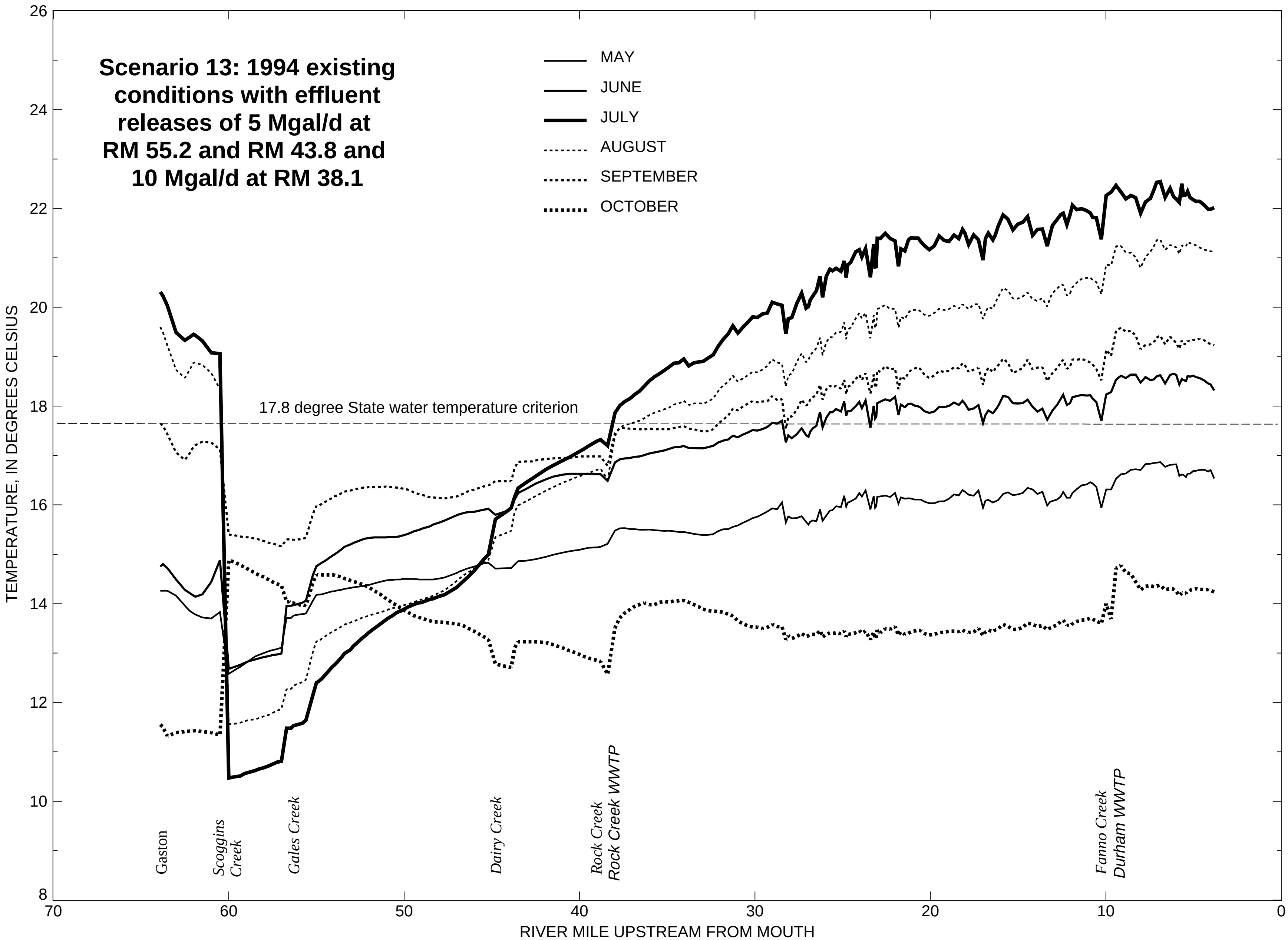


Figure 17. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 13, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

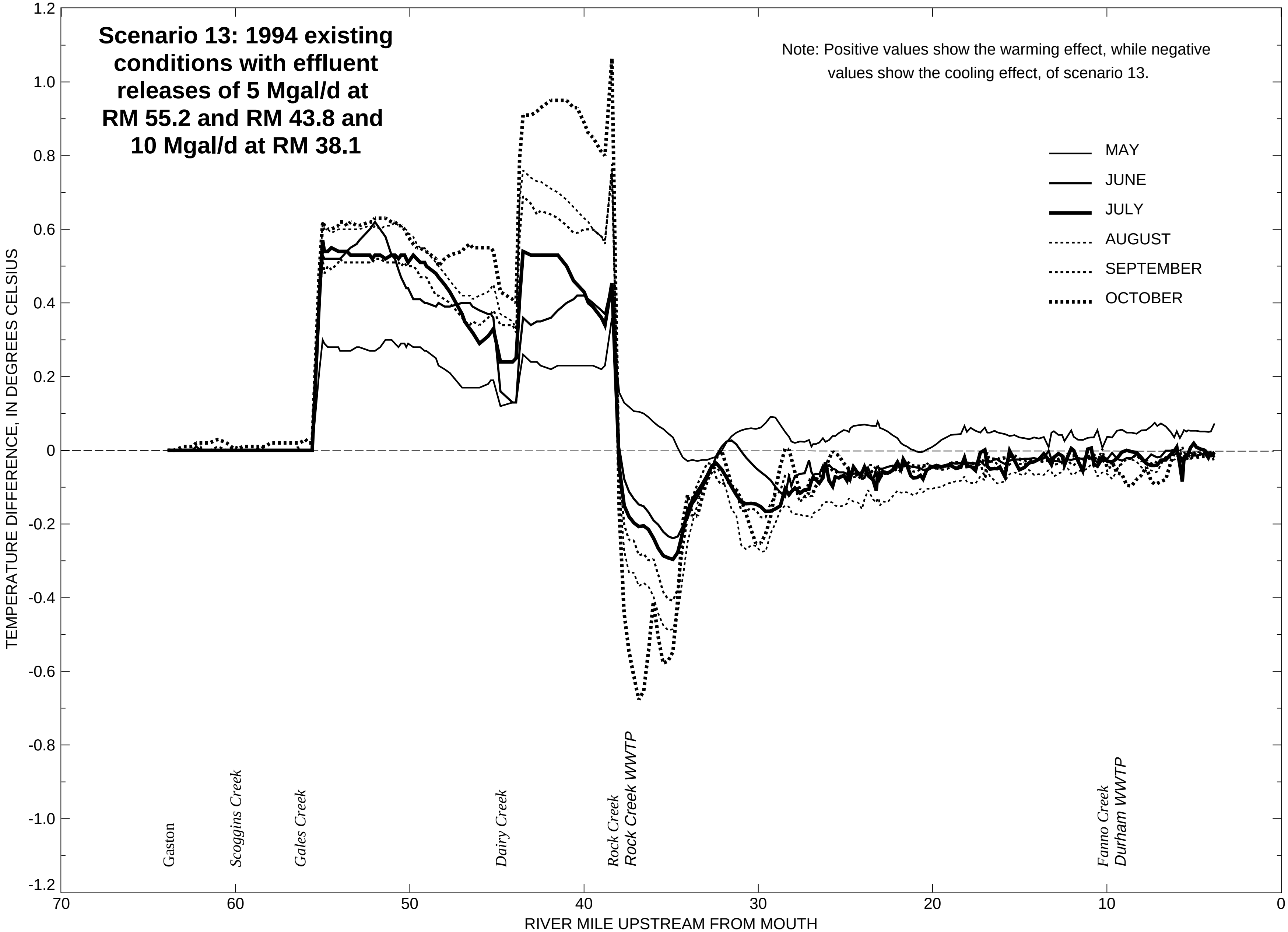


Figure 18. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 13, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

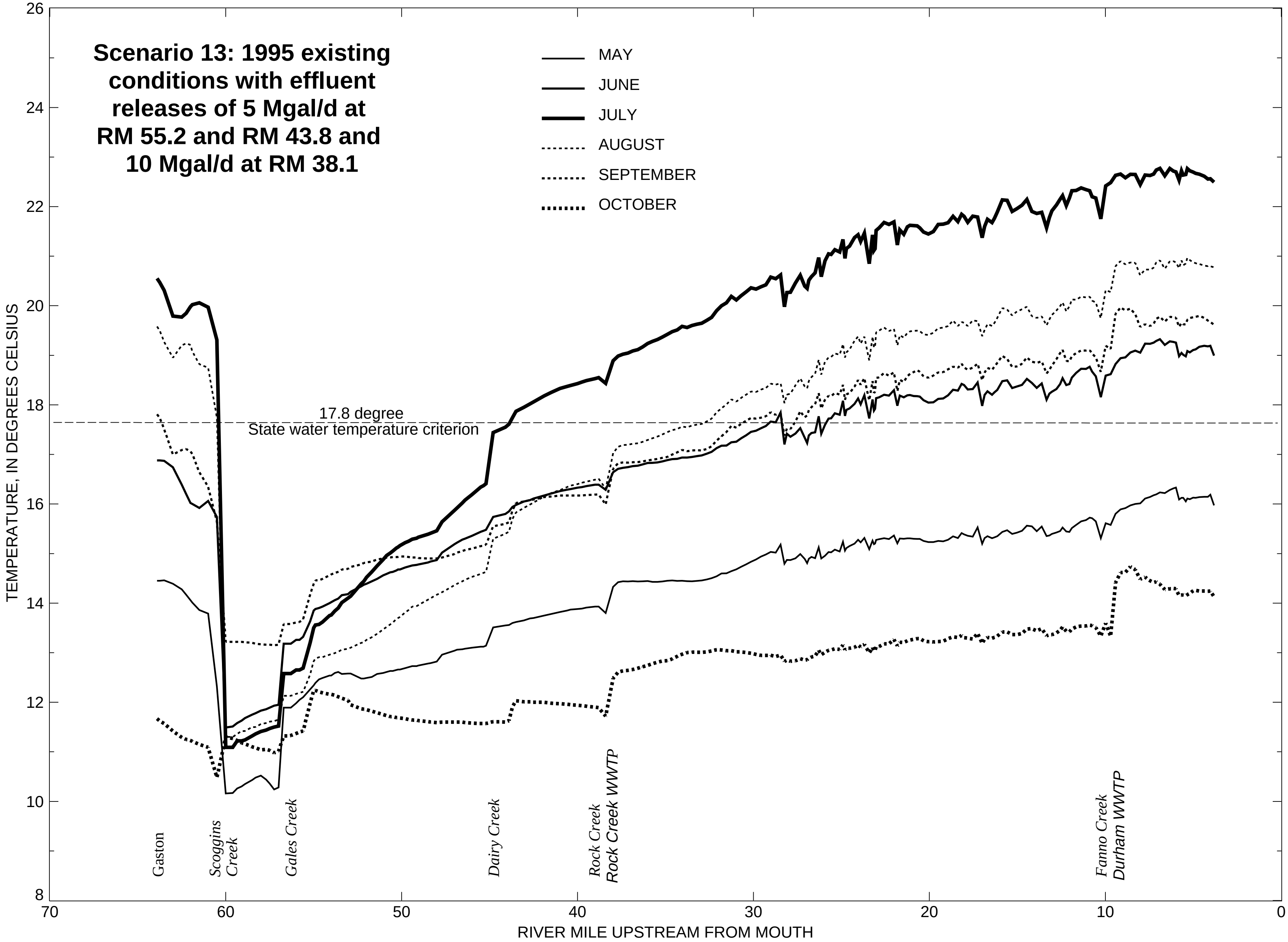


Figure 19. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 13, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

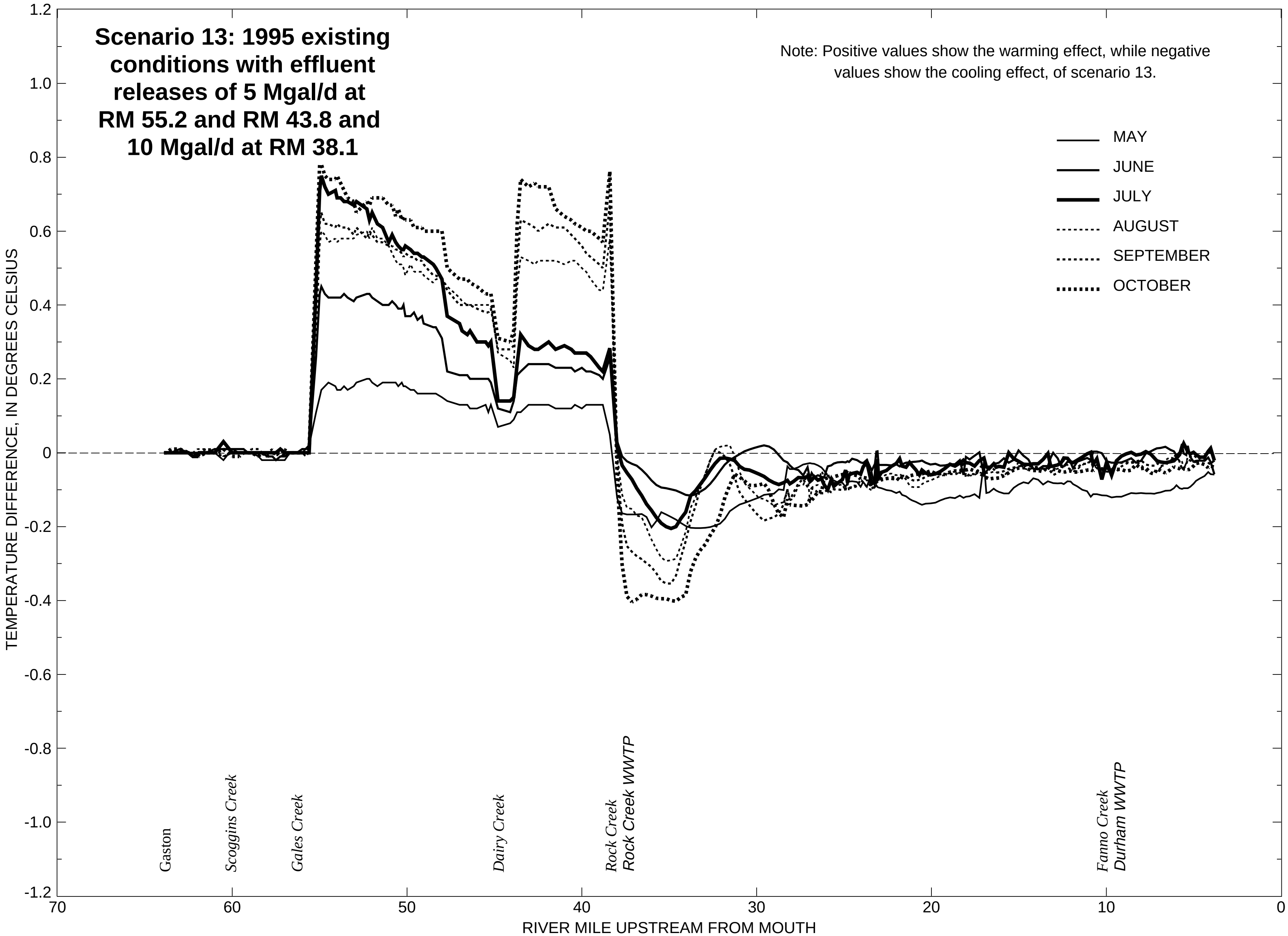


Figure 20. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 13, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

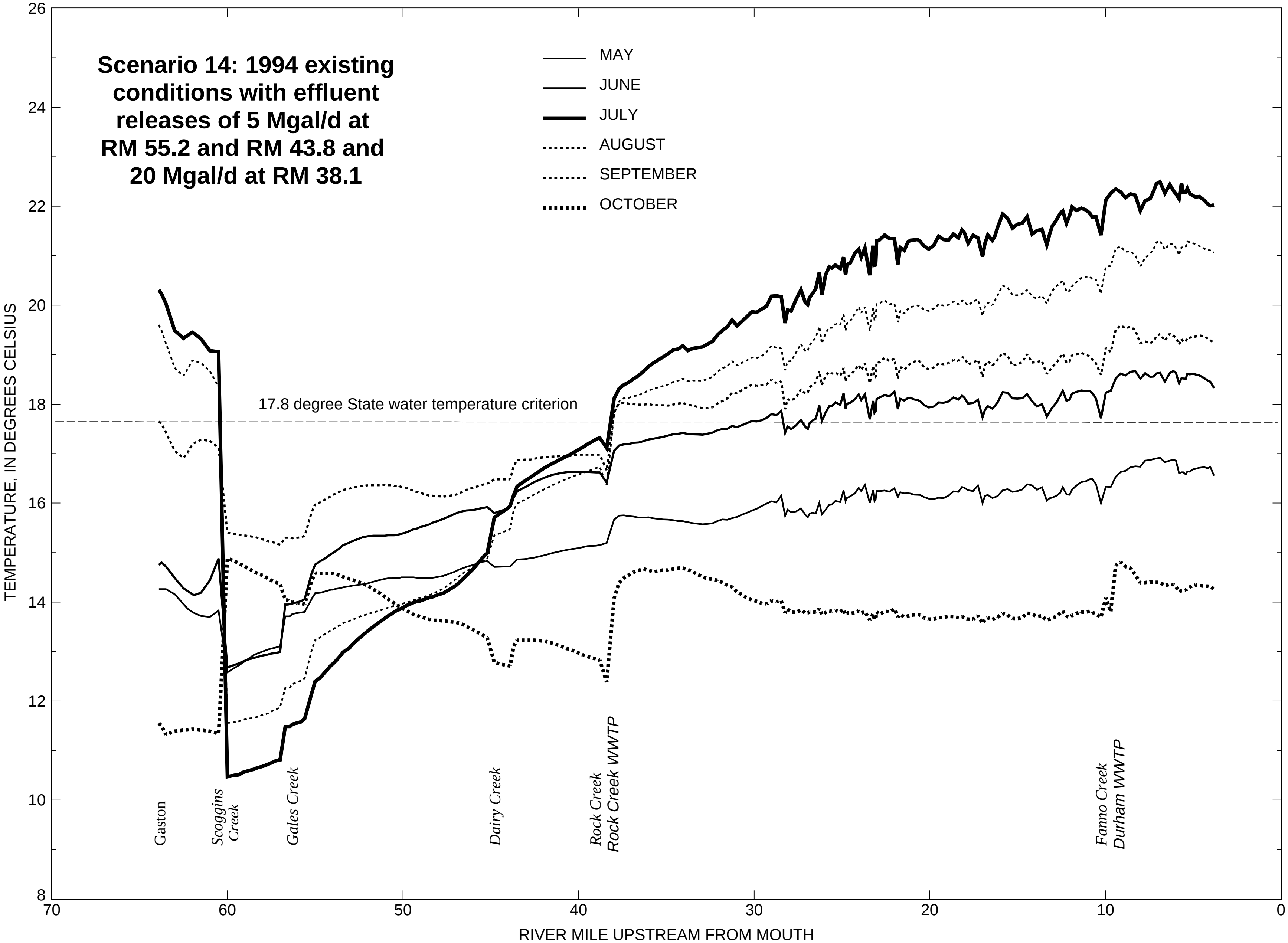


Figure 21. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 14, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 20 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

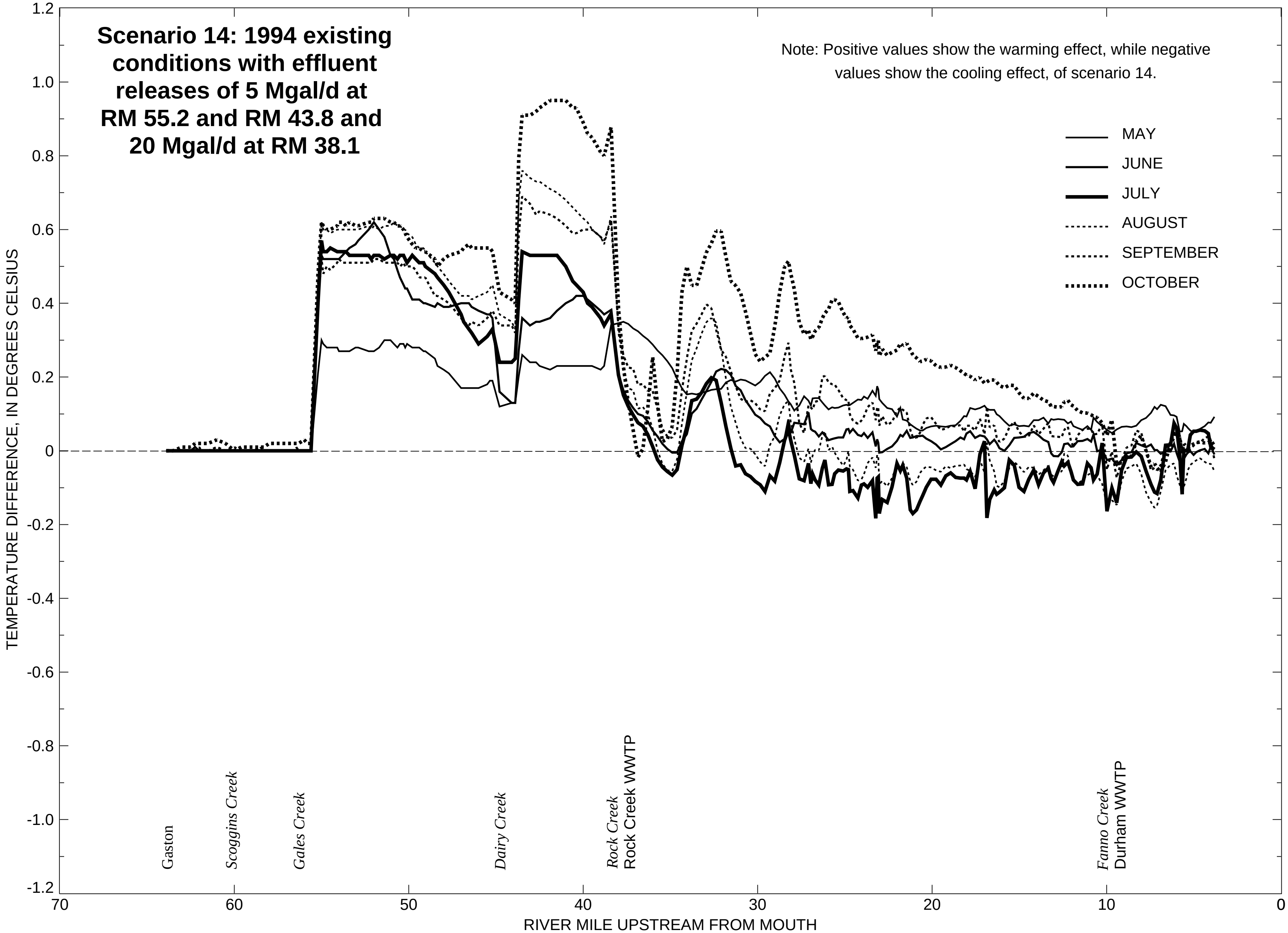


Figure 22. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 14, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 20 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

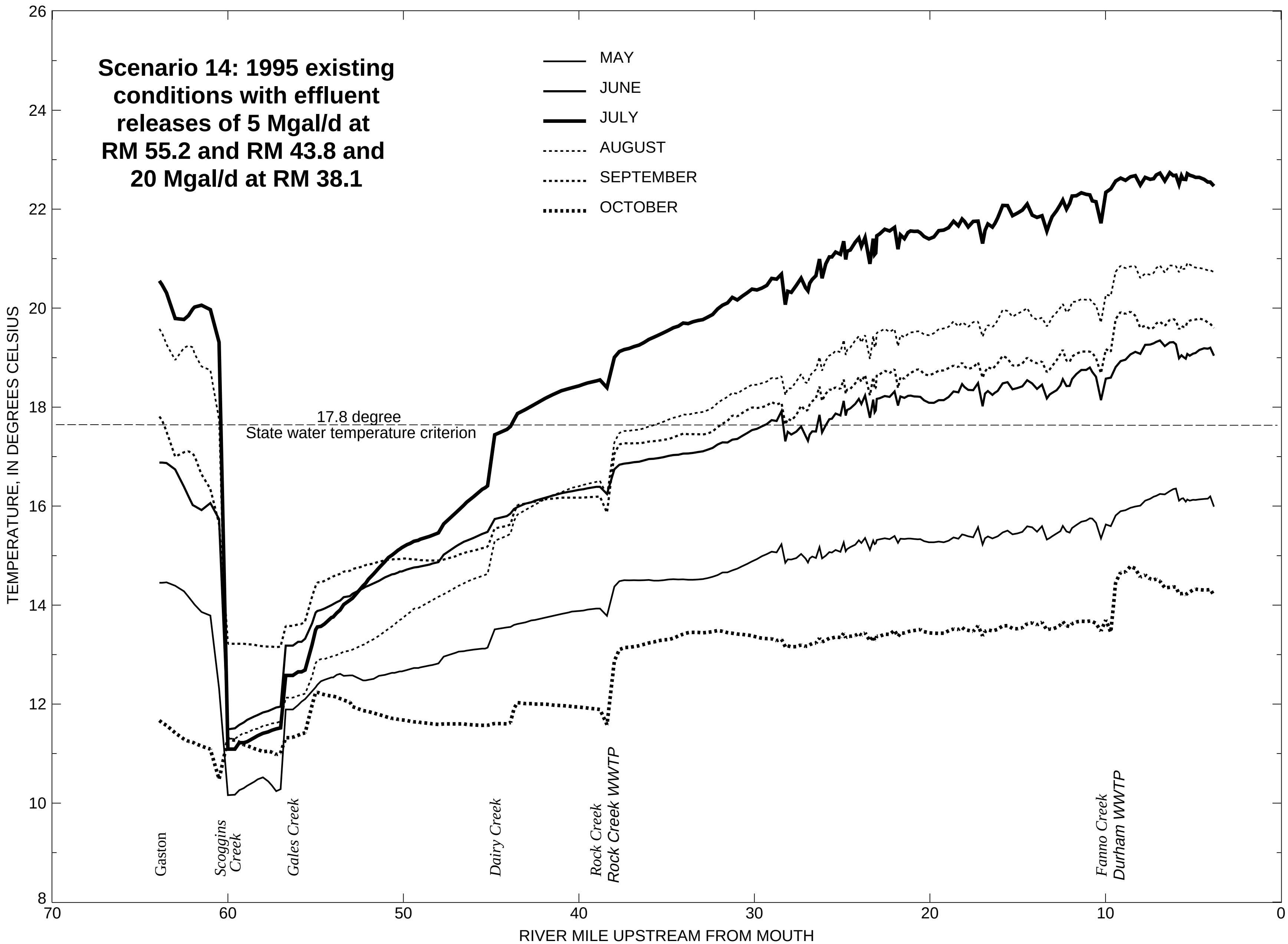


Figure 23. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 14, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 20 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

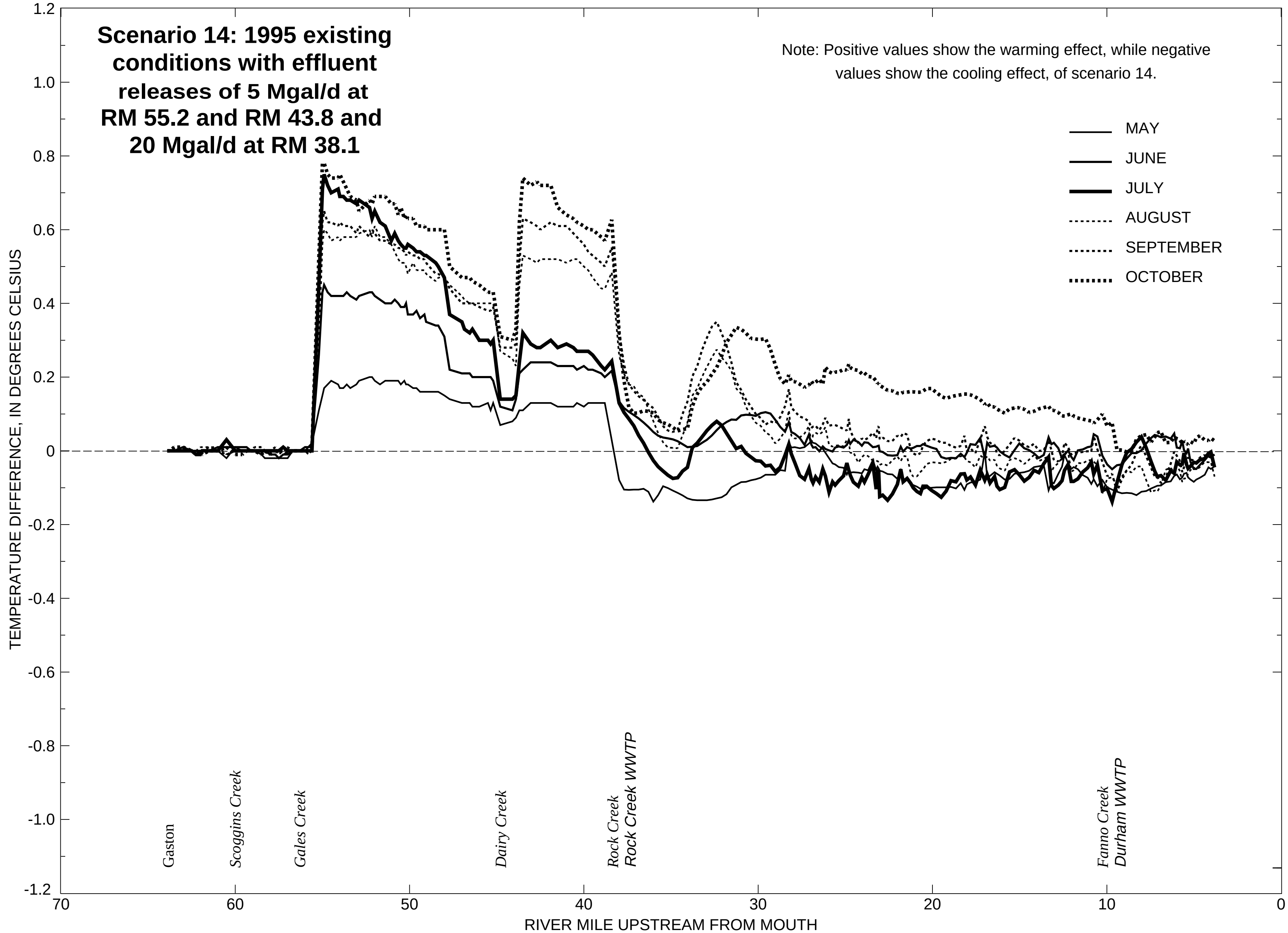


Figure 24. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 14, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 20 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

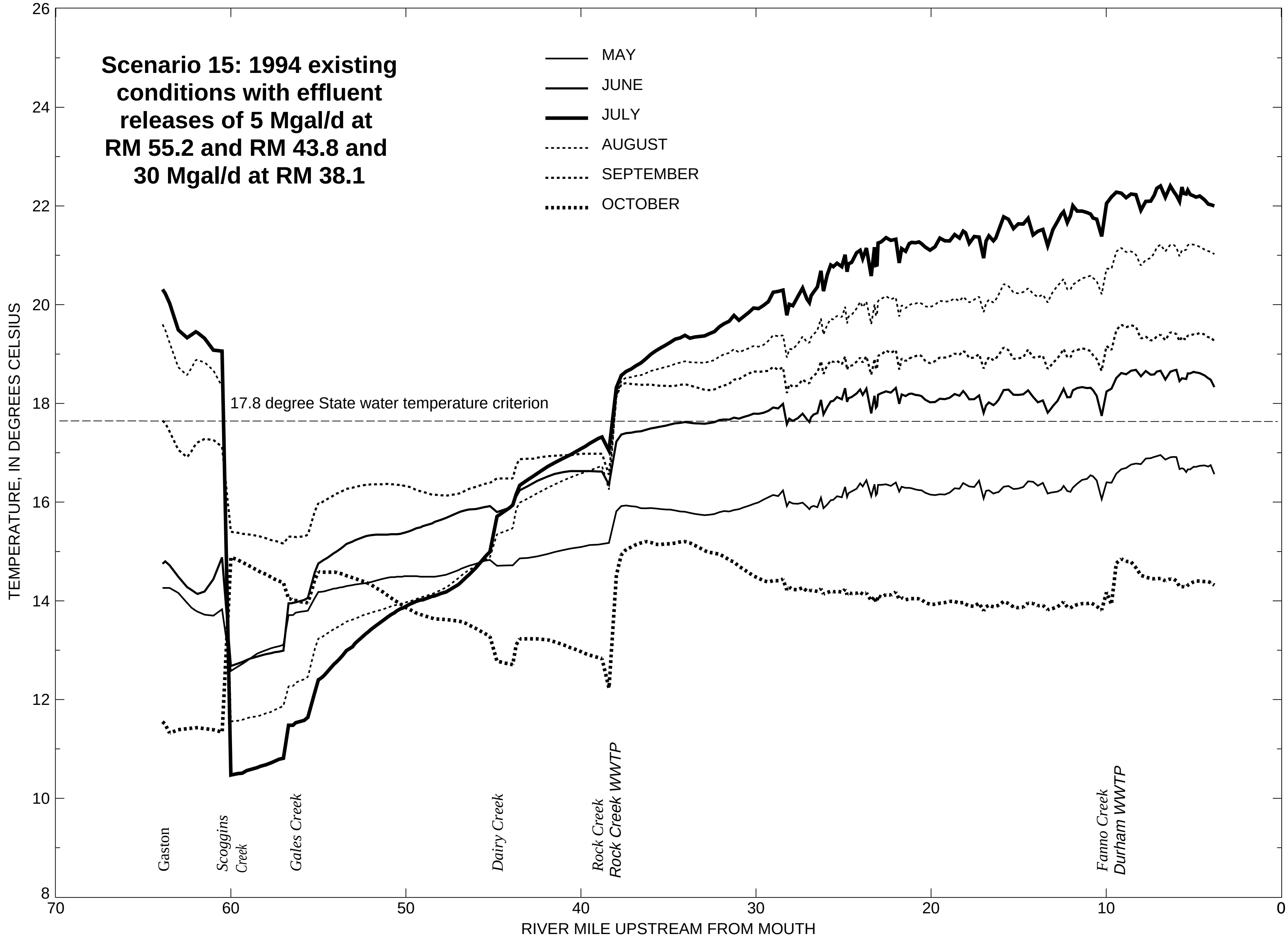


Figure 25. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 15, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 30 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

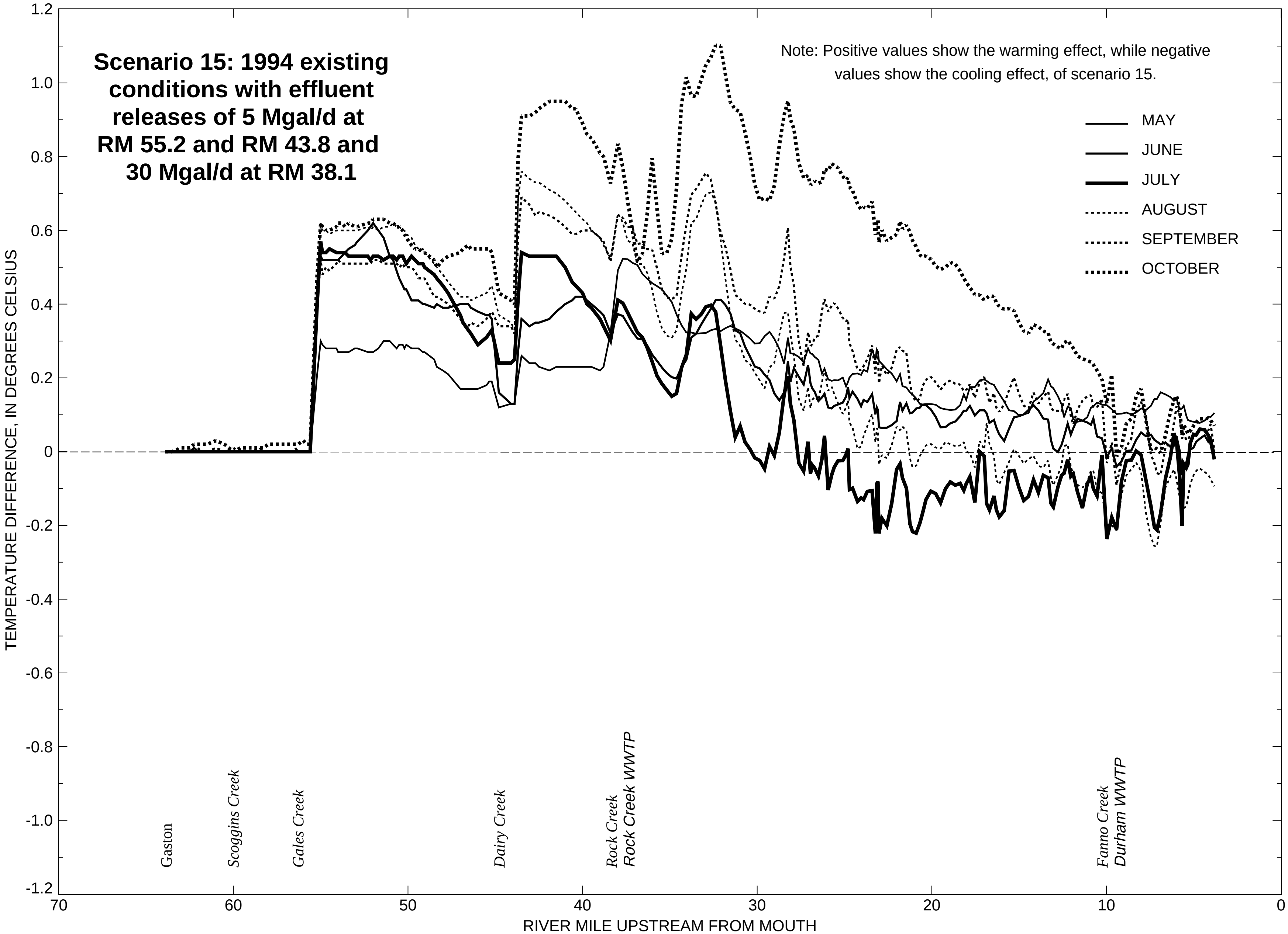


Figure 26. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 15, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 30 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

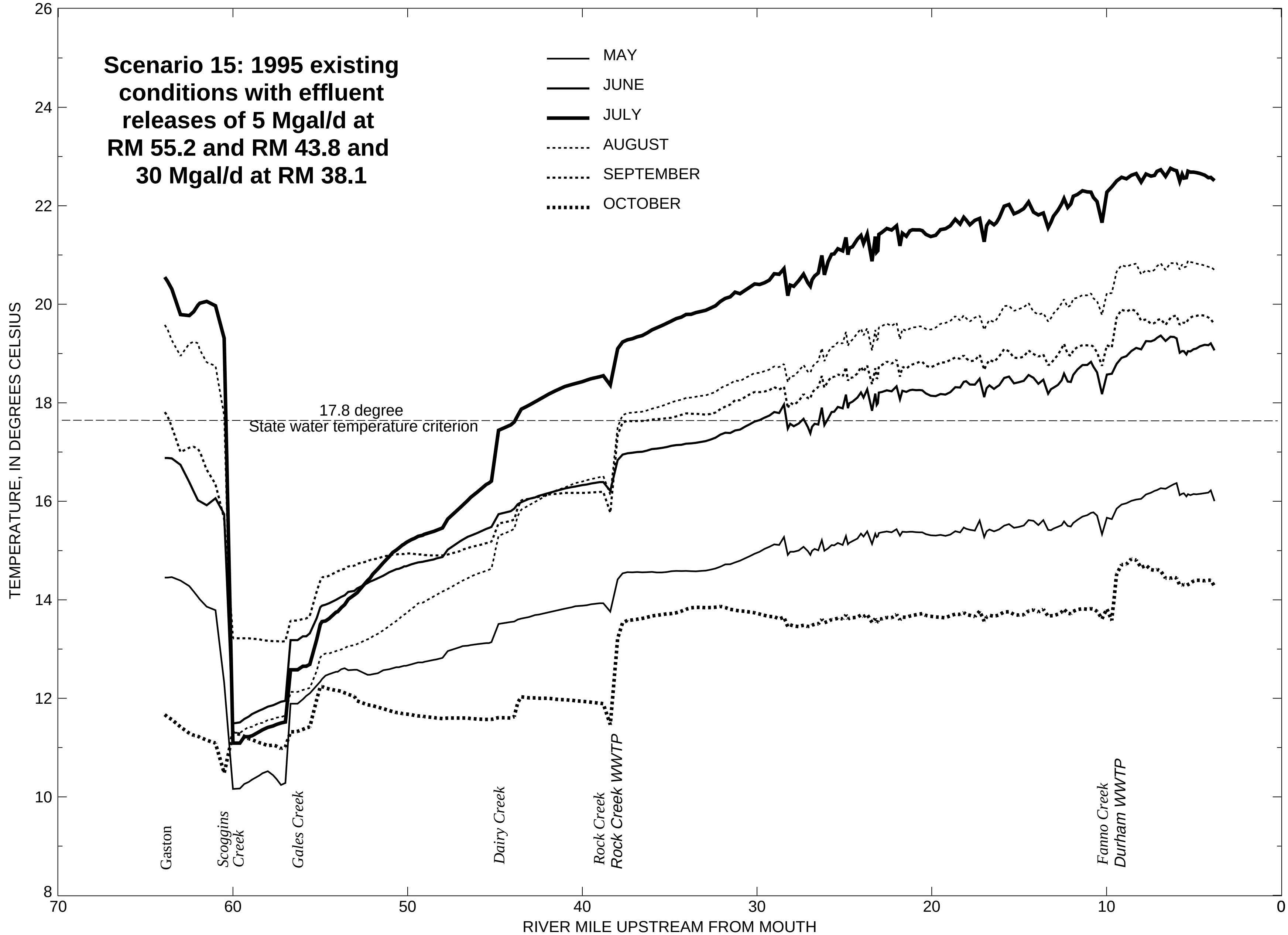


Figure 27. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 15, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 30 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

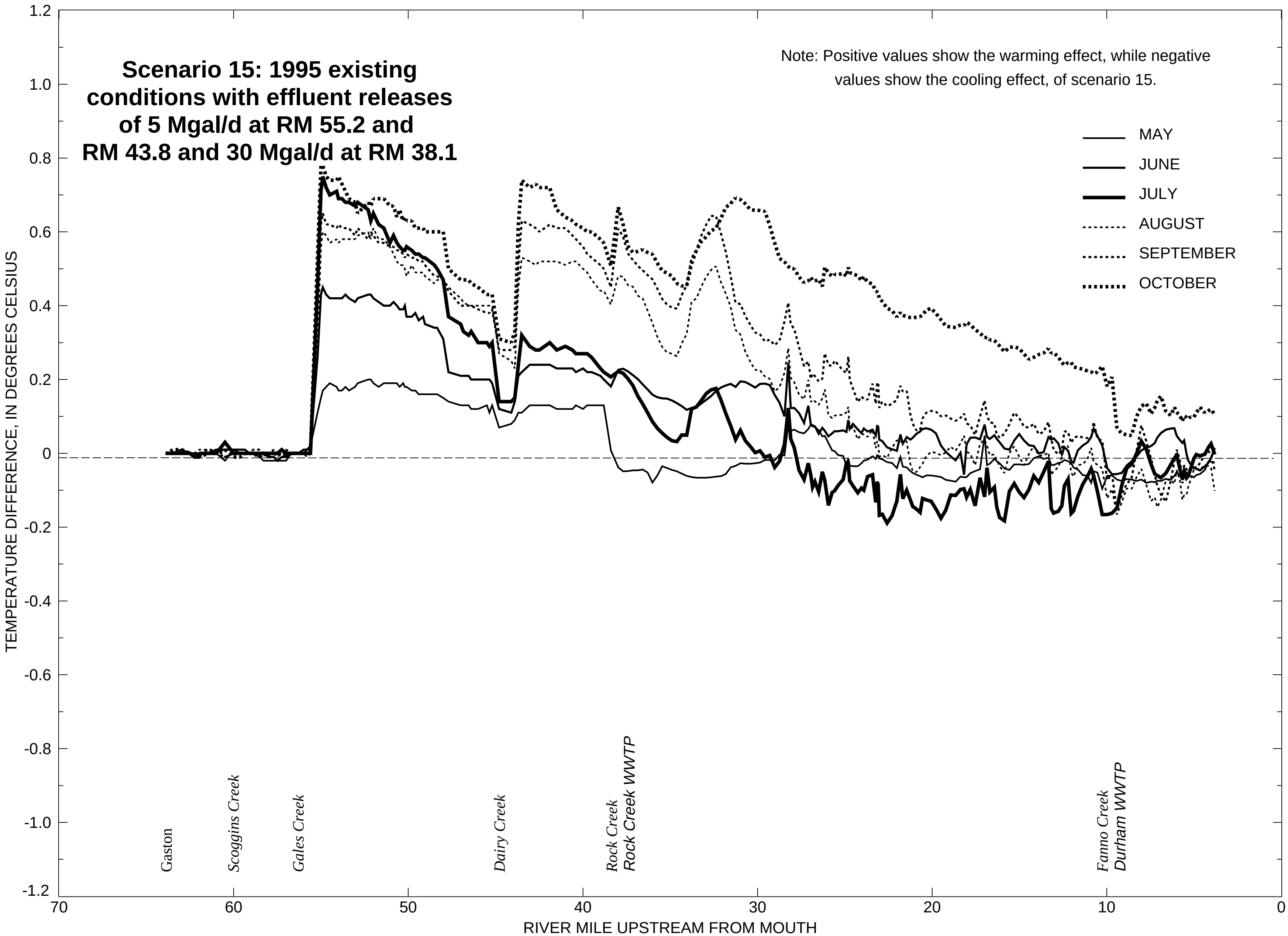


Figure 28. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 15, existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 30 Mgal/d at RM 38.1. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

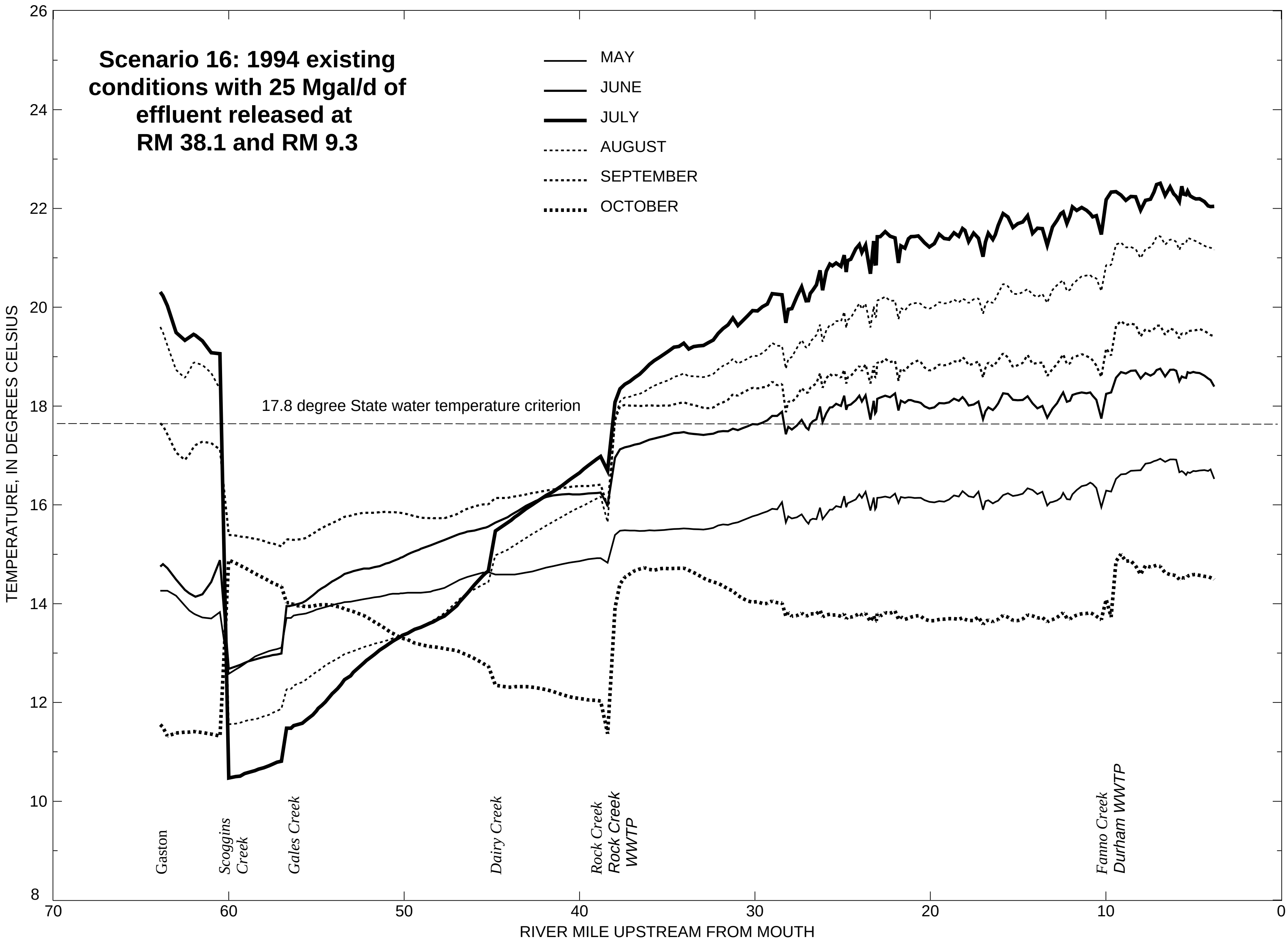


Figure 29. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 16, existing conditions with 25 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

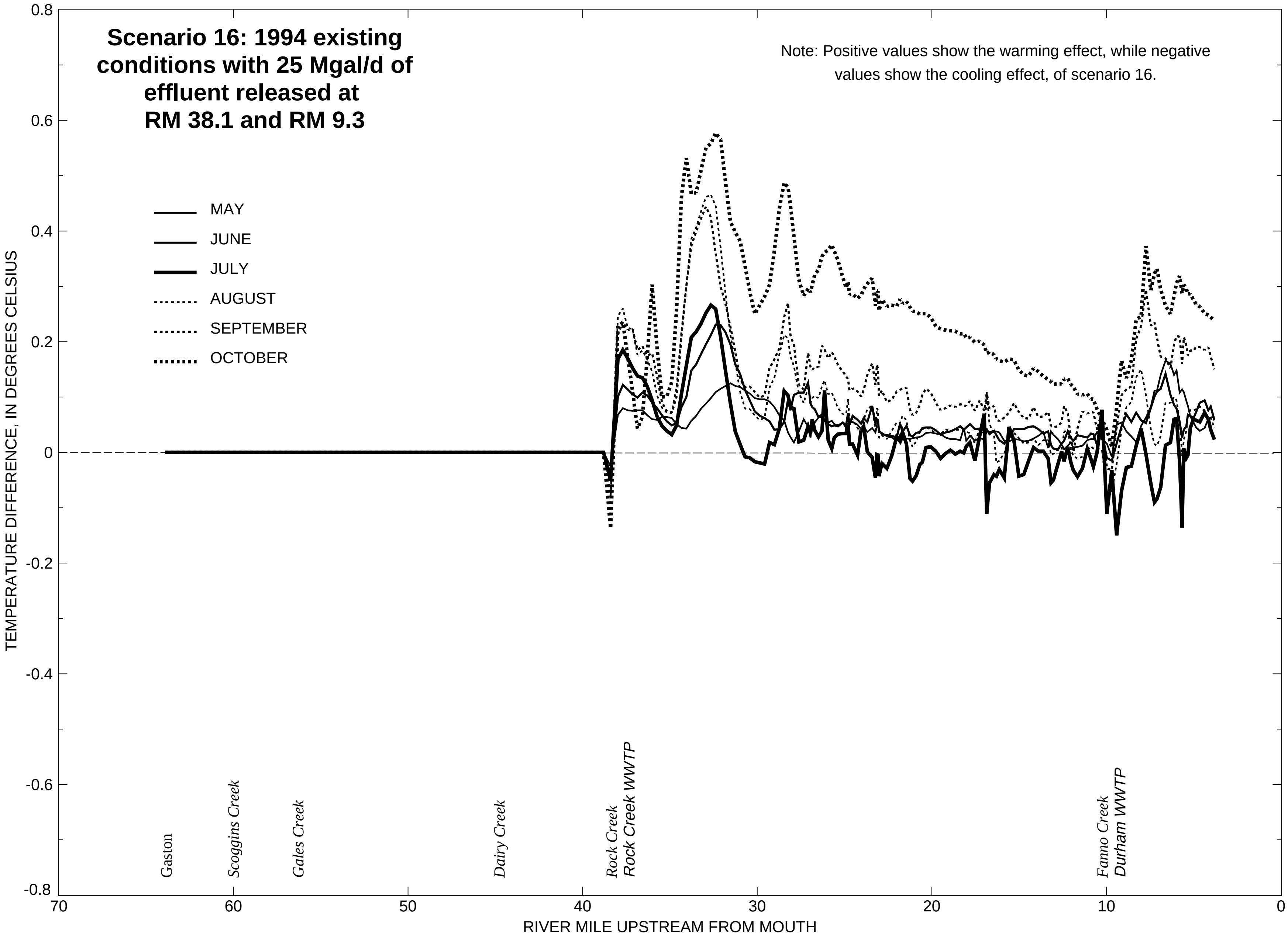


Figure 30. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 16, existing conditions with 25 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

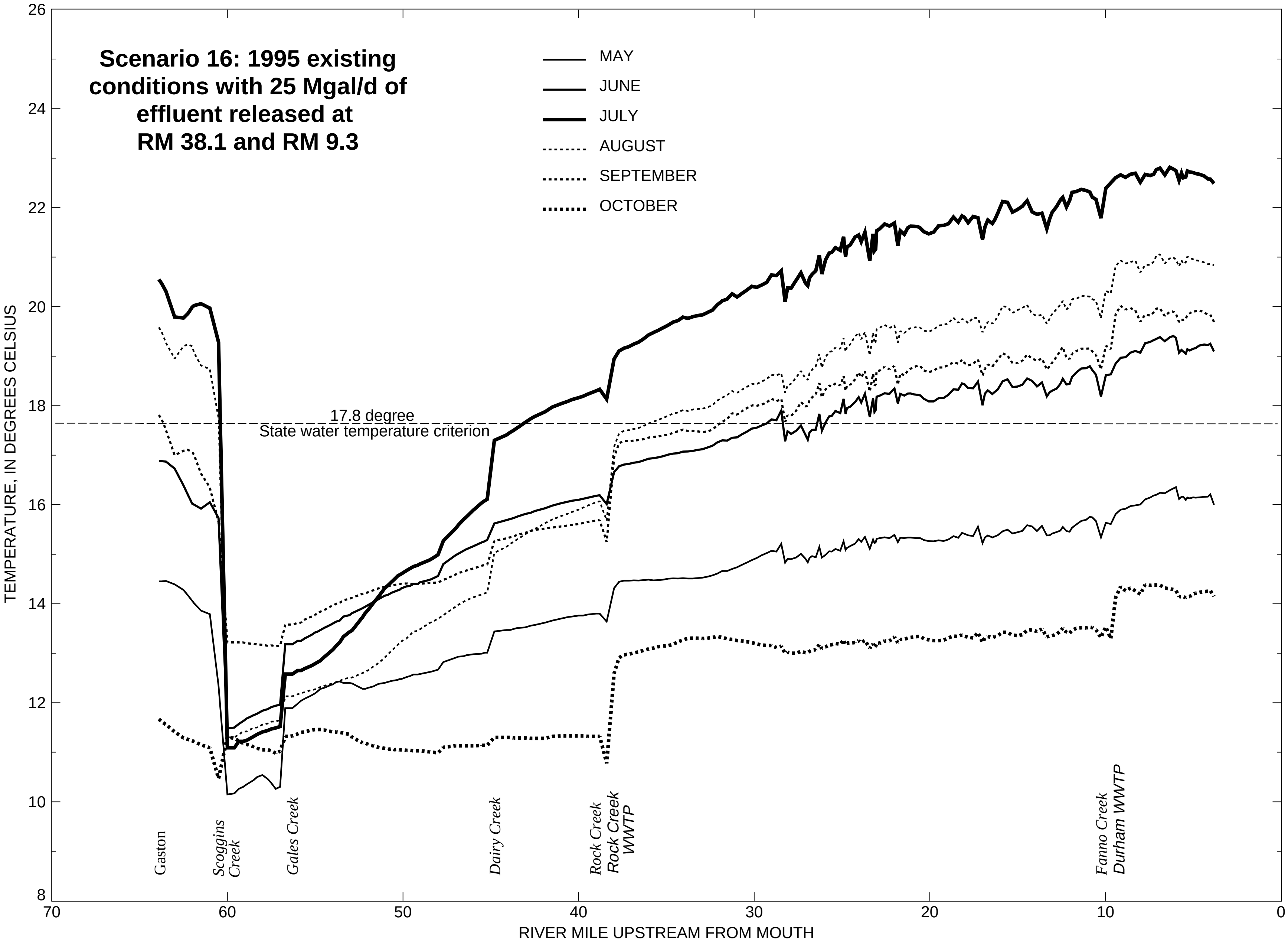


Figure 31. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 16, existing conditions with 25 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

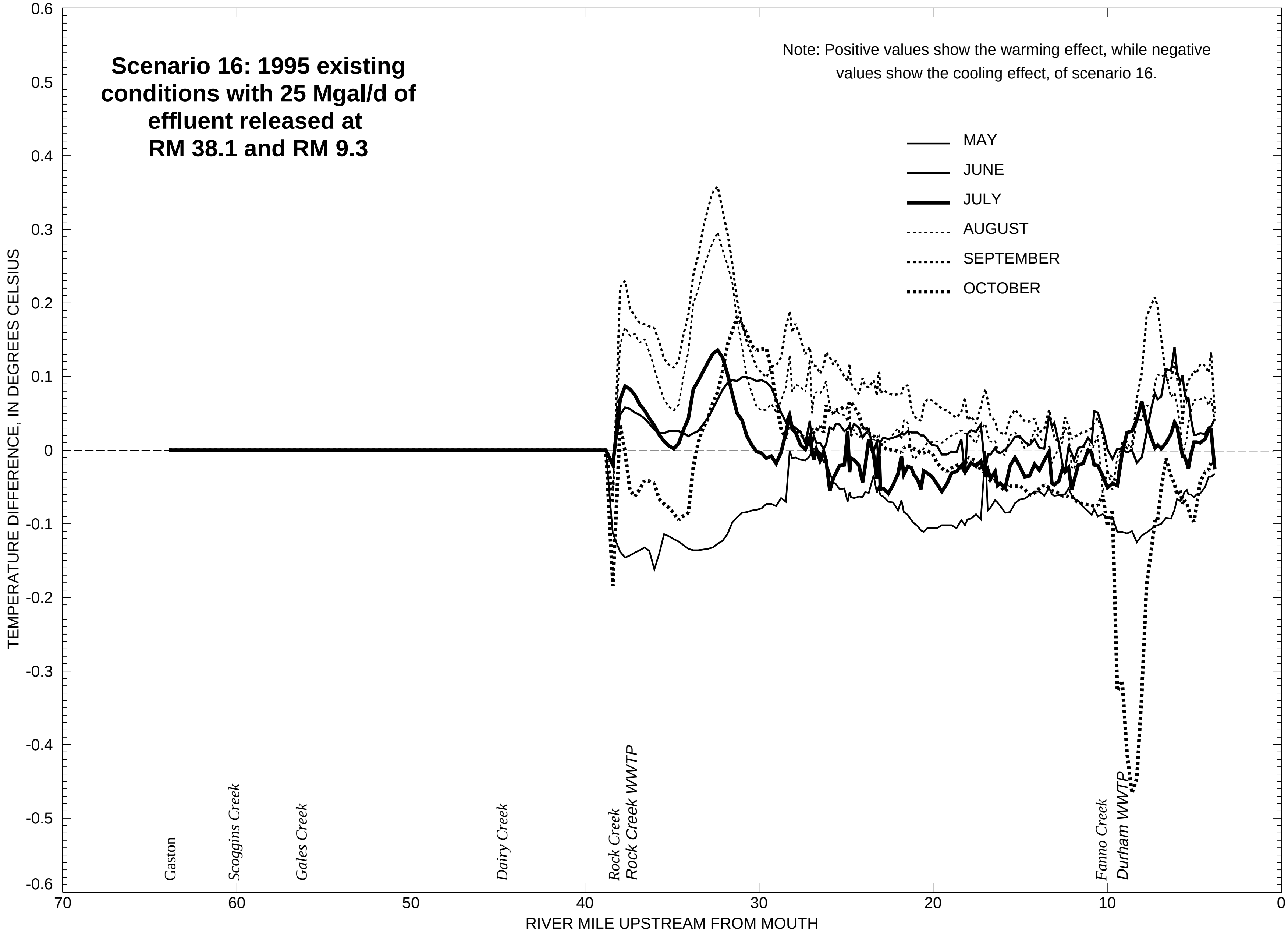


Figure 32. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 16, existing conditions with 25 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

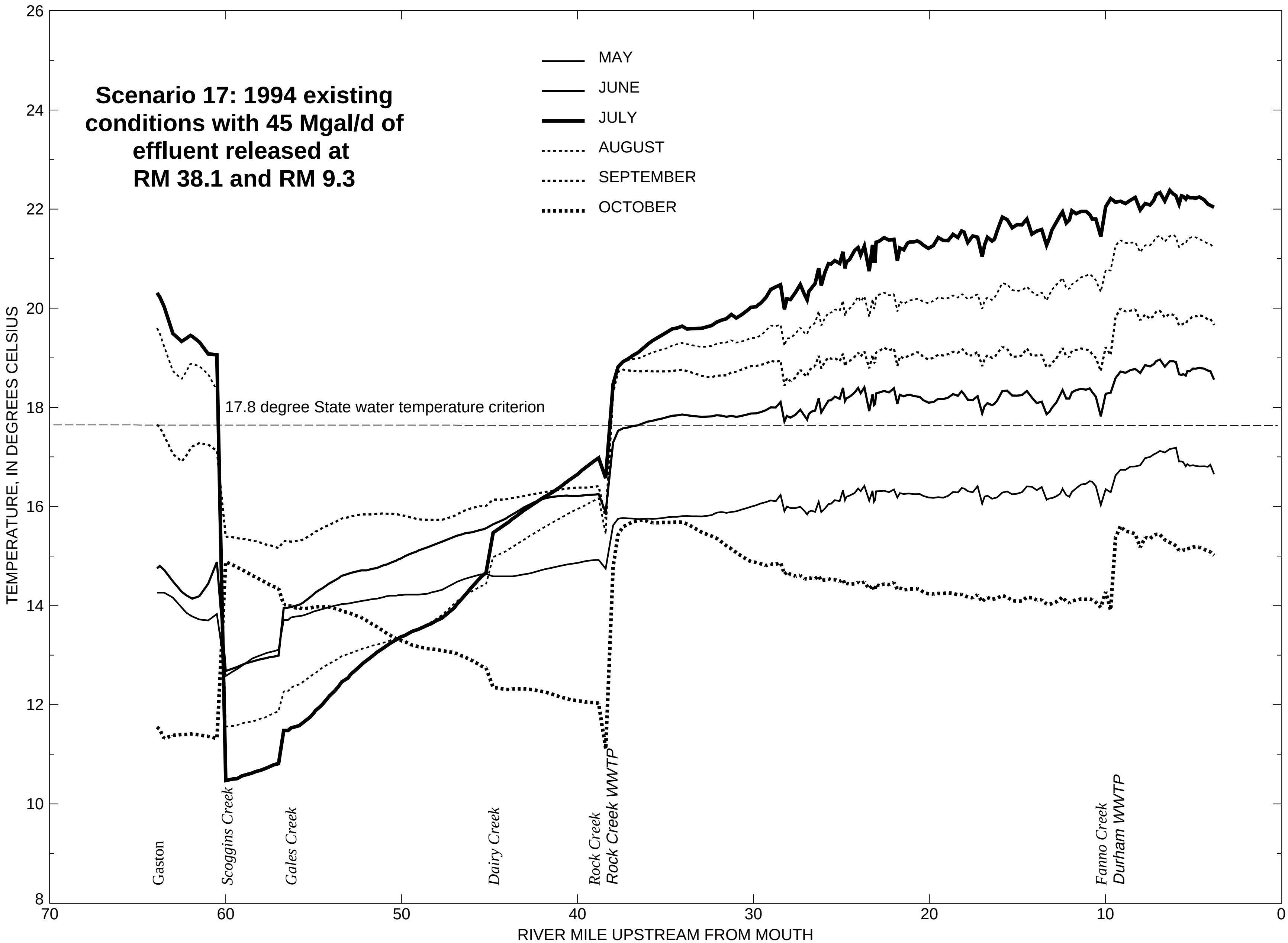


Figure 33. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 17, existing conditions with 45 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

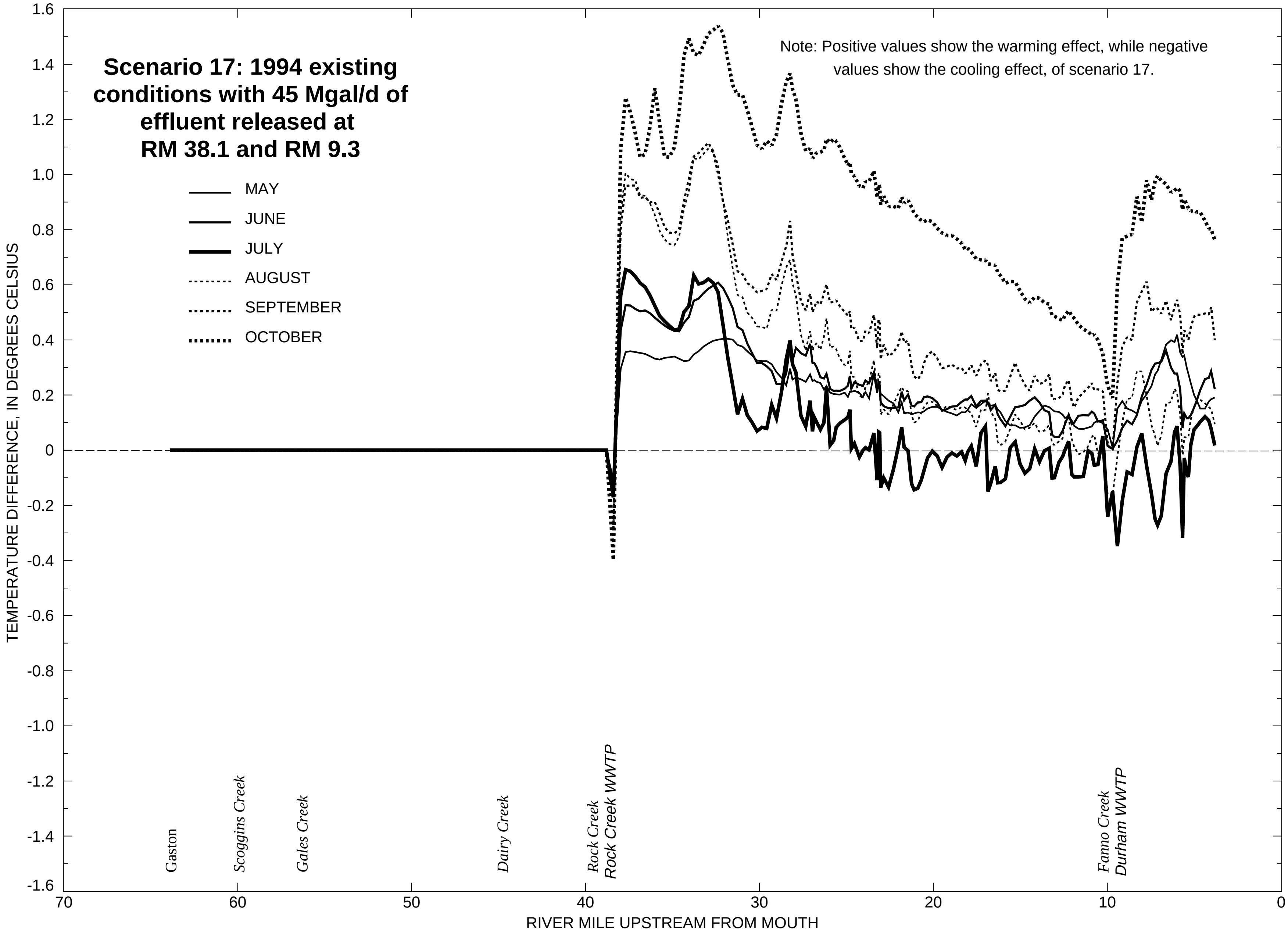


Figure 34. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 17, existing conditions with 45 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

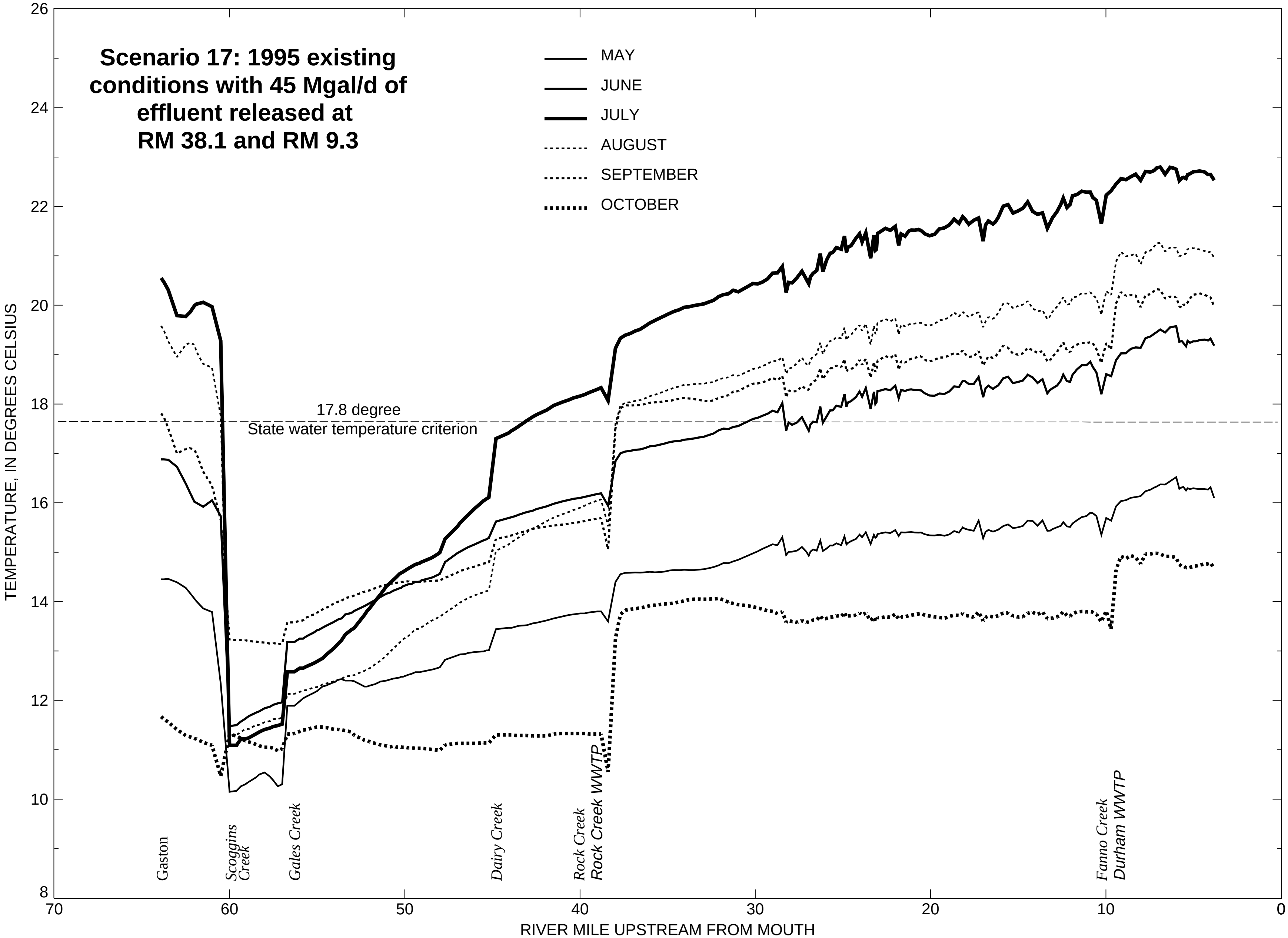


Figure 35. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 17, existing conditions with 45 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

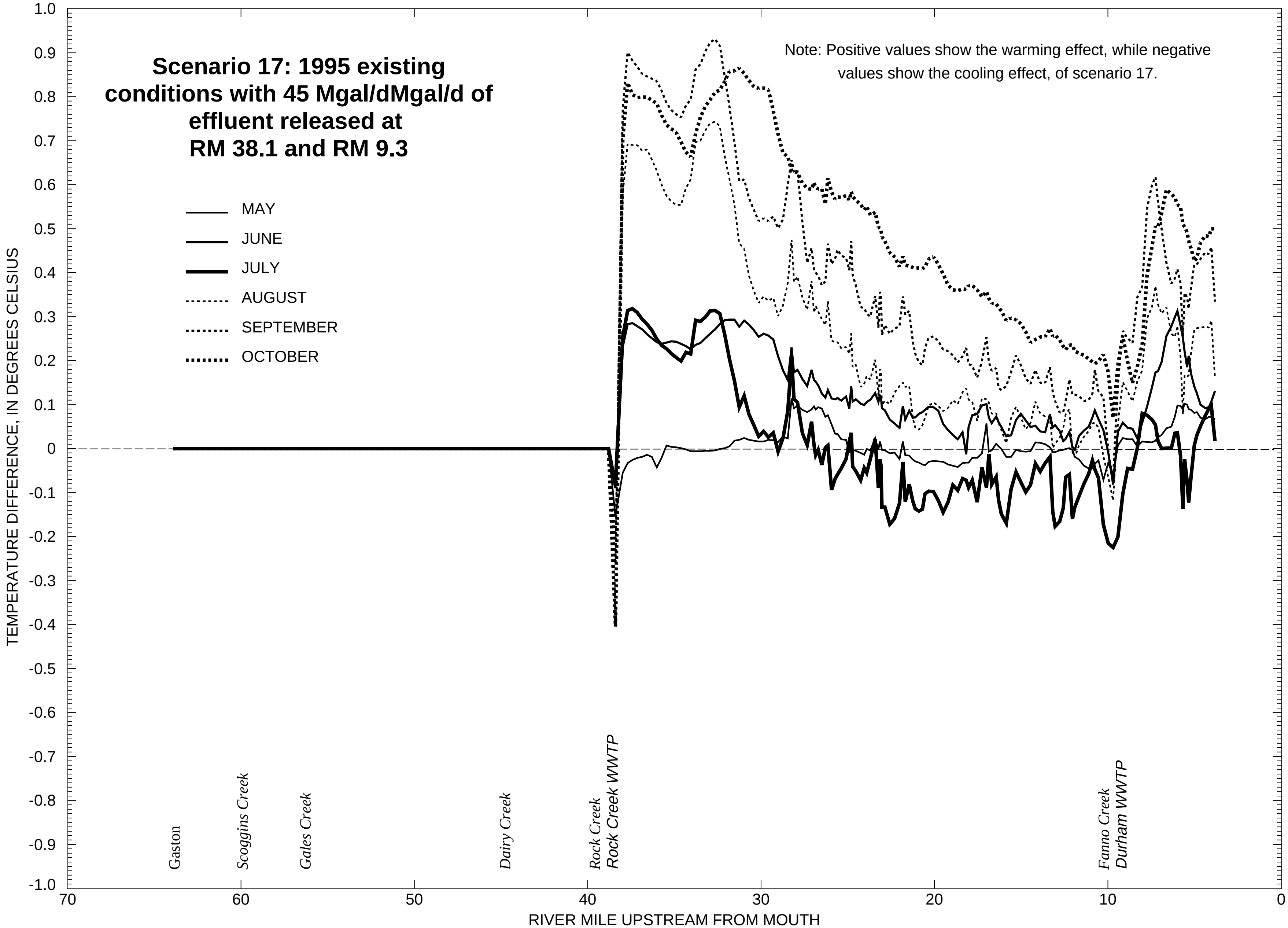


Figure 36. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 17, existing conditions with 45 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

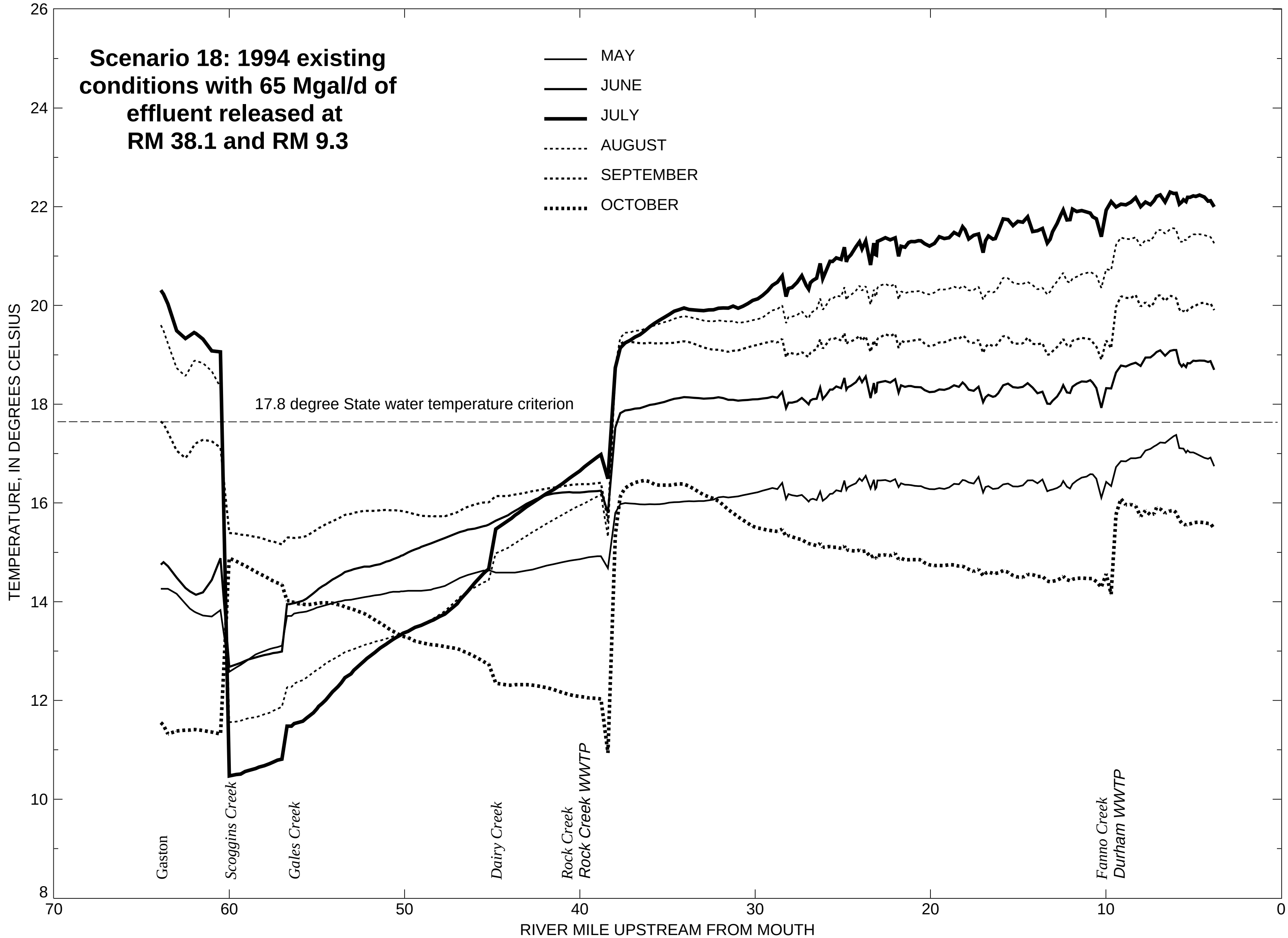


Figure 37. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 18, existing conditions with 65 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

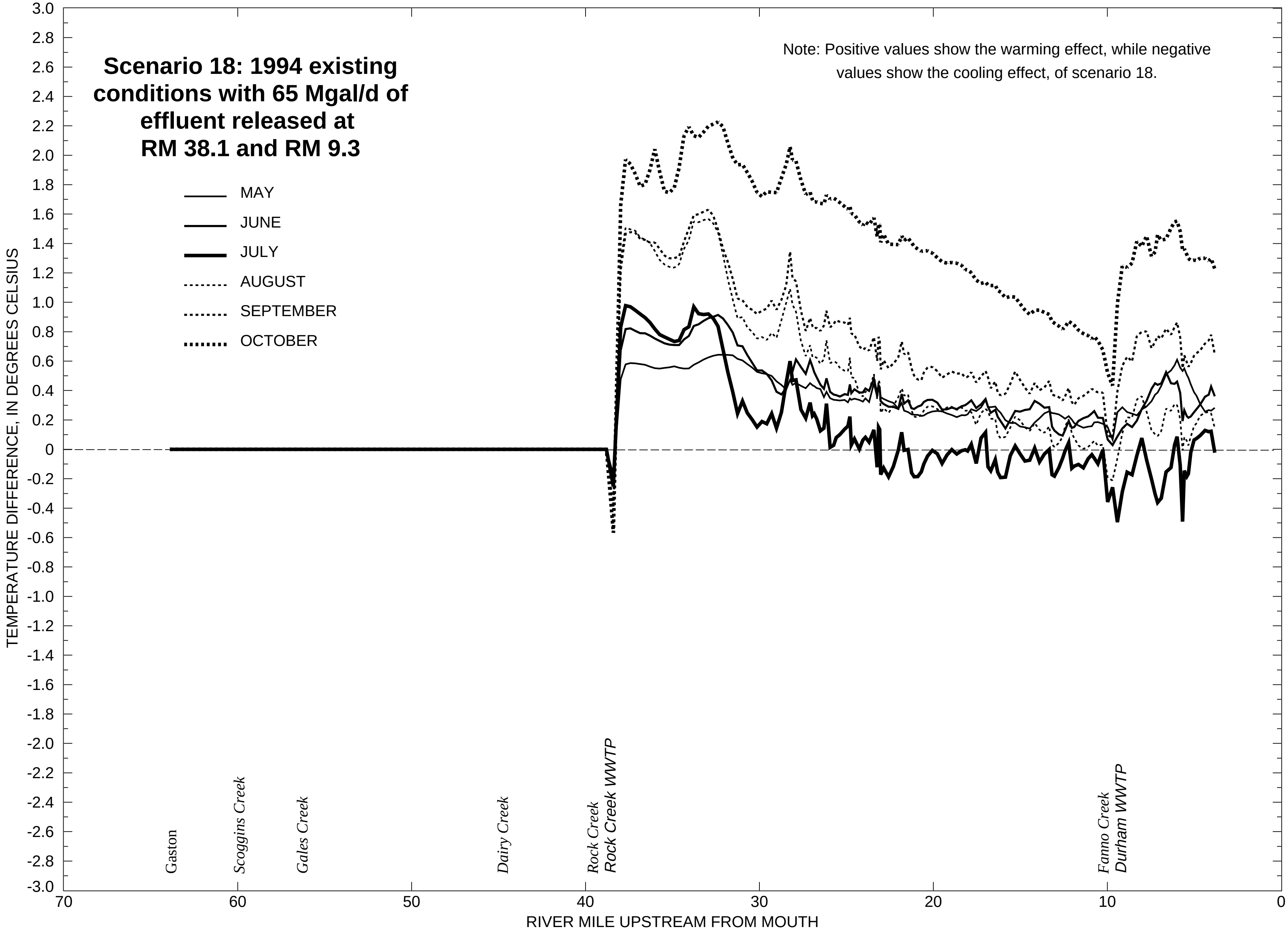


Figure 38. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 18, existing conditions with 65 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

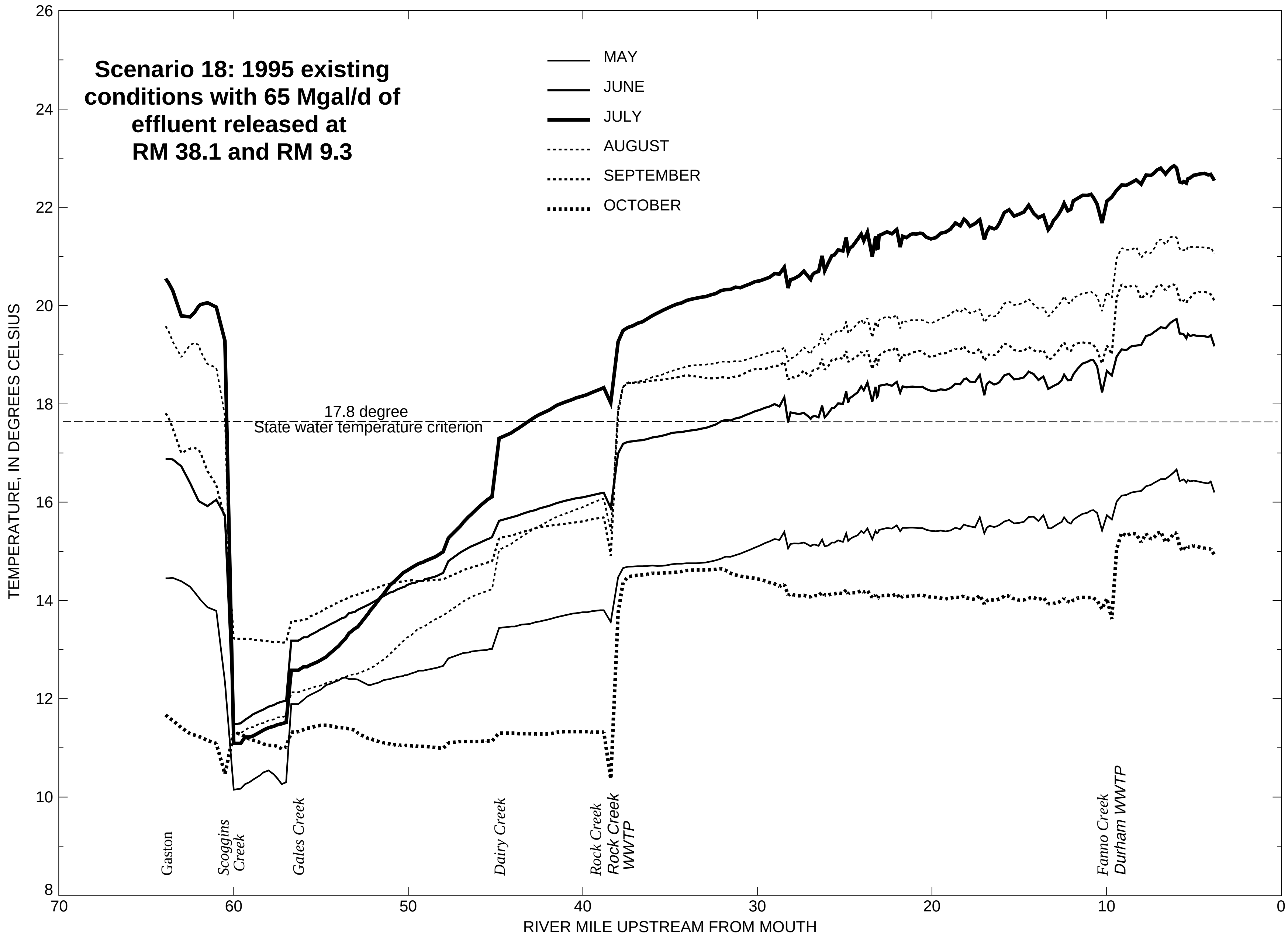


Figure 39. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 18, existing conditions with 65 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

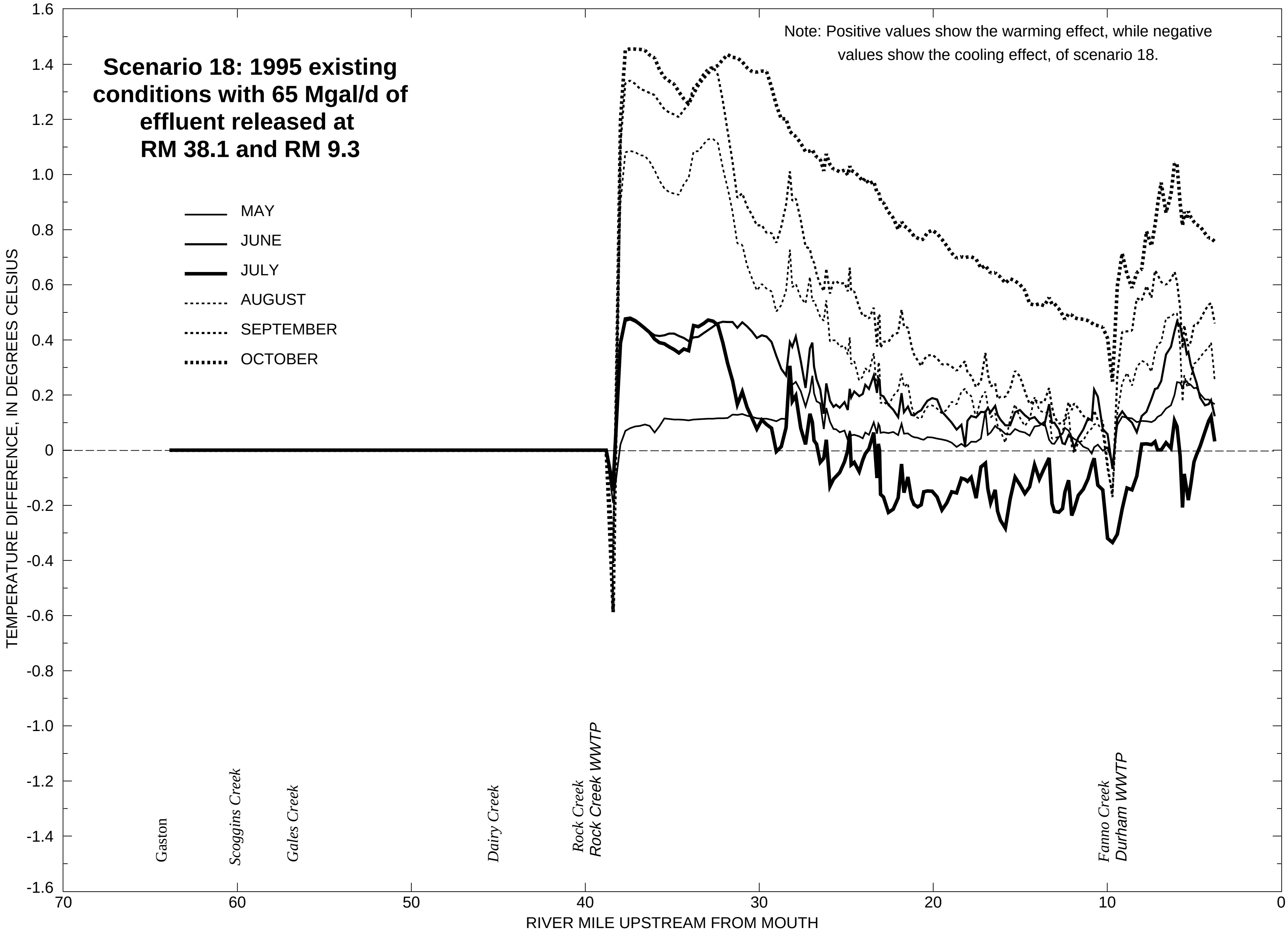


Figure 40. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 18, existing conditions with 65 Mgal/d of effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

Scenarios 19 and 20: Existing and "natural" conditions with Gaston temperature data replaced with Lee Falls data

Because of sparse riparian shading in the reach between Lee Falls near Cherry Grove (RM 70.0) and the model upper boundary at Gaston (RM 63.9), water entering the model's upstream boundary does not represent "natural" or "background" conditions. The intent of scenarios 19 and 20 was to determine the effect of cooler water entering the river system at Gaston relative to existing and "natural" conditions. For the existing conditions, 1994 and 1995 observed flow at Gaston were still used as input to the model simulations; however, to compensate for warming that may occur between Lee Falls and Gaston, observed water-temperature data at Gaston were replaced with observed water-temperature data collected at Lee Falls from May to October 1997. All other conditions in the models were held constant to existing conditions (scenario 1).

In the existing conditions simulation, water temperatures decreased substantially between Gaston (RM 63.9) and the confluence with Scoggins Creek (RM 60.0) by as much as 4.0^{o}C in July (figs. 41–44); however, the effect of the temperature decrease was overwhelmed by the large volume of colder water flowing from Scoggins Creek as a result of releases from Henry Hagg Lake. For most of the reach downstream of RM 60.0, the overall cooling effect of this scenario was less than 0.5^{o}C (figs. 42 and 44).

For the "natural" conditions scenario, Gaston water-temperature data were again substituted with 1997 Lee Falls water-temperature data for the 1994 and 1995 simulations. All other conditions in the model were held to the "natural" conditions defined in scenario 3 instead of the existing conditions (scenario 1). A full description of scenario 3 is provided on page 27 in Risley (1997). The simulation of "natural" conditions was based on the following assumptions:

(1) No flow augmentation from the Trask River (Barney Reservoir) to the main stem of the Tualatin River was provided.

(2) Both Henry Hagg Lake and the Oswego diversion dam at RM 3.4 were assumed not to exist.

(3) No withdrawals for irrigation or urban water supply were made.

(4) No flow diversions for the Oswego Canal were made.

(5) No effluent was released from WWTPs.

(6) Maximum possible riparian shading along the main stem was assumed.

In scenario 20, as in scenario 19, water temperatures decreased substantially between Gaston (RM 63.9) and the confluence with Scoggins Creek (RM 60.0) (figs. 45–48). Between Scoggins Creek and near the Dairy Creek confluence (RM 44.8), water temperatures gradually increased because the unnaturally cool water released from Henry Hagg Lake was not present; however, nearly all of the upper river reach above Rood Bridge (RM 38.4) for every month was not in violation of the water-quality standard. This was an improvement over the 1994 "natural" conditions scenario simulation shown in Risley (1997). In that simulation, which used observed Gaston water-temperature data, approximately 5 miles of the reach downstream of Gaston (RM 63.9) had temperatures greater than 17.8^{o}C for July and August. For the lower river section below Rood Bridge, the water temperatures generally increased (1.0^{o}C or less) for July and August, and decreased for other months.

Scenario 21: Existing conditions with WWTP effluent temperature equal to receiving river temperature

In this scenario, existing conditions (scenario 1) were simulated for 1994 and 1995, except the temperature of the effluent from the two WWTPs was no different than the receiving river temperature at the WWTPs (RM 38.1 and RM 9.3). The intent of this scenario was to examine the hydrologic effects of the volume of WWTP effluent flow on river temperature, as opposed to the direct effects of warmer effluent temperature. This scenario was similar to scenario 7 (Risley, 1997); however, in scenario 7 effluent flows from both WWTPs were completely eliminated.

The effect of scenario 21 on the river system was similar to the effect of scenario 7 (figs. 49–54). Temperatures downstream of RM 38.1 decreased by as much as 2.4^{o}C. The reduction then tapers off to 0.5^{o}C upstream of RM 9.3. Downstream of RM 9.3, temperatures decreased by as much as 1.2^{o}C; however, because the flow in the river downstream of the WWTPs was greater in scenario 21 than in scenario 7, scenario 21 had the effect of decreasing river temperatures slightly more than scenario 7. The magnitude of this difference generally ranged from 0.3 to 0.1^{o}C.

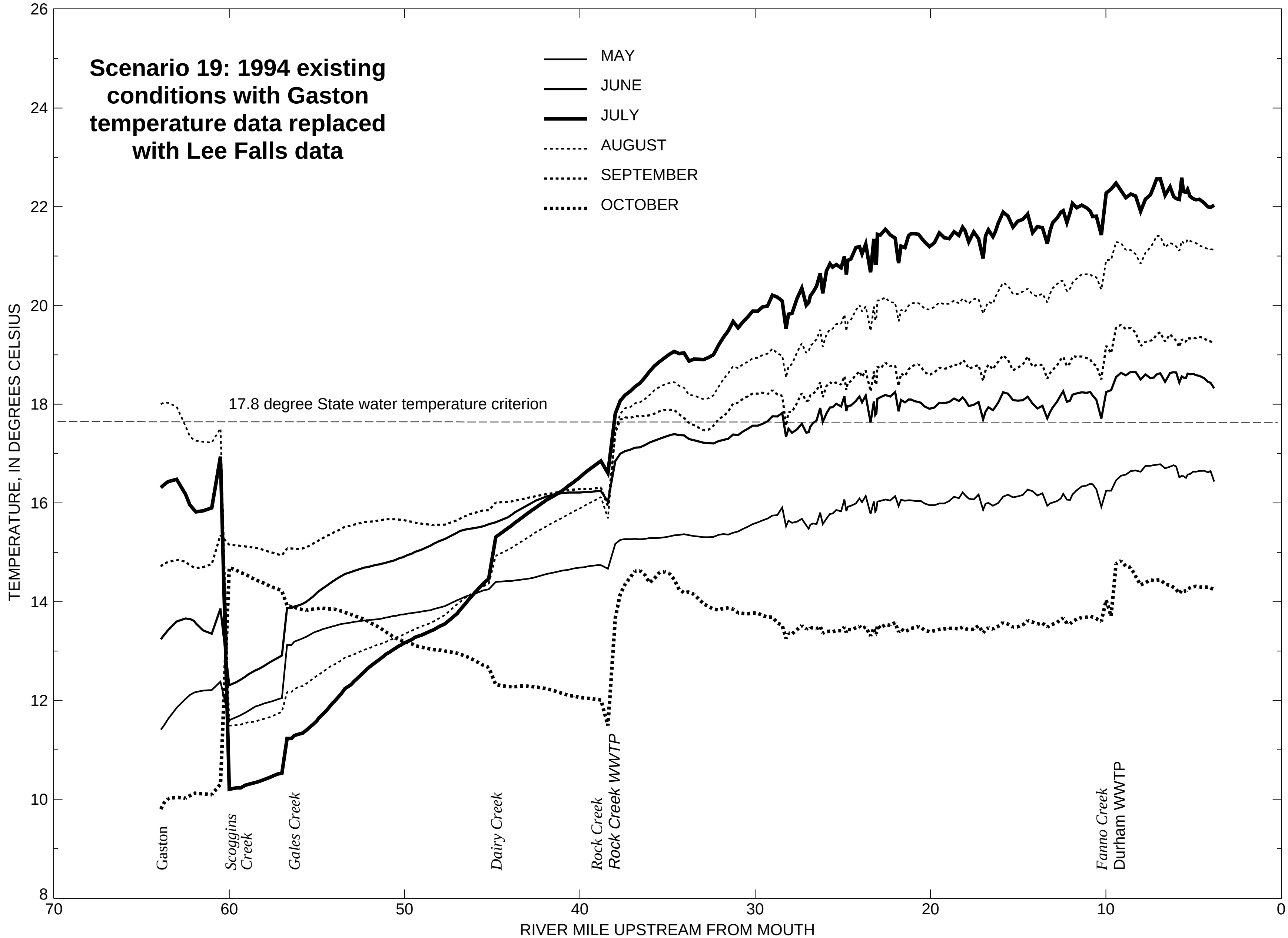


Figure 41. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 19, existing conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

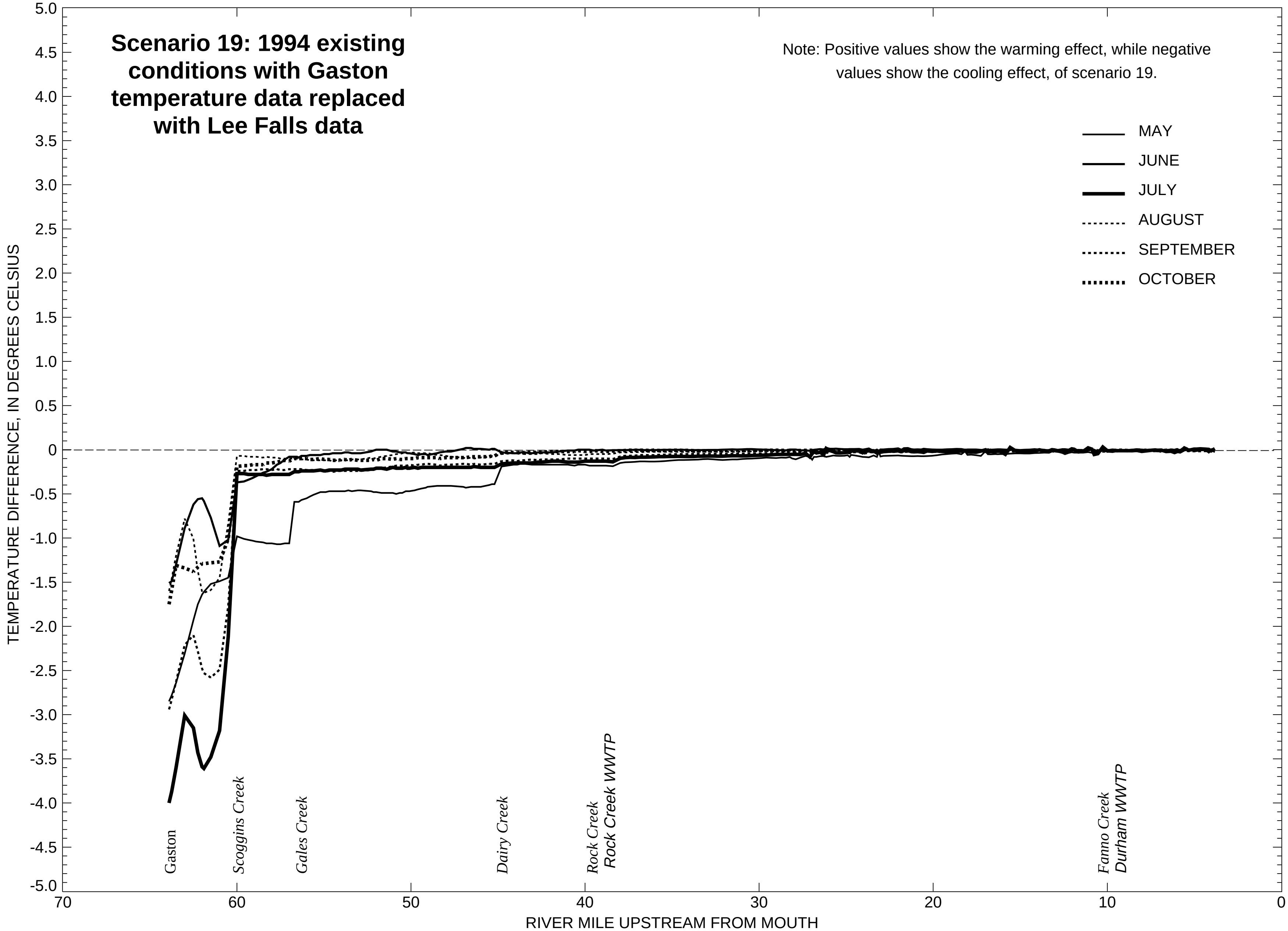


Figure 42. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 19, existing conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

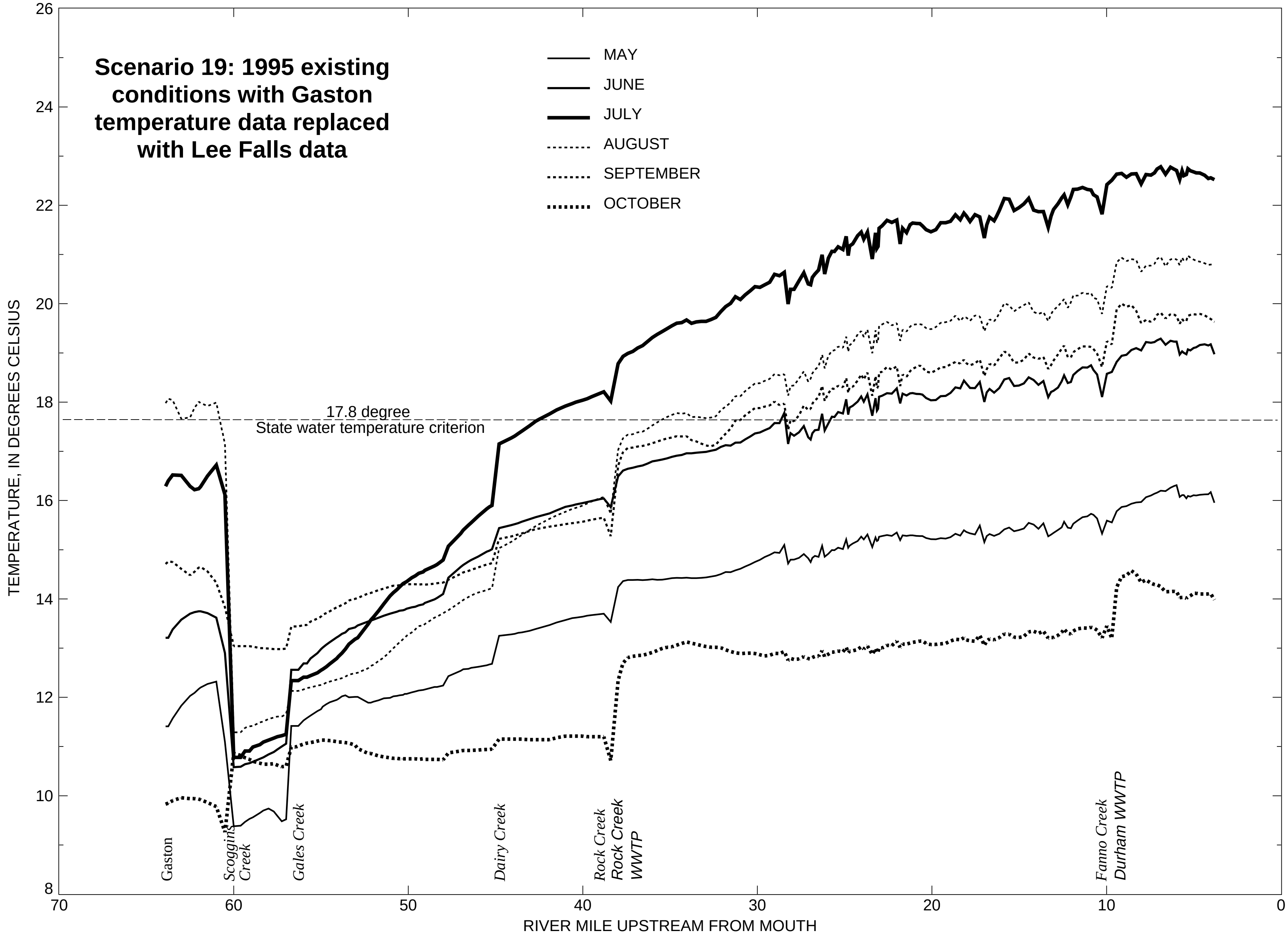


Figure 43. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 19, existing conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

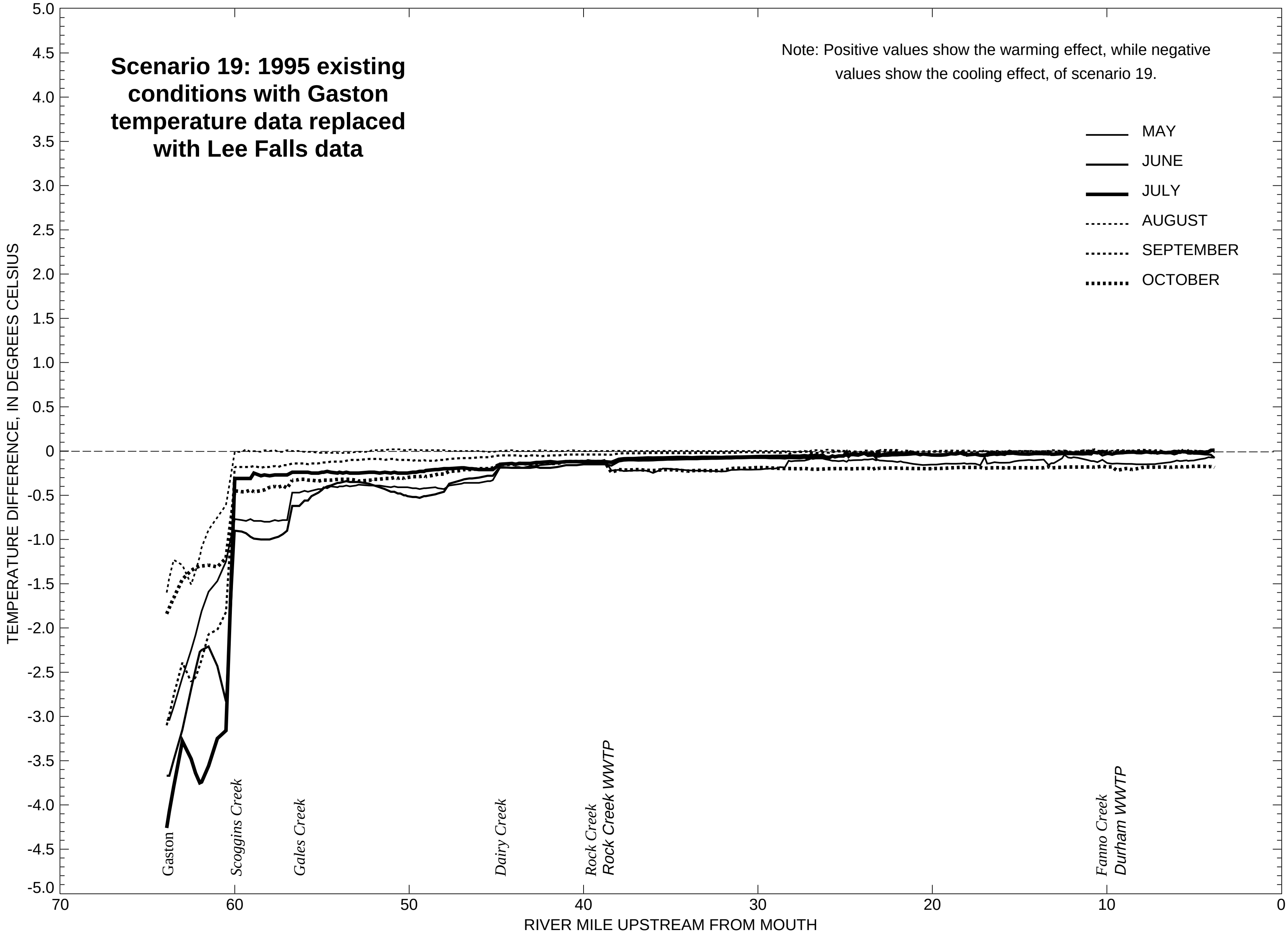


Figure 44. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 19, existing conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

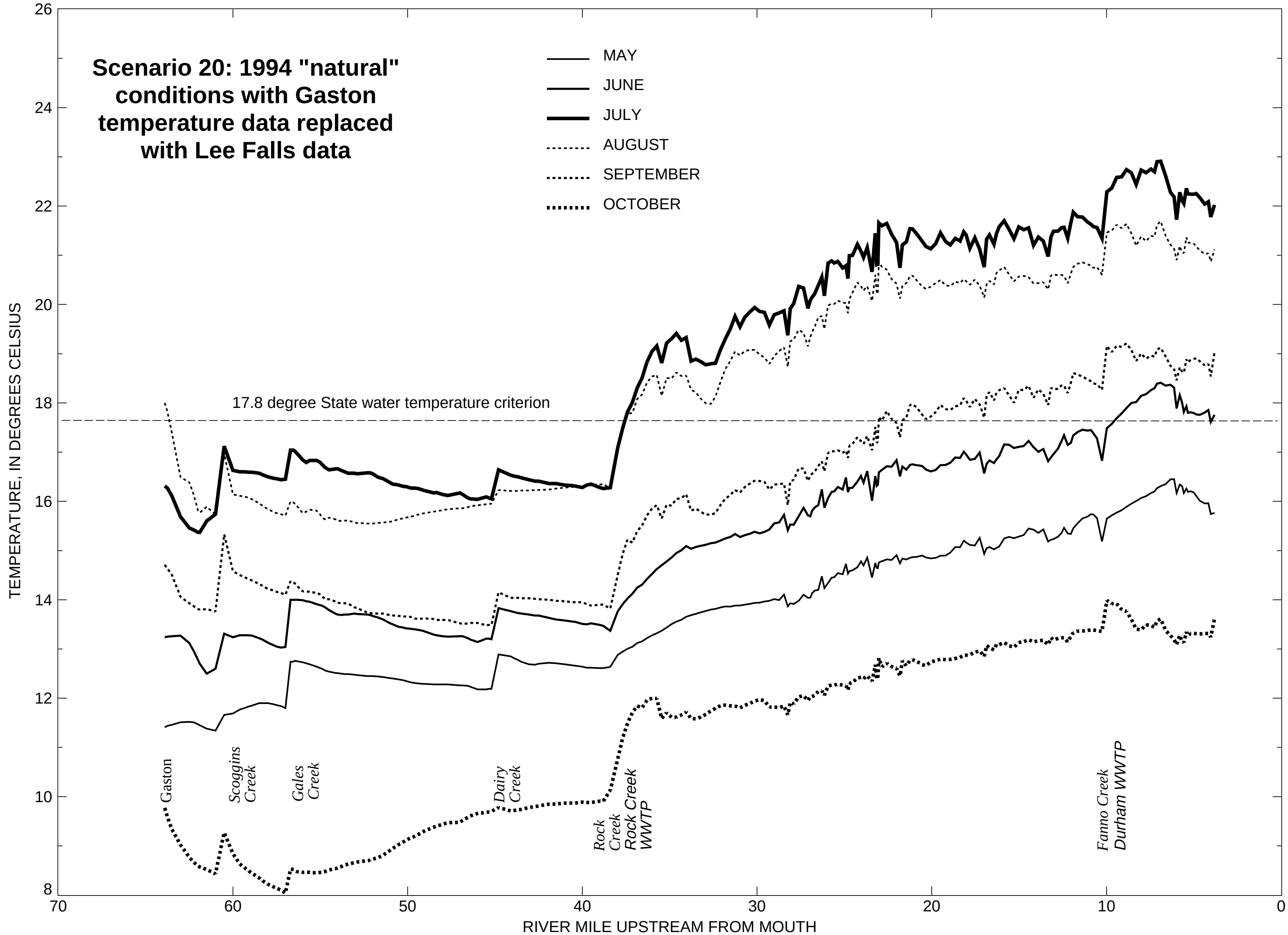


Figure 45. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 20, “natural” conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

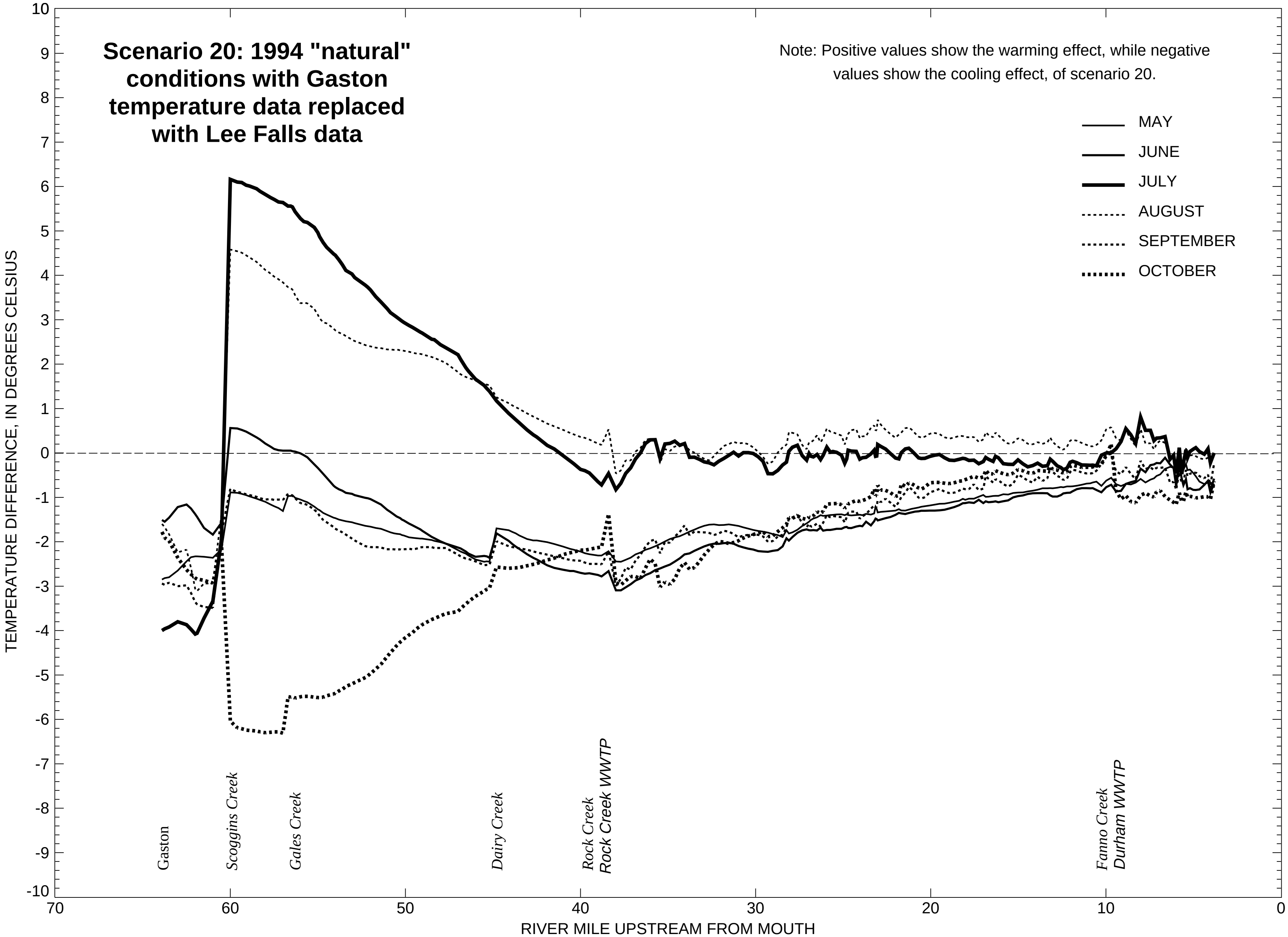


Figure 46. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 20, “natural“ conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

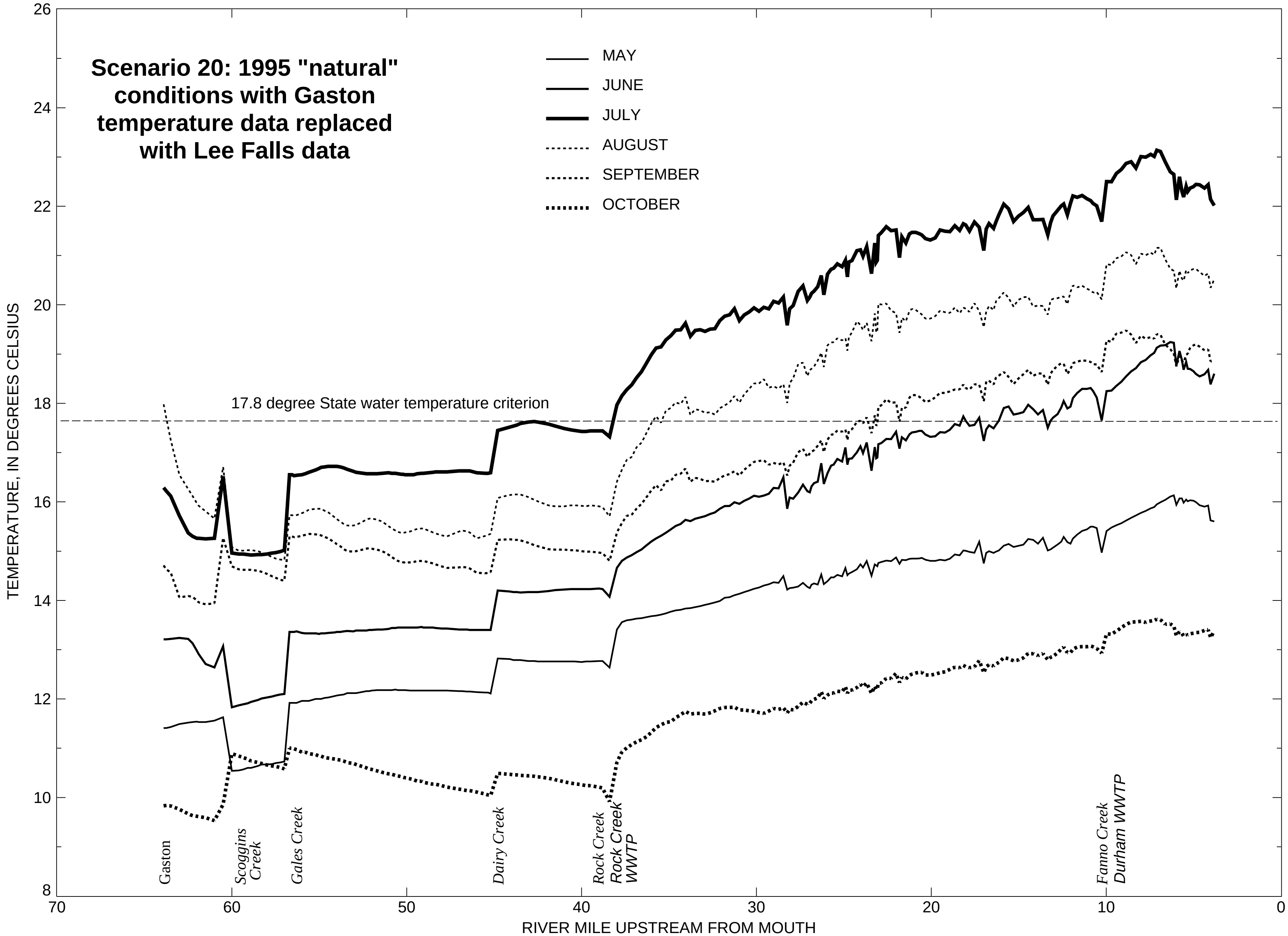


Figure 47. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 20, “natural“ conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

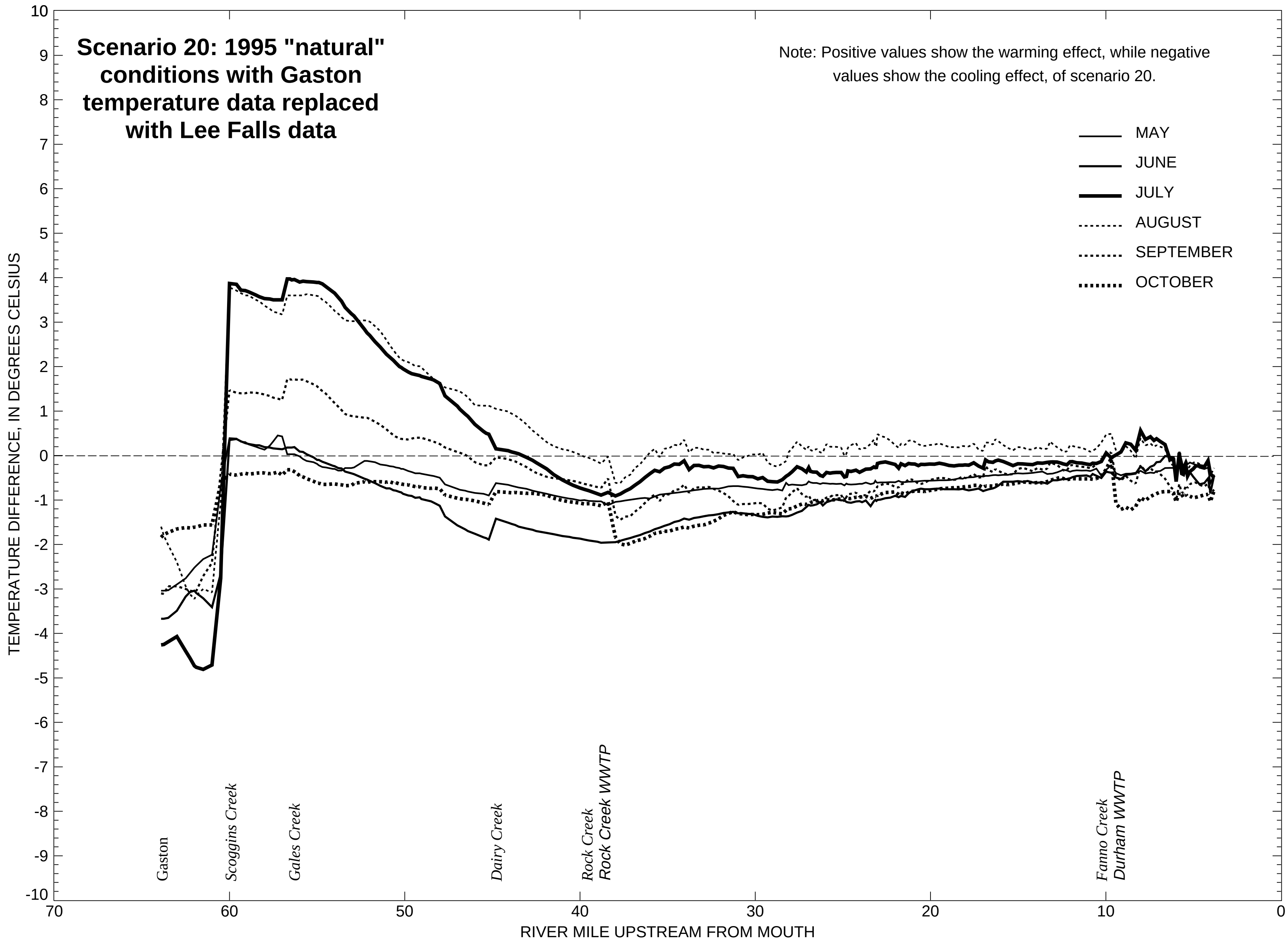


Figure 48. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 20, “natural“ conditions with Gaston temperature data replaced with Lee Falls data. (WWTP, wastewater-treatment plant.)

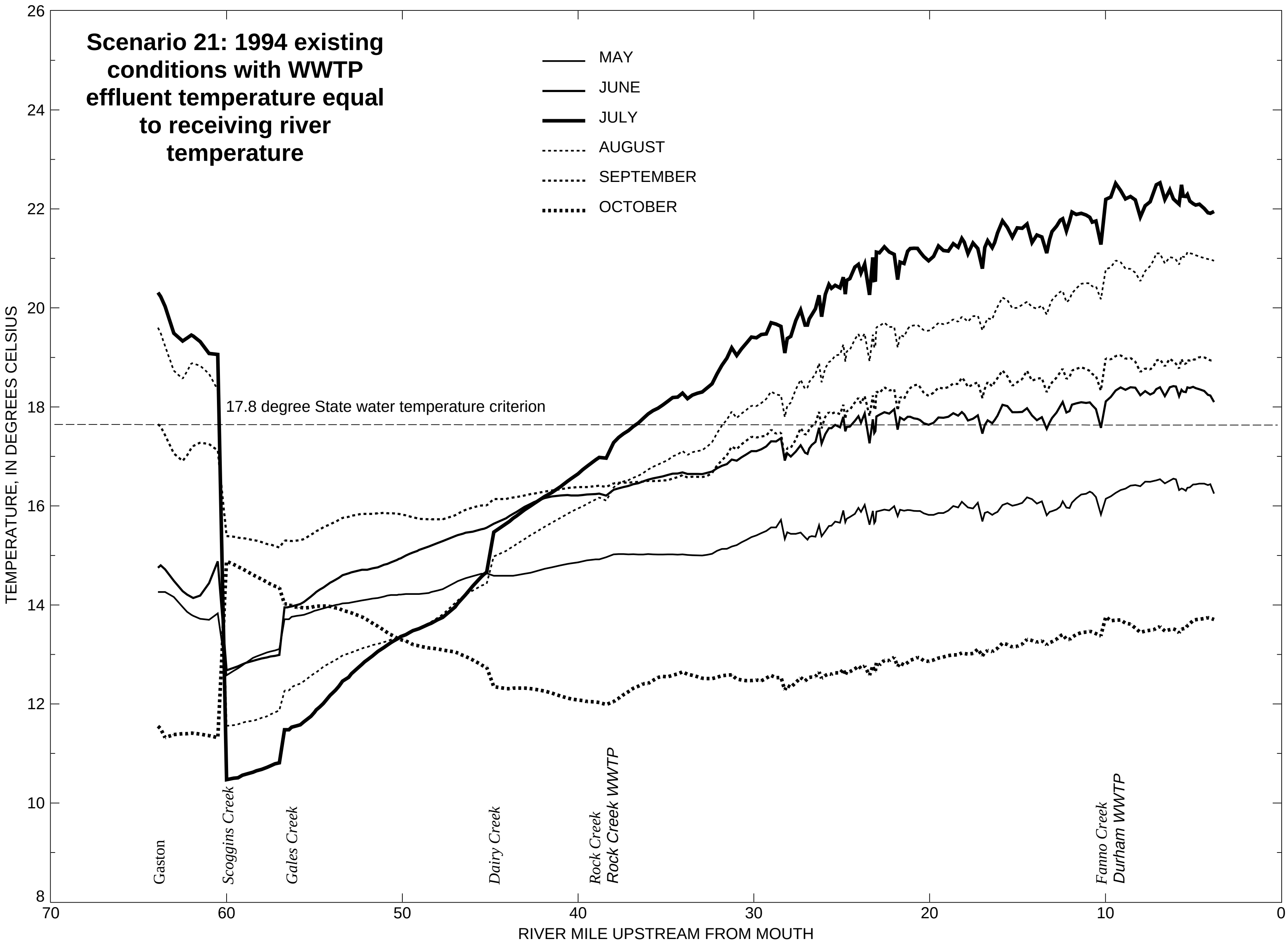


Figure 49. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

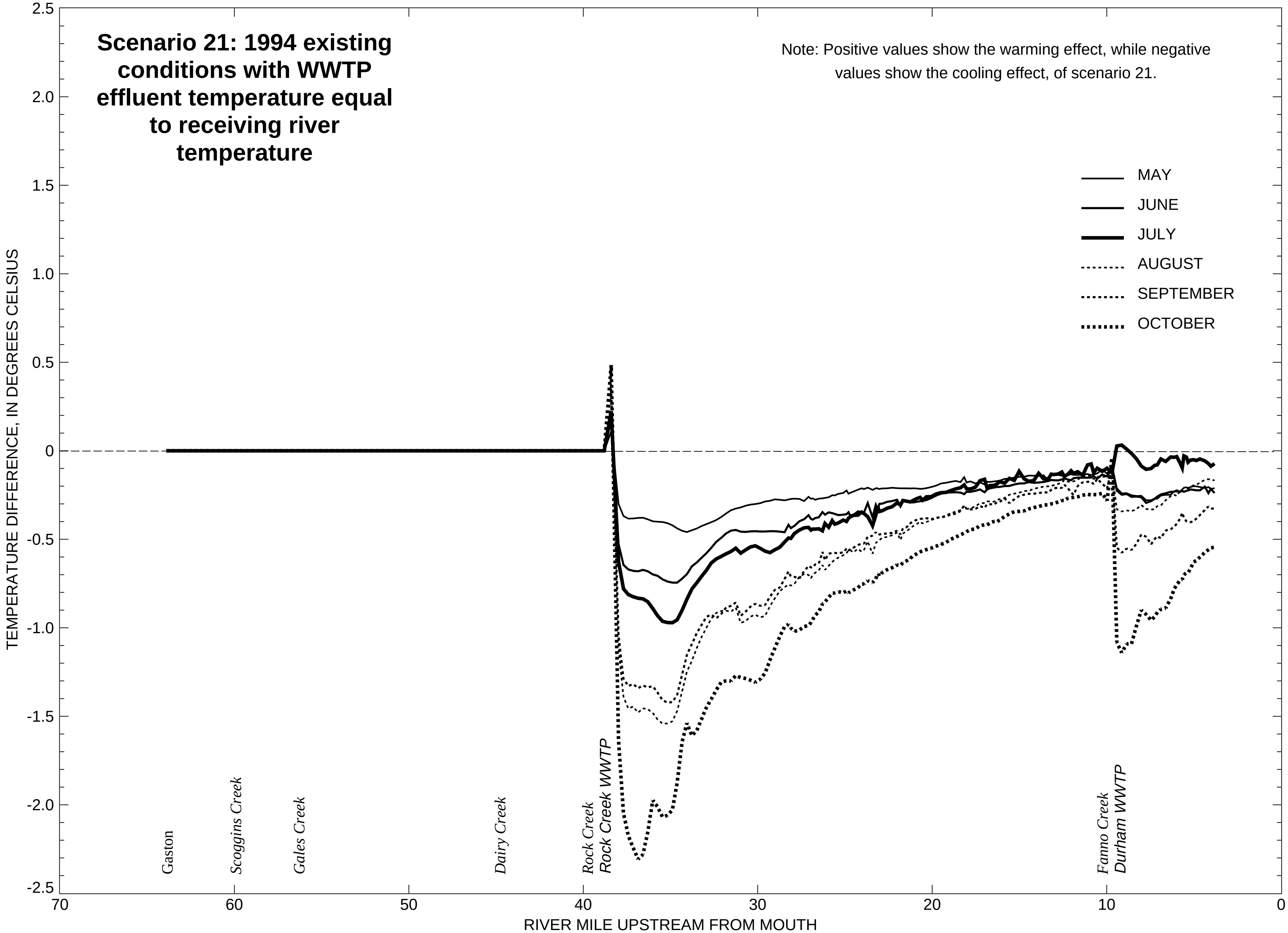


Figure 50. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

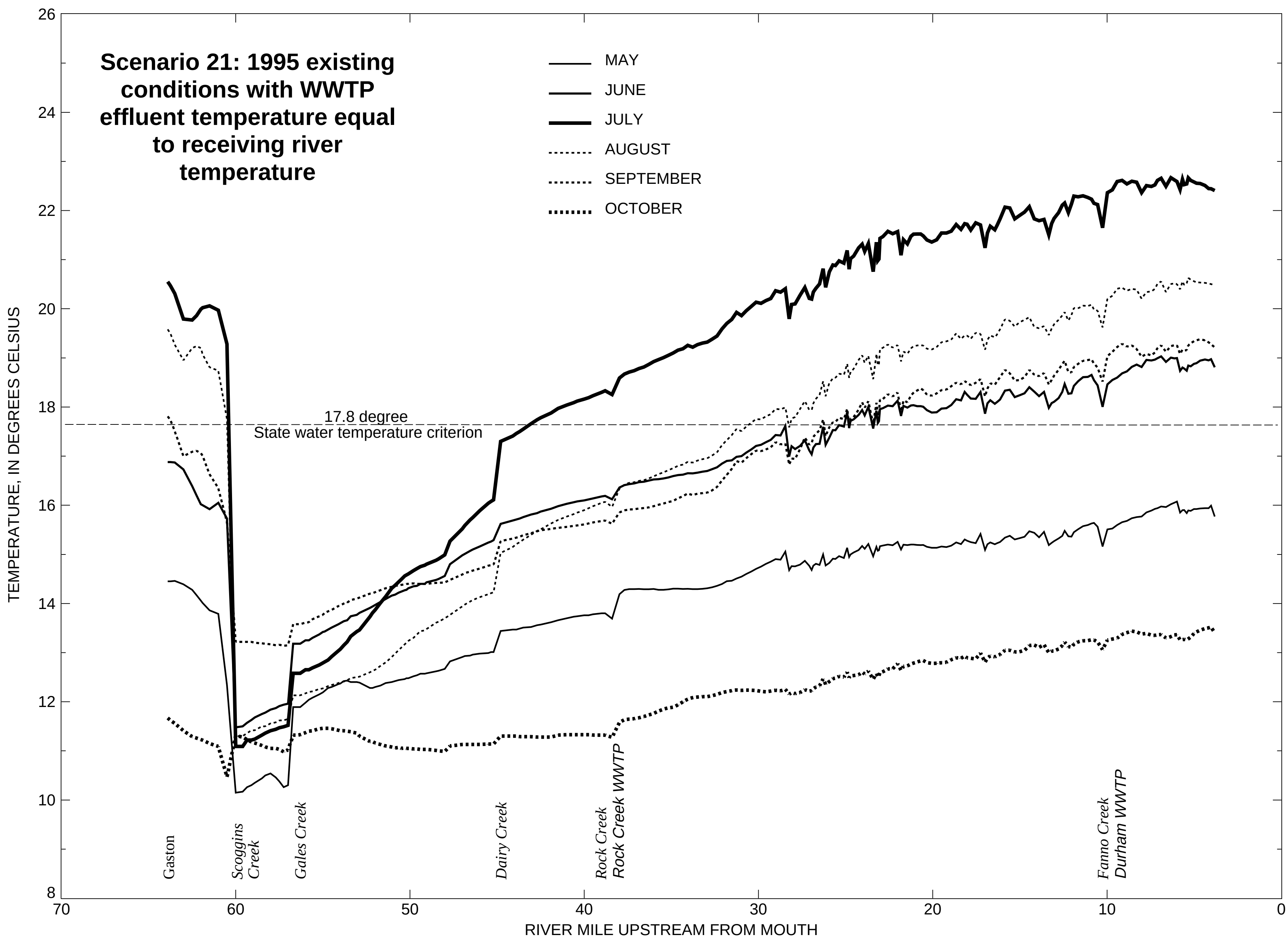


Figure 51. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

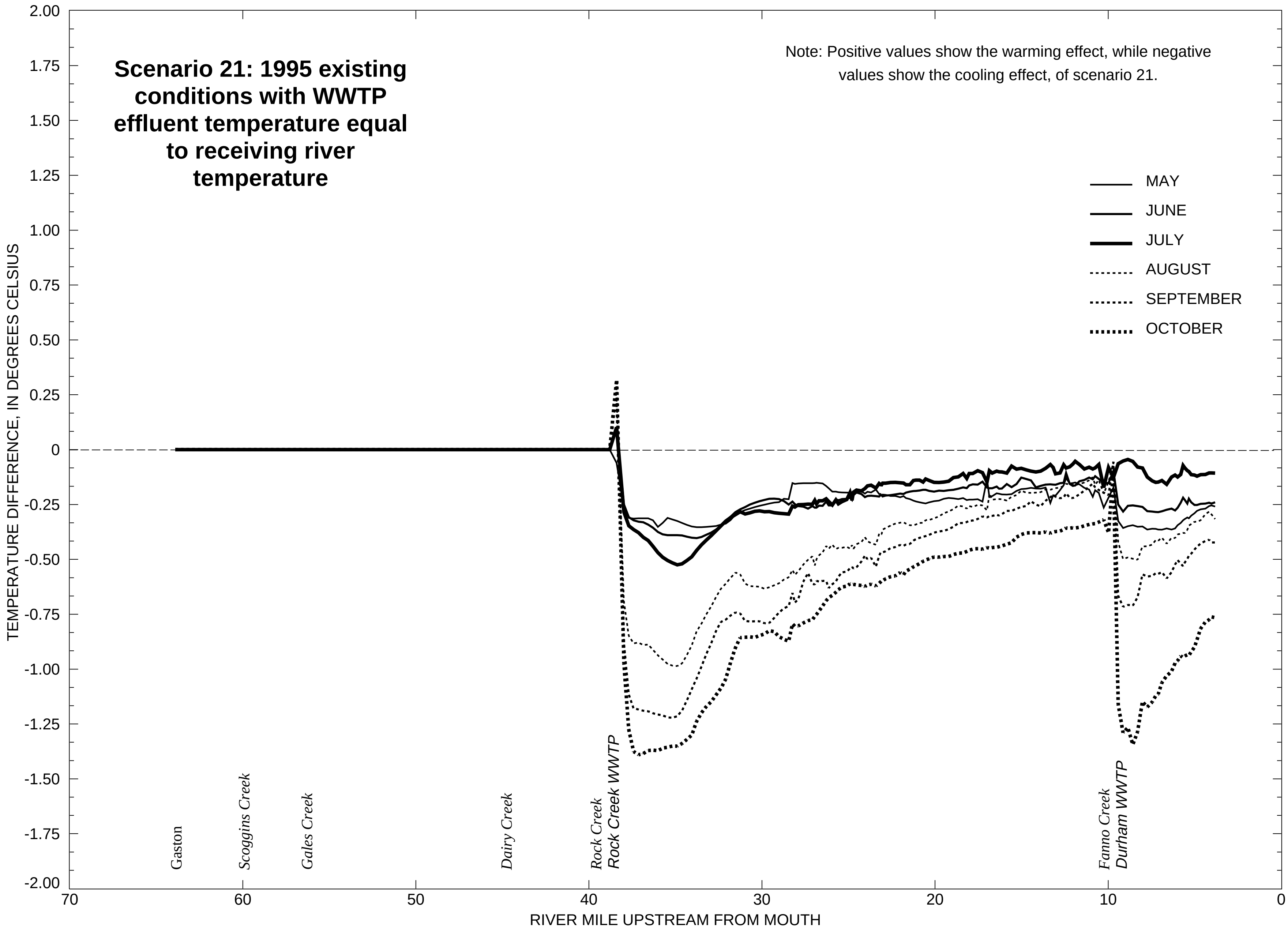


Figure 52. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

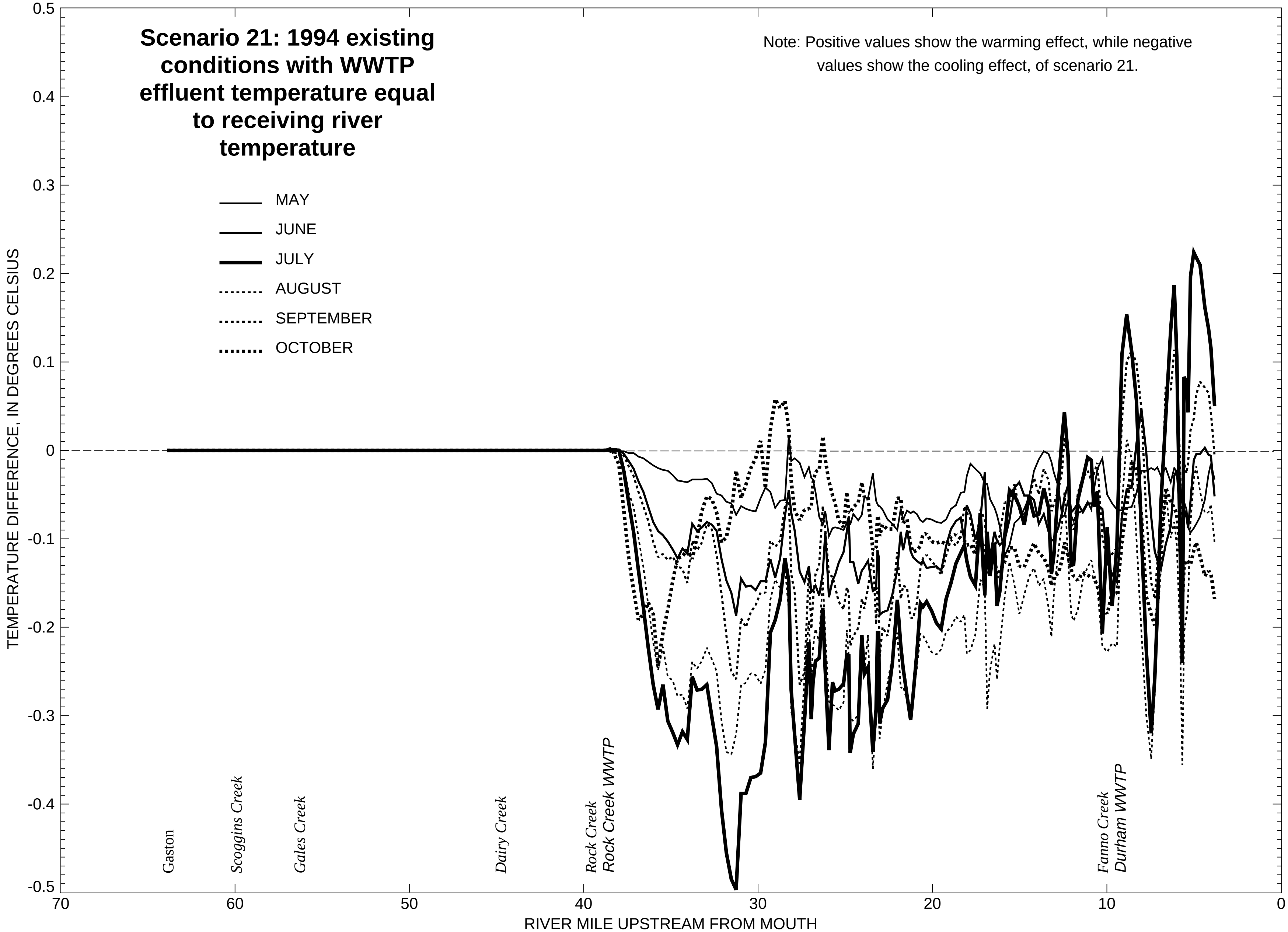


Figure 53. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 7, existing conditions without WWTPs, and scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

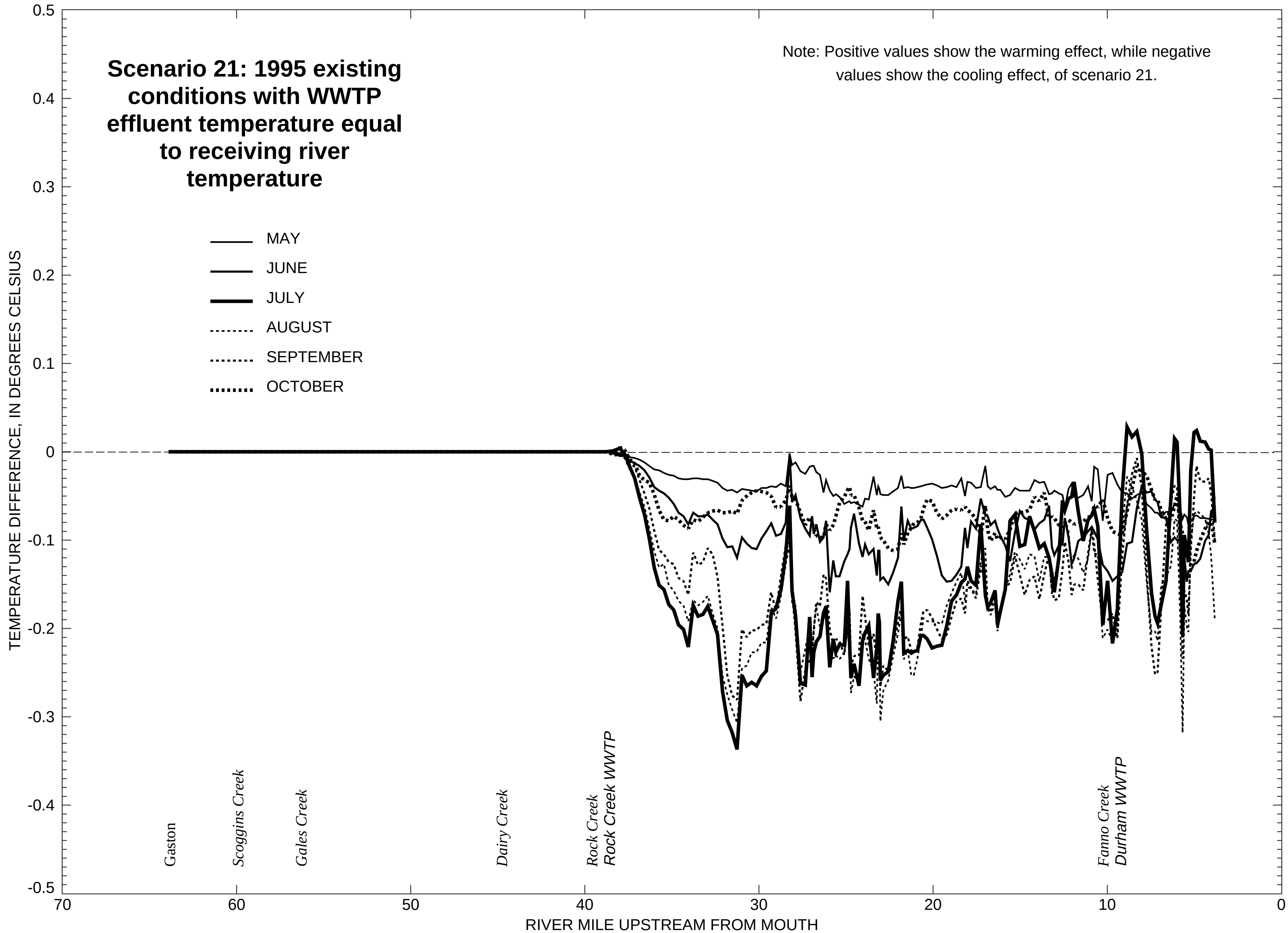


Figure 54. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 7, existing conditions without WWTPs, and scenario 21, existing conditions with WWTP effluent temperature equal to receiving river temperature. (WWTP, wastewater-treatment plant.)

Scenario 22: Existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall

To mitigate water-quality problems and maintain a minimum flow in the river during the summer, the USA purchases an annual allotment of flow from Henry Hagg Lake. These flows are released from Scoggins Dam and enter the river from Scoggins Creek. The purpose of scenario 22 was to determine if the temperature impact of effluent released from the WWTPs could be lessened if the 1994 and 1995 USA allotted flow (when less than but not exceeding 10 Mgal/d) were released into the river near the Rock Creek WWTP (RM 38.1). On days when the USA allotted flow was greater than 10 Mgal/d, the excess of 10 Mgal/d was released into the system at Scoggins Dam. Measured 1994 and 1995 Scoggins Dam temperature data were used as the temperature of the allotted flow released at RM 38.1 (Measured 1994 and 1995 Rock Creek WWTP effluent flow and temperature data were still used for the released effluent).

With a decrease in the cooler Scoggins Creek flows entering the river at RM 60.0, the simulations showed temperature increases for all the months except October (figs. 55–58). The magnitude of the increase was generally under 0.6^{o}C for 1994 and 0.3^{o}C for 1995; however, downstream of the Rock Creek WWTP (RM 38.1), temperatures decreased from as much as 0.7^{o}C in 1994 and 0.3^{o}C in 1995 for all months except October; however, the effect of the 10 Mgal/d release becomes gradually less pronounced downstream.

Scenarios 23, 24, 25, and 26: Existing conditions with 20, 25, 45, and 65 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3

In scenarios 23, 24, 25, and 26, the 1994 and 1995 measured effluent temperature data from the WWTPs were used, except that the temperatures were not permitted to be greater than 17.8^{o}C. The flow of effluent from each WWTP was constant during the simulation periods: 20, 25, 45, and 65 Mgal/d, respectively, for the four scenarios. All other existing conditions were used.

For most of the months, the temperature in the reaches downstream of both WWTPs decreased for all four simulations (figs. 59–74). The magnitude of the decrease in temperature was usually less than 1.0^{o}C, but reached 2.0^{o}C in some locations. For scenario 23, the rate of effluent flow was 20 Mgal/d, which was not much more than the mean rate of effluent released from the WWTPs in 1994 and 1995. In this scenario, most of the decrease in temperature was in proximity of the WWTPs; however, in scenario 26, the impact of the 65 Mgal/d of effluent released from Rock Creek WWTP can be seen all the way downstream to the Durham WWTP (RM 9.3). Downstream of the Durham WWTP, temperatures decreased by an even greater magnitude. The temperature of the river in that reach was already well above 17.8^{o}C. But, the substantial volume of effluent released from Durham WWTP (65 Mgal/d) had a temperature of 17.8^{o}C or less and produced a greater reduction.

Simulation results for the 16 scenarios specific to 5 locations on the river, Golf Course Road (RM 51.5), Rood Bridge (RM 38.4), Scholls Bridge (RM 26.9), Elsner Road (RM 16.2), and Stafford Road (RM 5.5) are shown in tables 8 through 22. There is a set of three tables for each location. The first table shows comparisons of the monthly mean of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperatures averaged over each month (May through October) for the 16 scenarios. The second table shows the difference in the mean water temperature resulting from each scenario (scenarios 11–26) relative to existing conditions (scenario 1) for each month. The third table shows the percentage of time that the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature exceeds 17.8^{o}C for each scenario during each month (May through October).

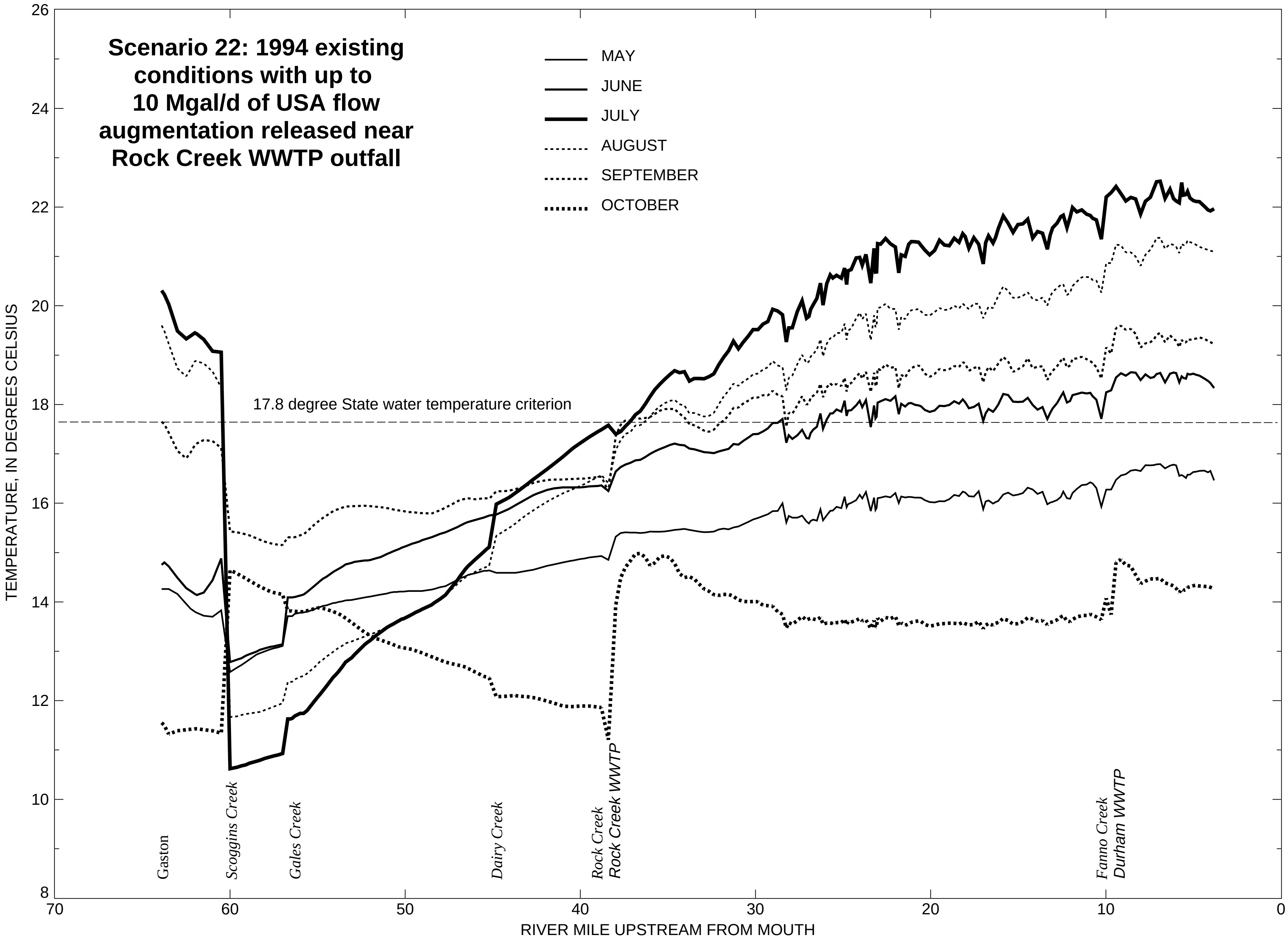


Figure 55. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 22, existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall. (Mgal/d, million gallons per day; USA, Unified Sewerage Agency; and WWTP, wastewater-treatment plant.)

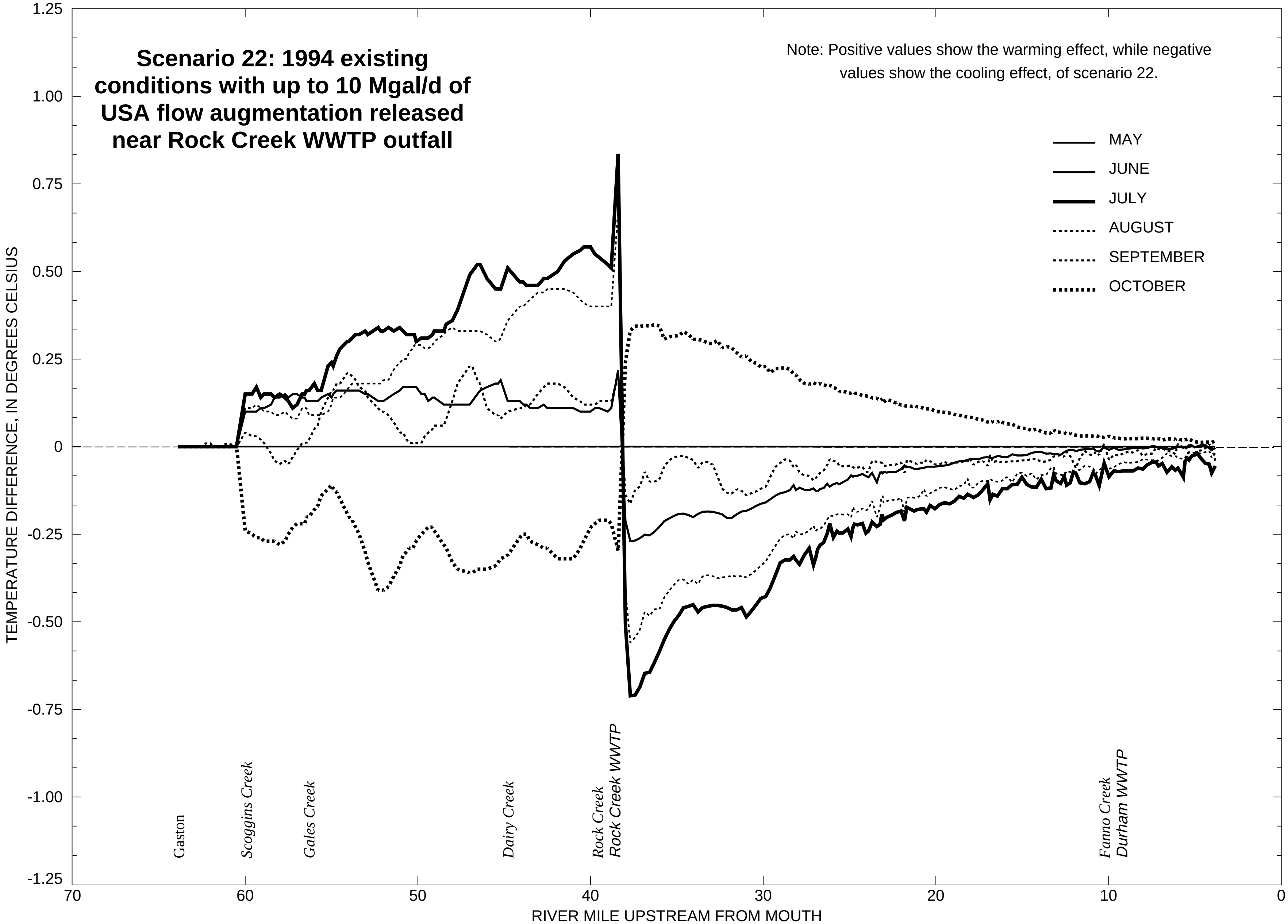


Figure 56. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 22, existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall. (Mgal/d, million gallons per day; USA, Unified Sewerage Agency; and WWTP, wastewater-treatment plant.)

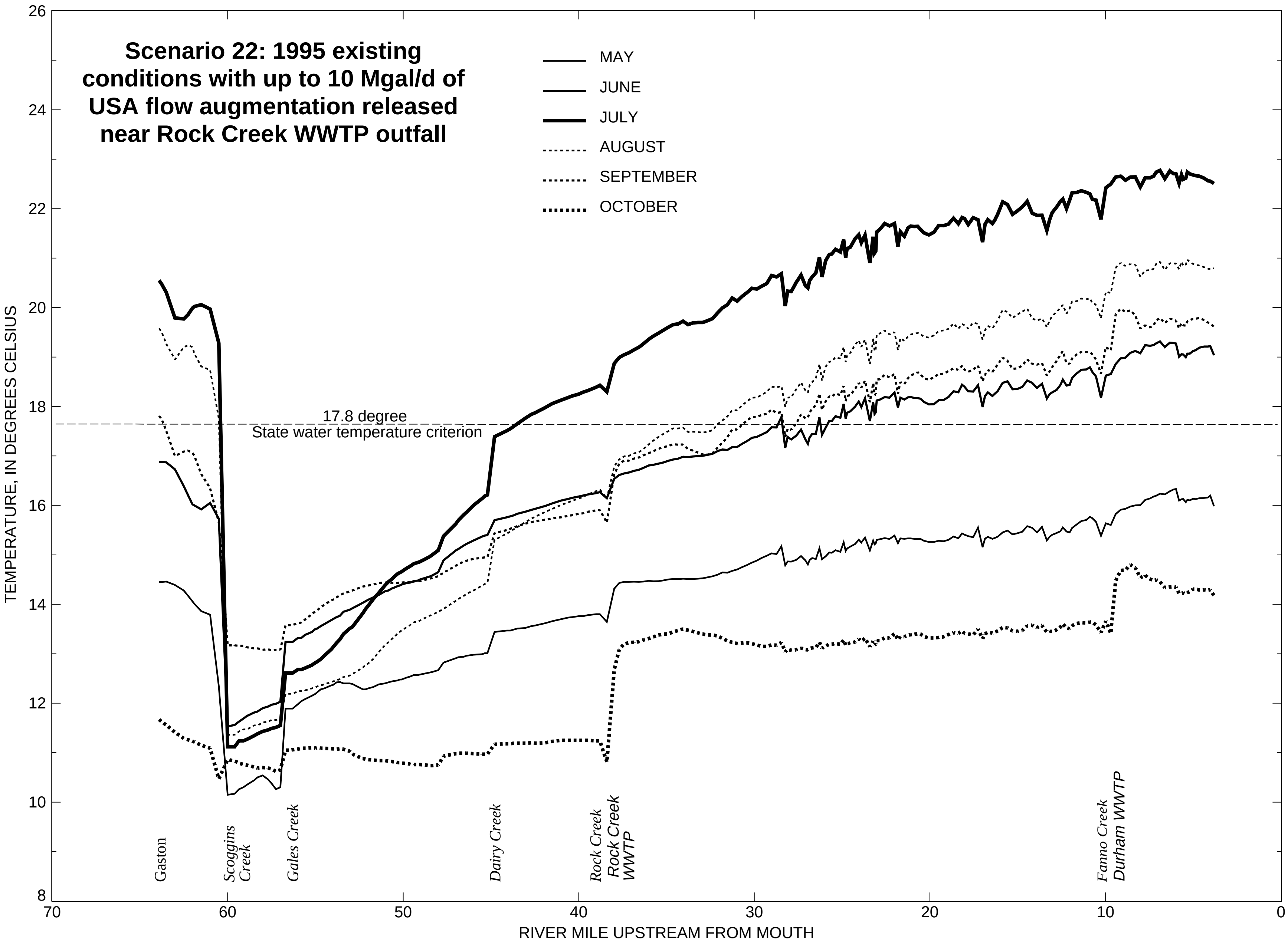


Figure 57. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 22, existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall. (Mgal/d, million gallons per day; USA, Unified Sewerage Agency; and WWTP, waste-water-treatment plant.)

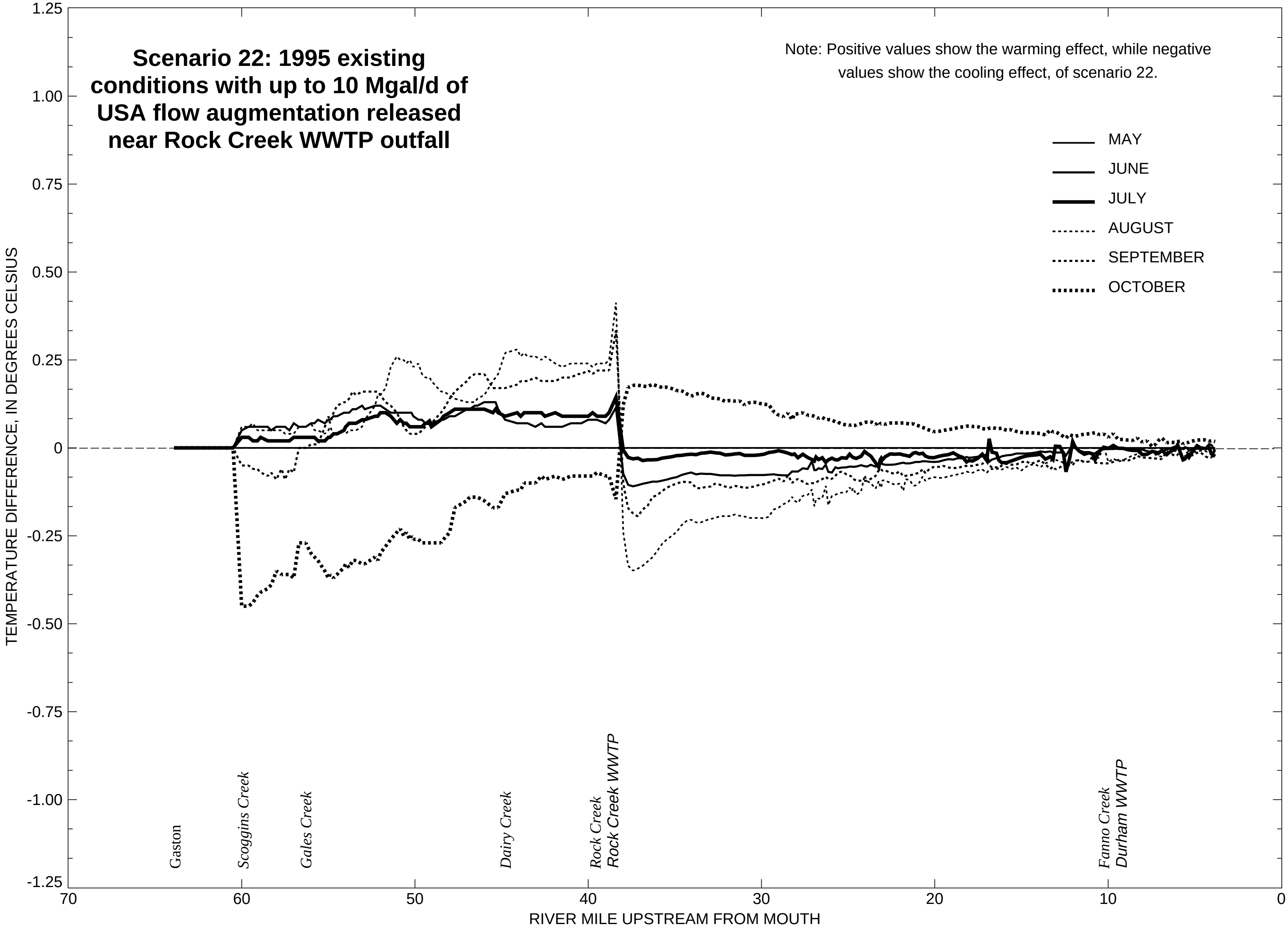


Figure 58. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 22, existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall. (Mgal/d, million gallons per day; USA, Unified Sewerage Agency; and WWTP, wastewater-treatment plant.)

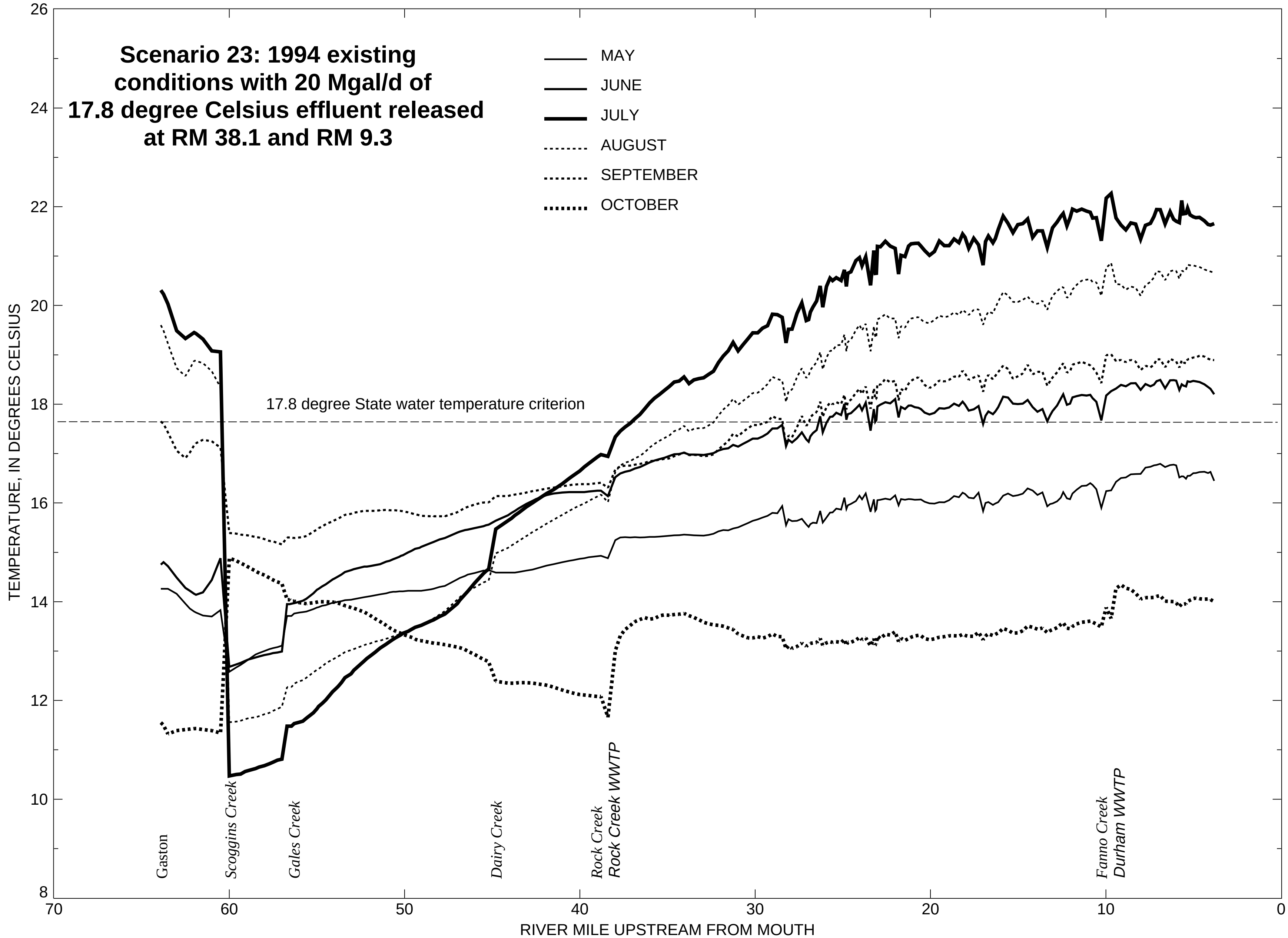


Figure 59. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 23, existing conditions with 20 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

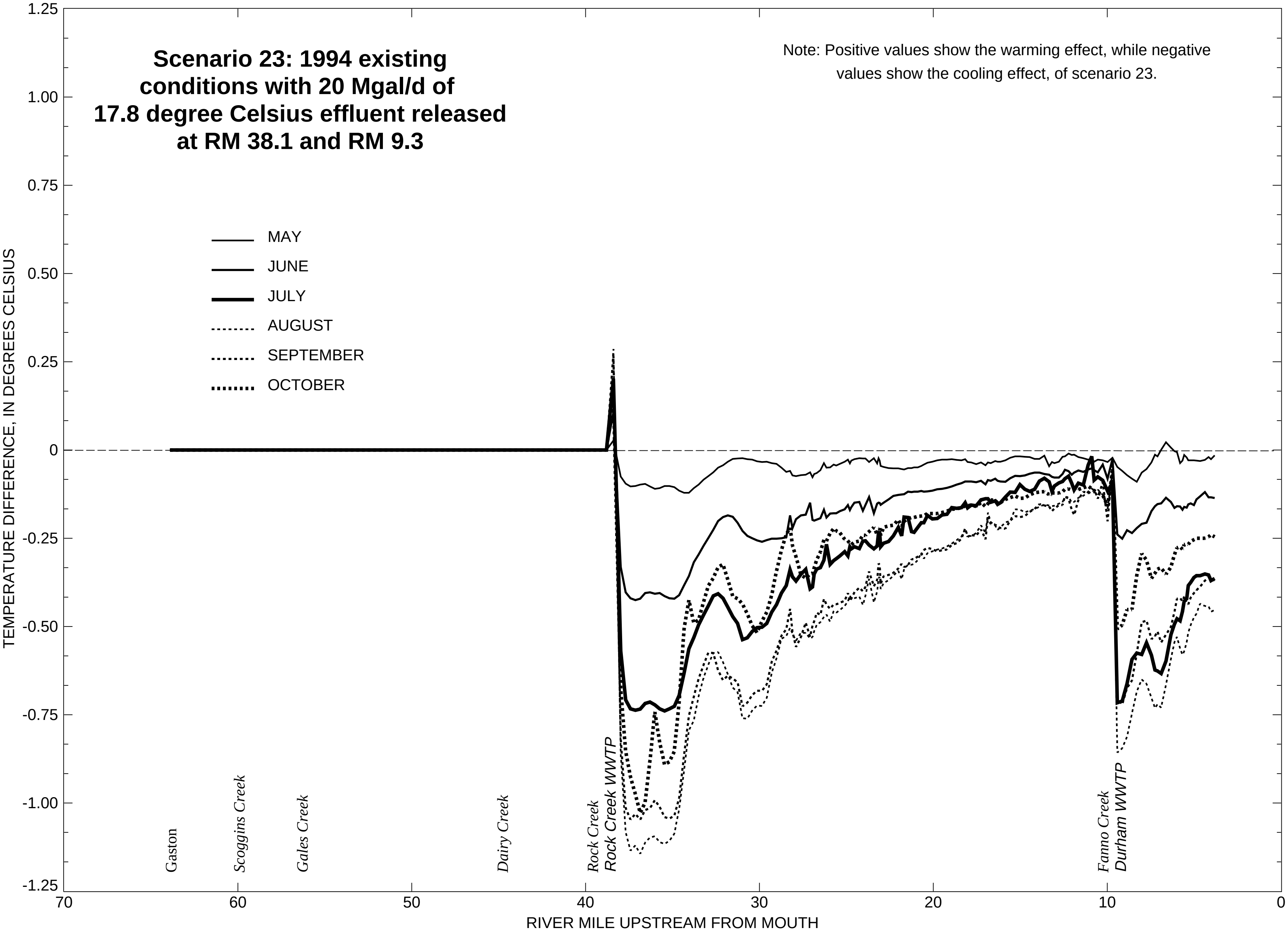


Figure 60. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 23, existing conditions with 20 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

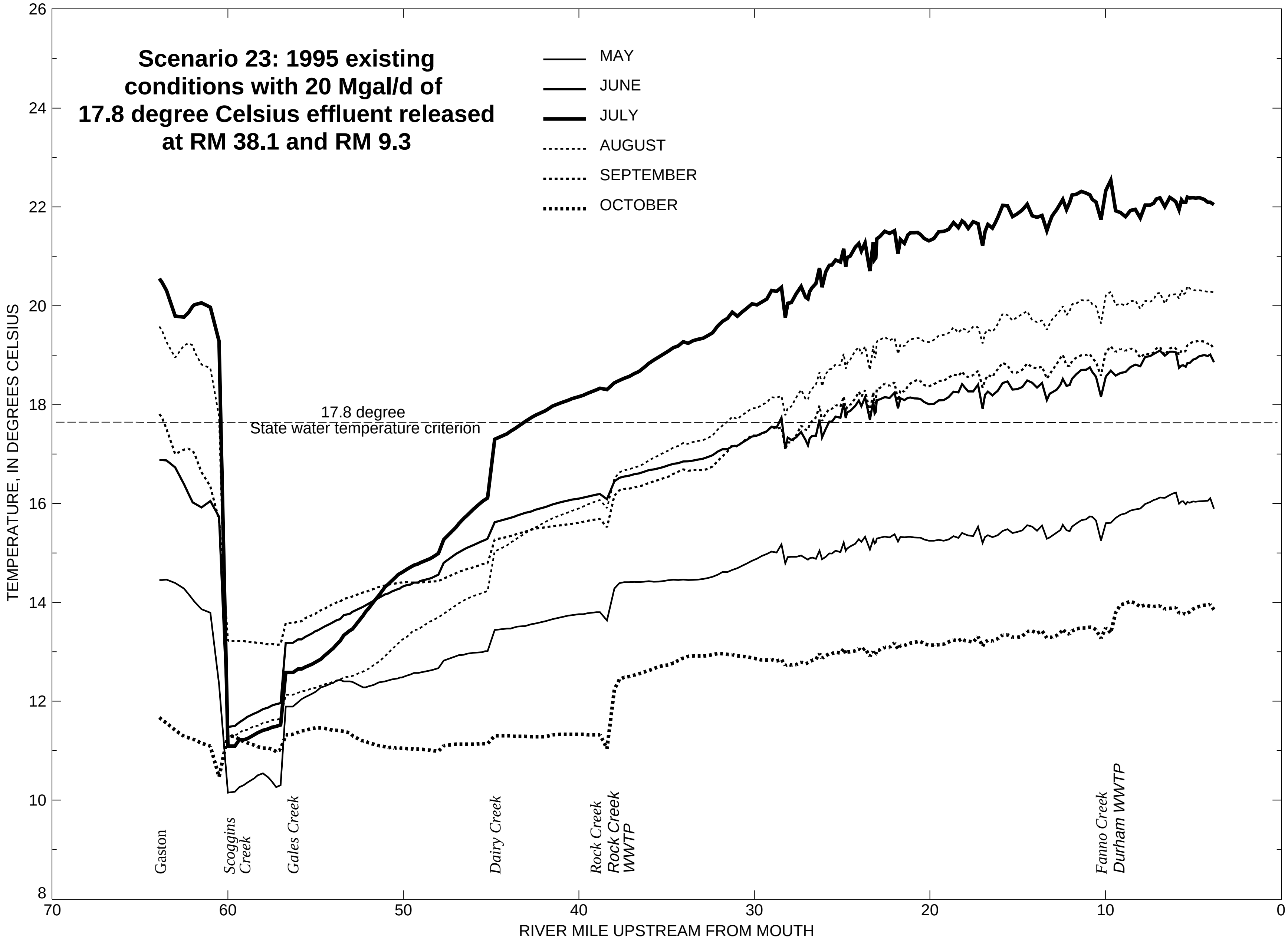


Figure 61. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 23, existing conditions with 20 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

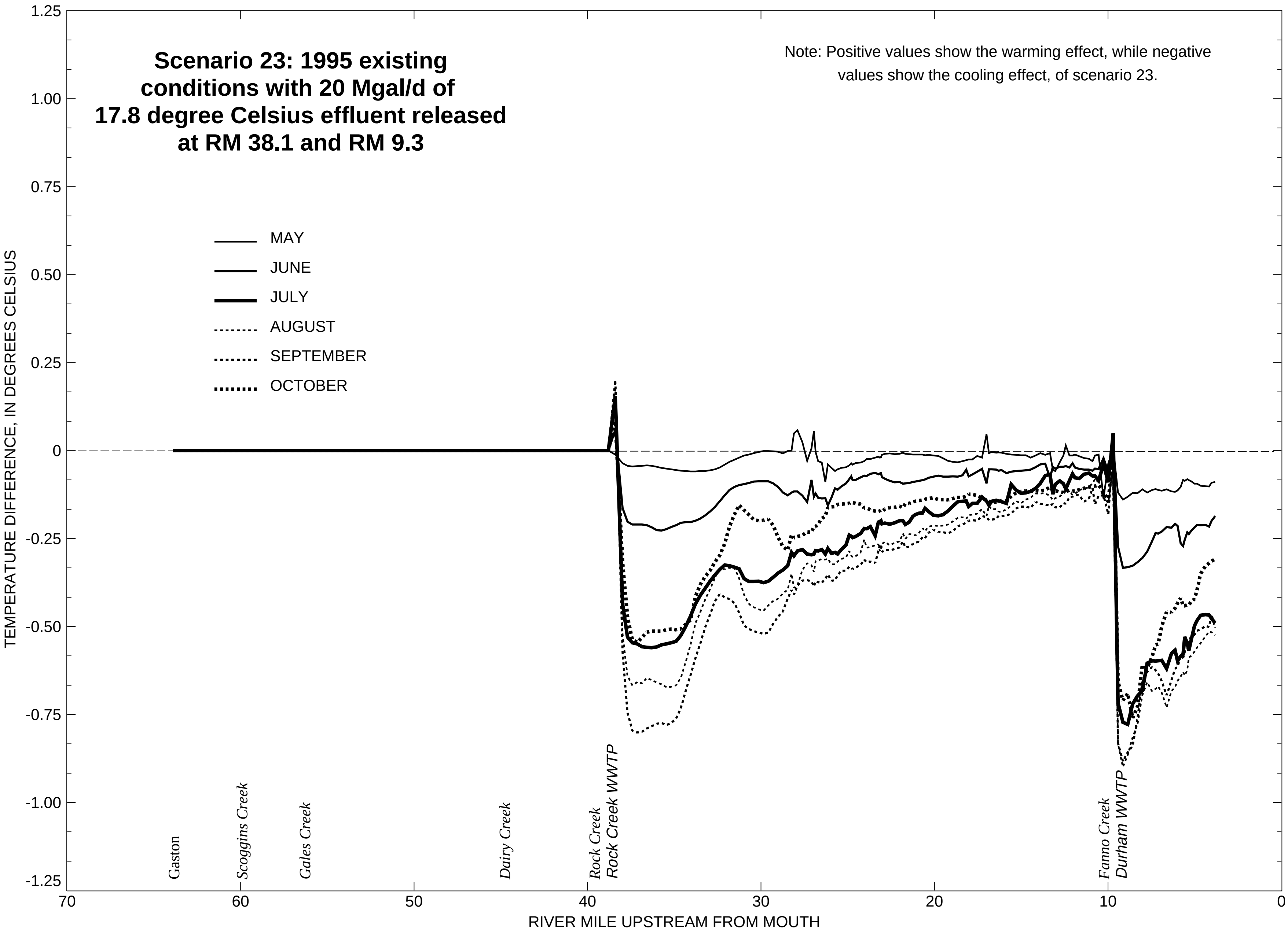


Figure 62. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 23, existing conditions with 20 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

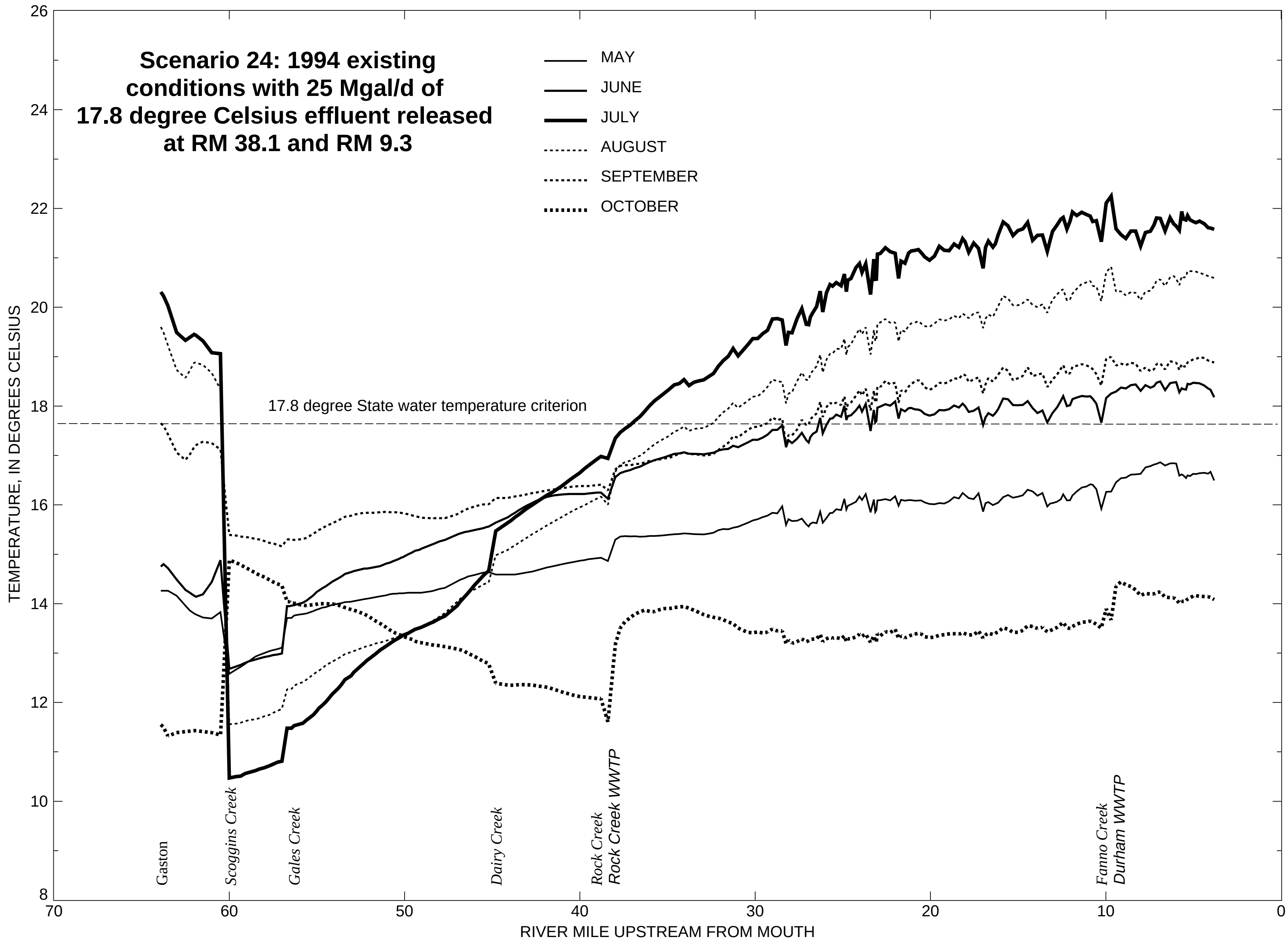


Figure 63. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 24, existing conditions with 25 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

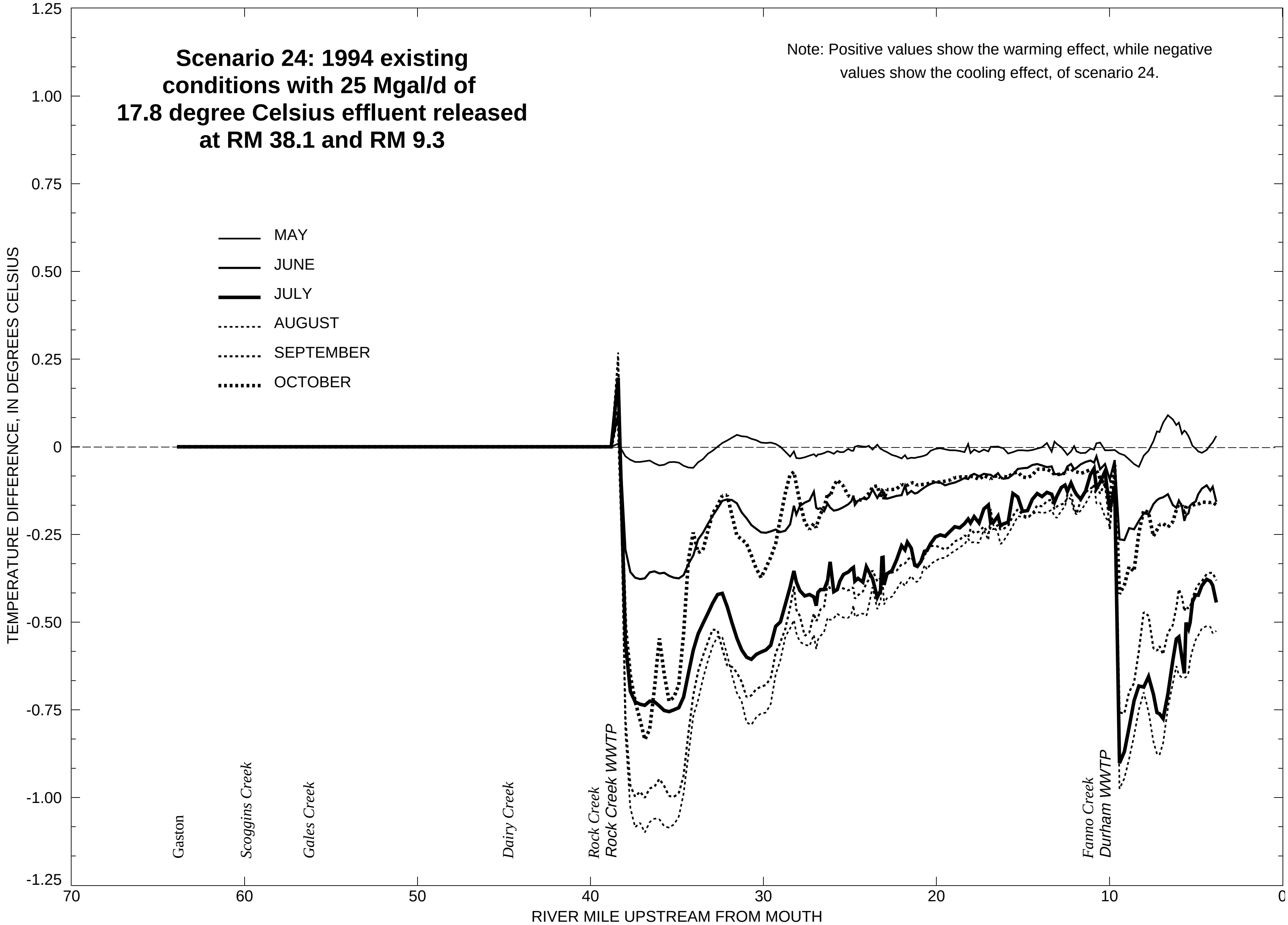


Figure 64. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 24, existing conditions with 25 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

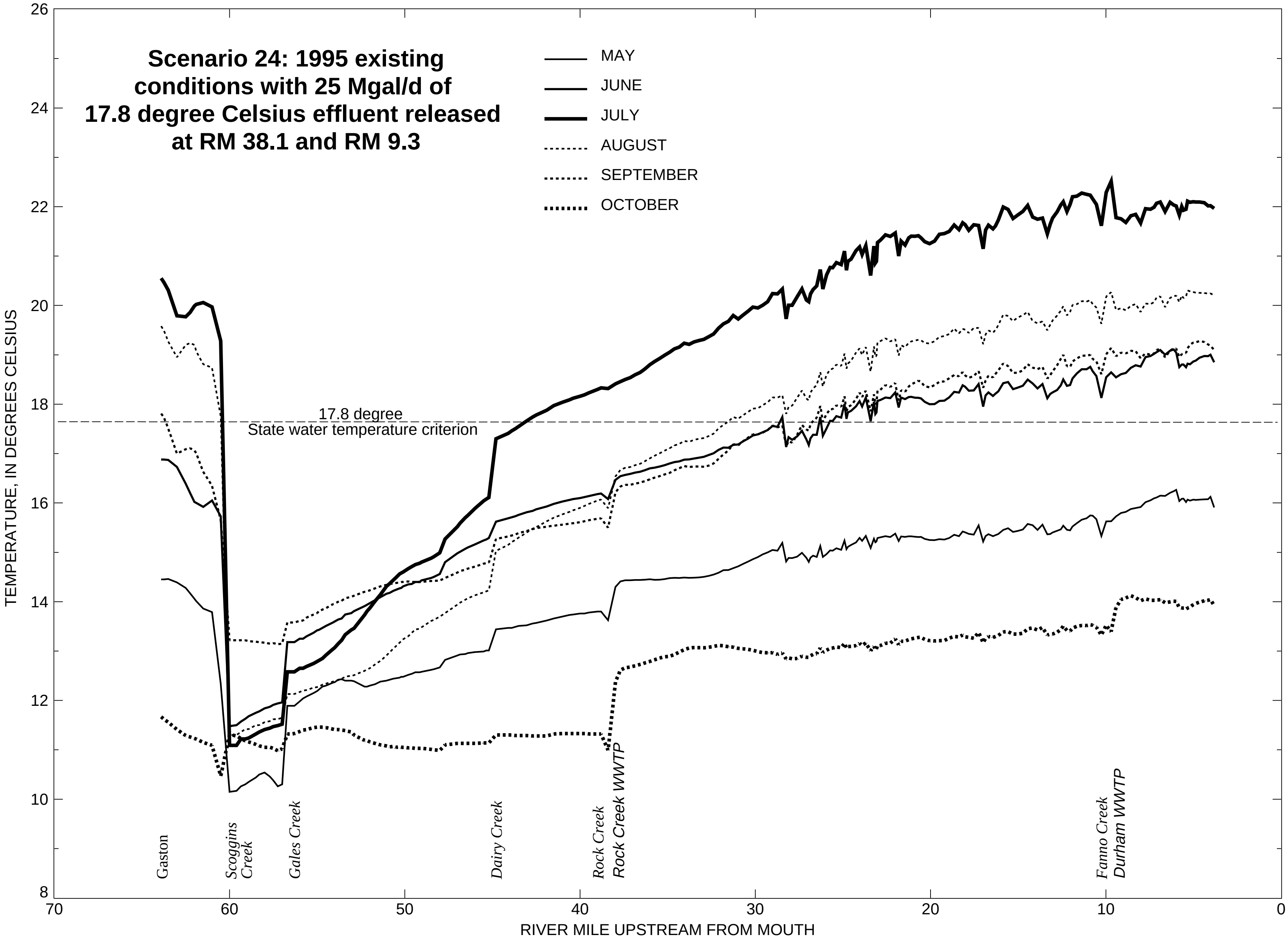


Figure 65. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 24, existing conditions with 25 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

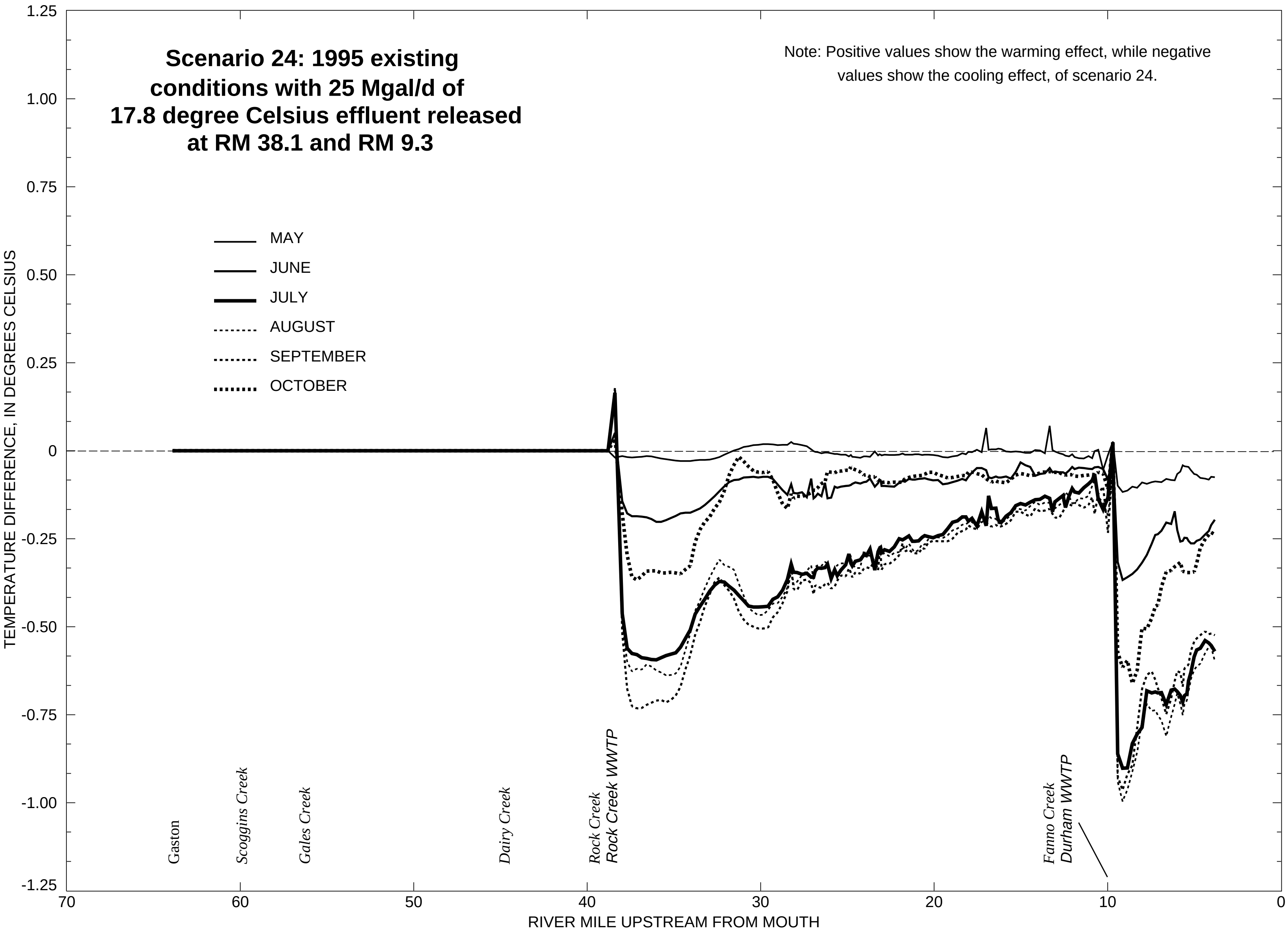


Figure 66. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 24, existing conditions with 25 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

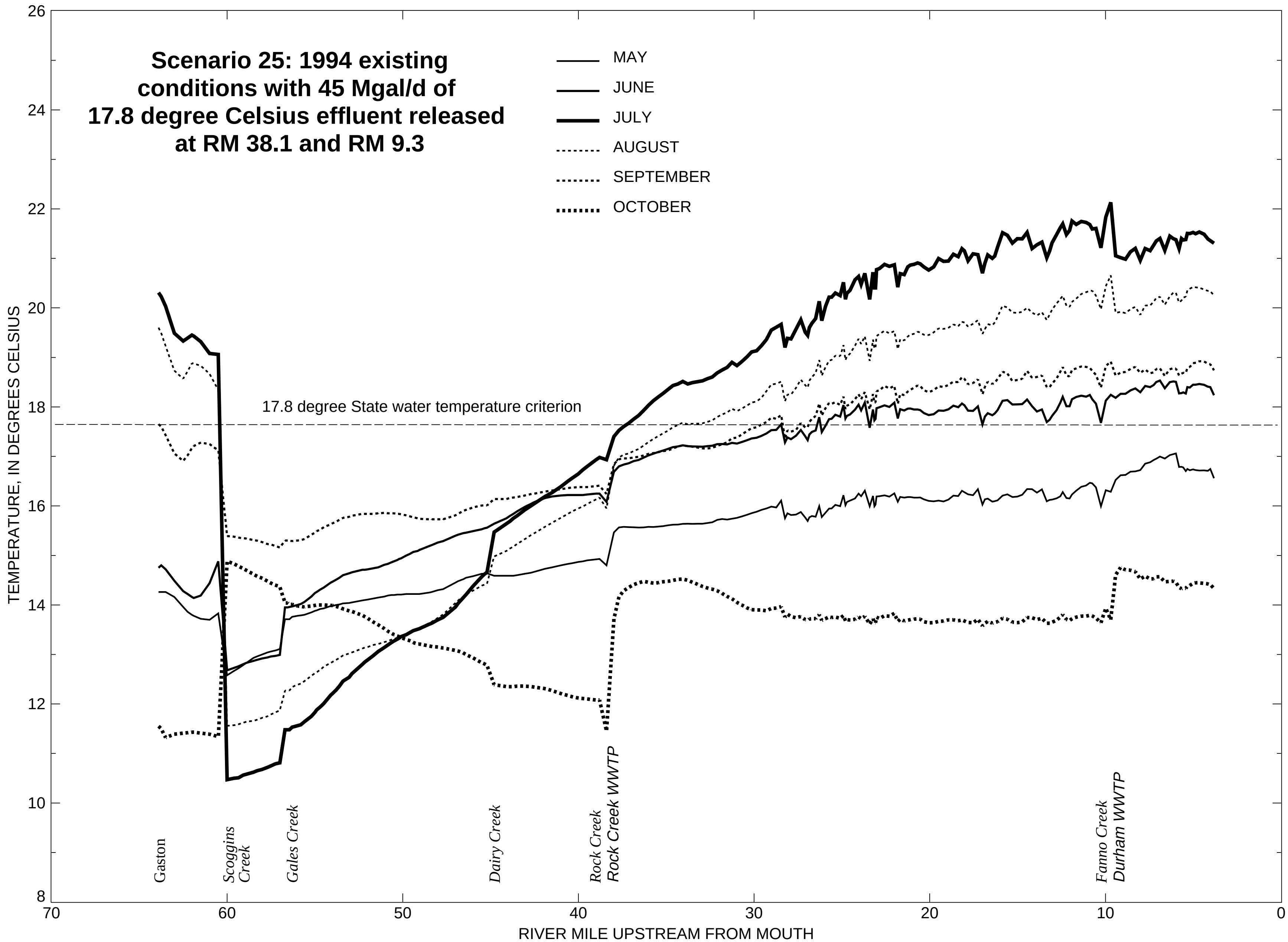


Figure 67. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 25, existing conditions with 45 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

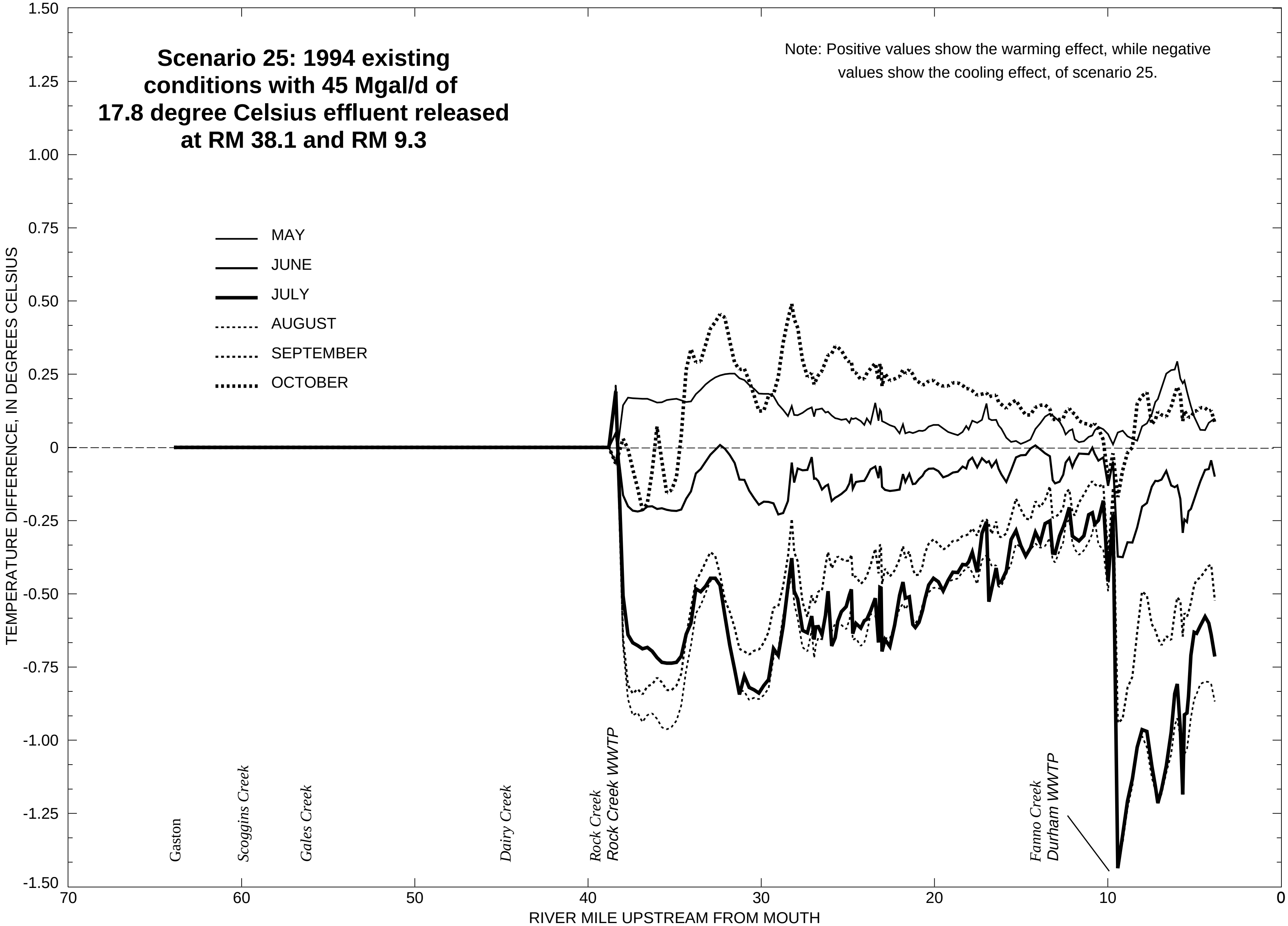


Figure 68. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 25, existing conditions with 45 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

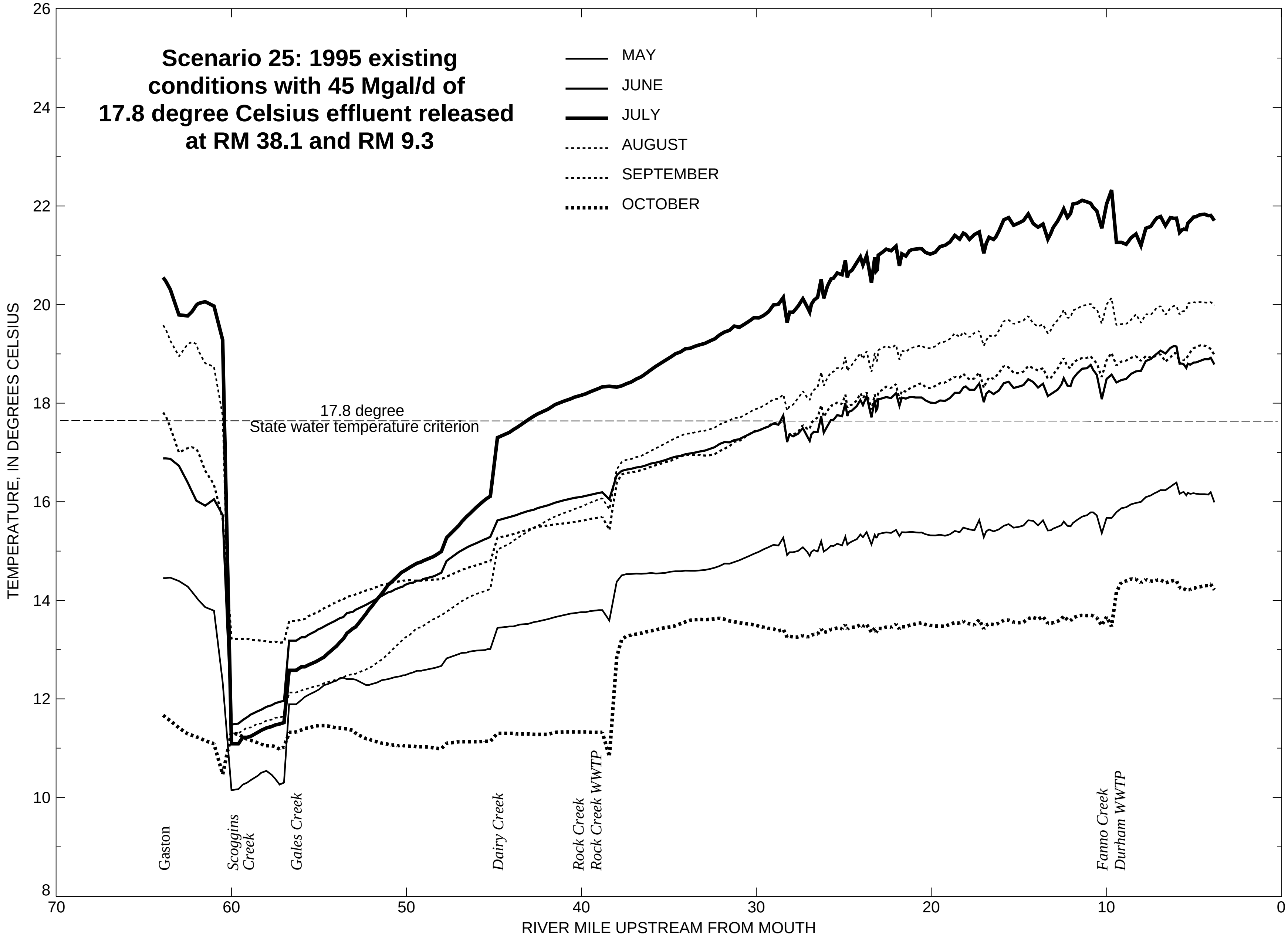


Figure 69. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 25, existing conditions with 45 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

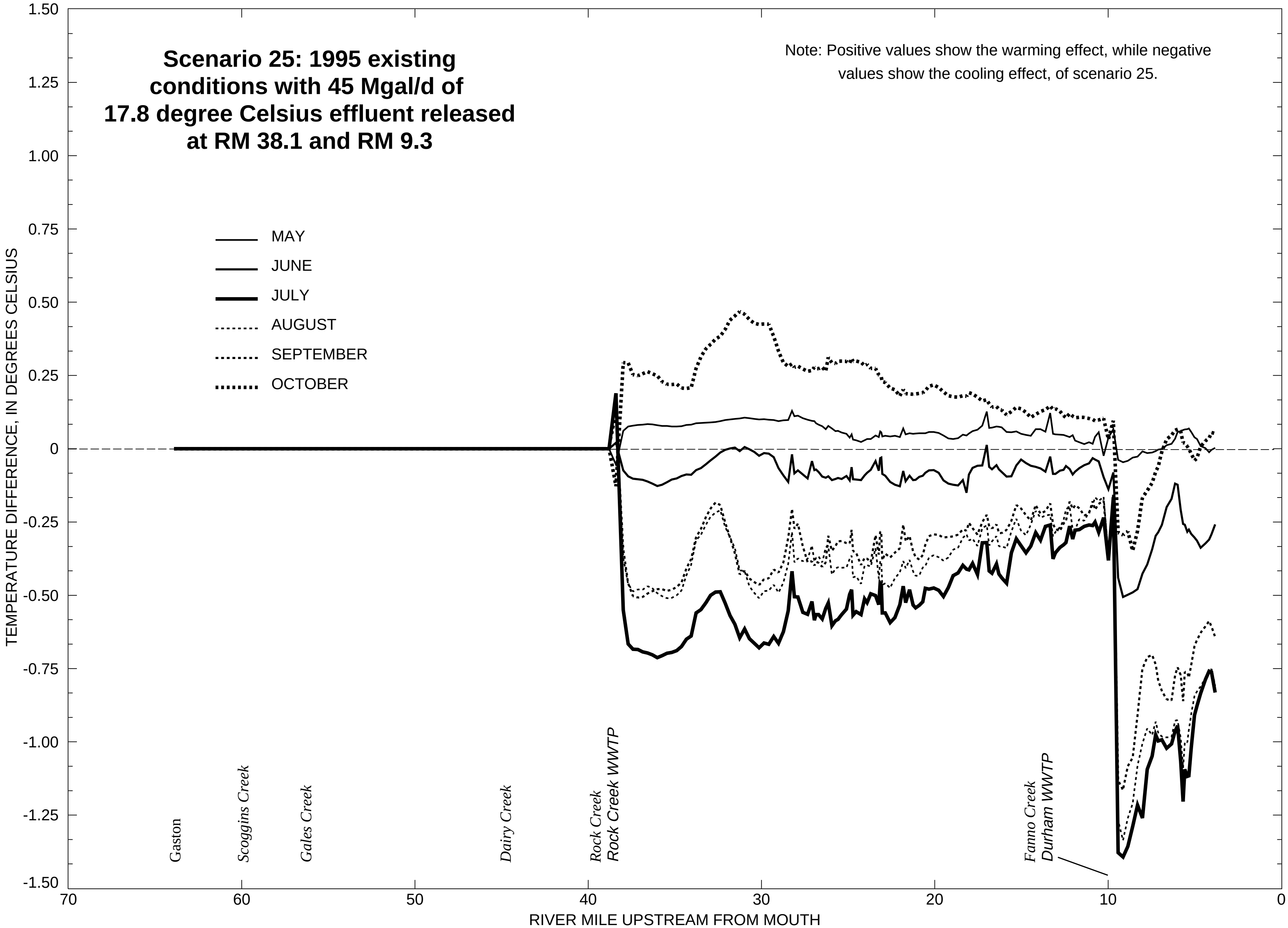


Figure 70. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 25, existing conditions with 45 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

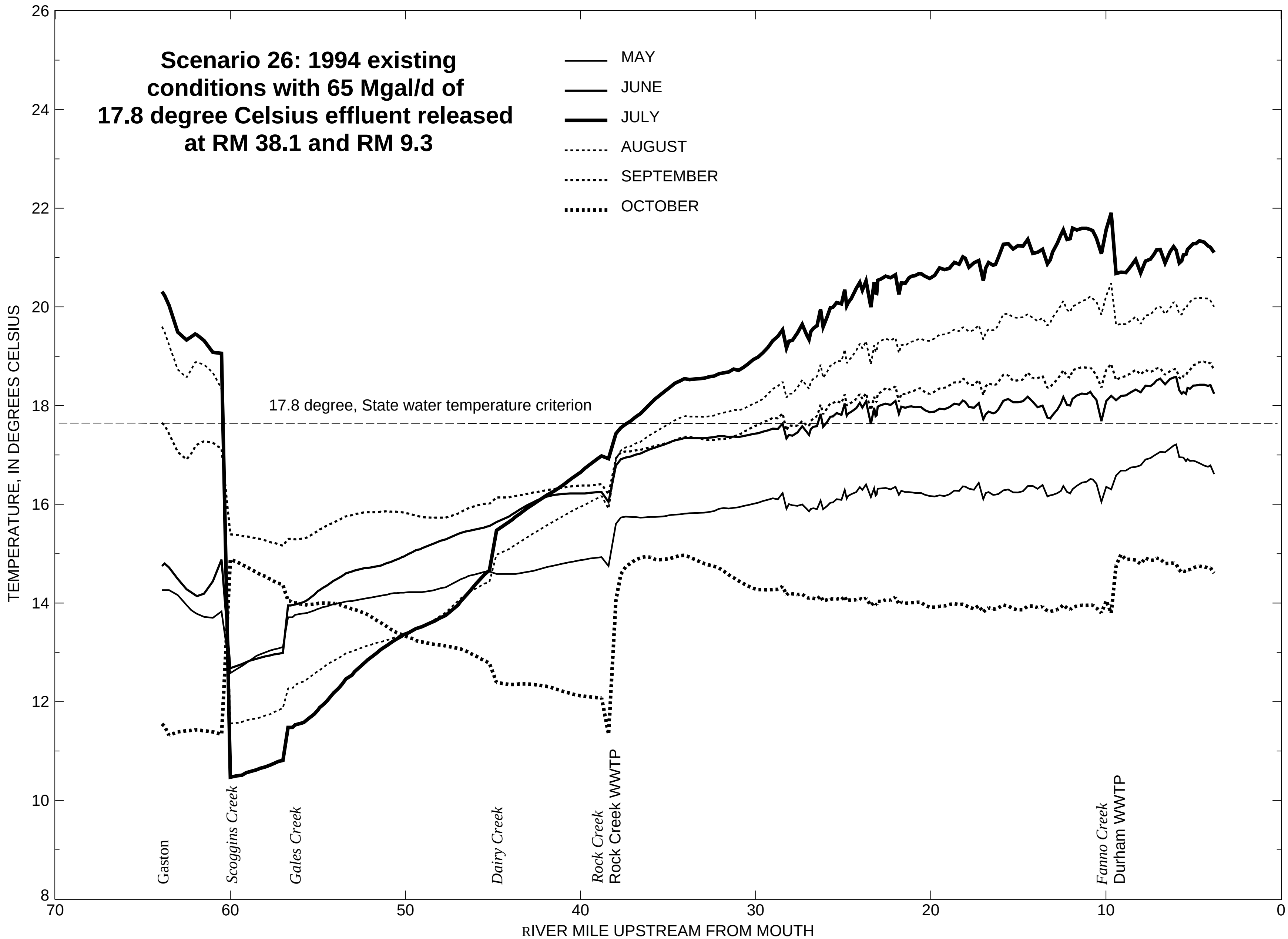


Figure 71. Monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 26, existing conditions with 65 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

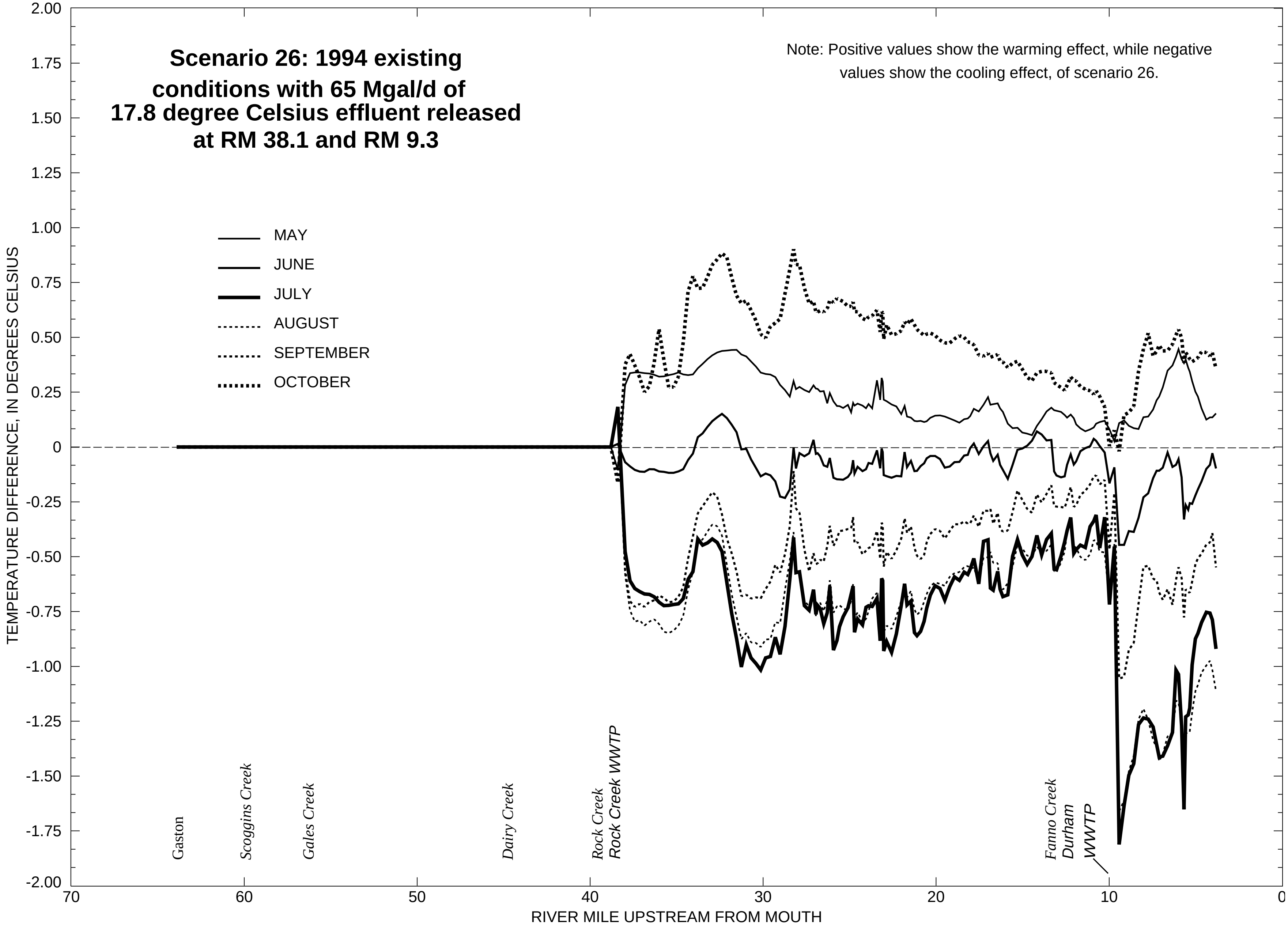


Figure 72. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1994 water temperatures for scenario 1, existing conditions, and scenario 26, existing conditions with 65 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

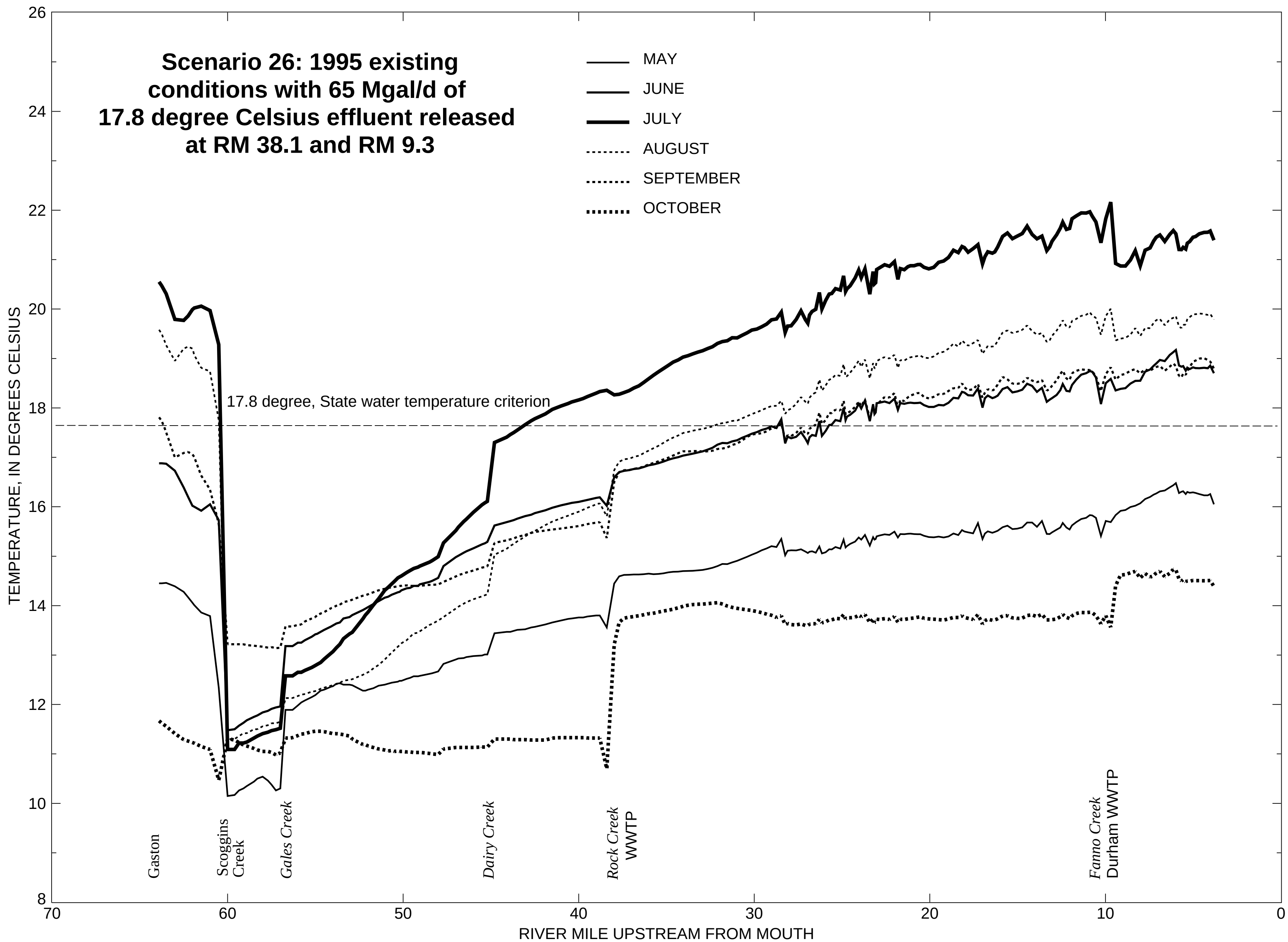


Figure 73. Monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 26, existing conditions with 65 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

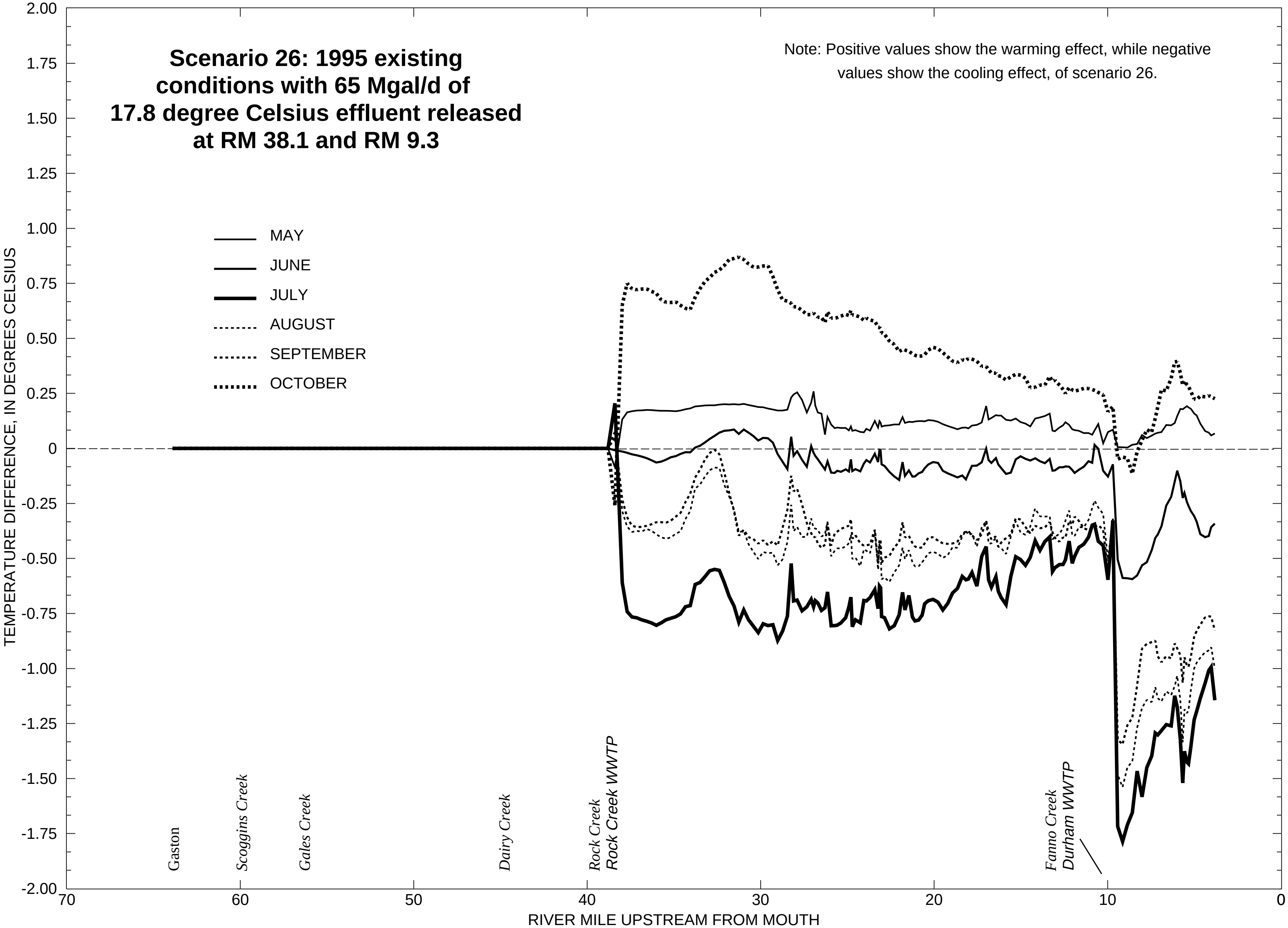


Figure 74. Difference between the monthly mean of the 7-day moving average of daily maximum simulated 1995 water temperatures for scenario 1, existing conditions, and scenario 26, existing conditions with 65 Mgal/d of 17.8 degree Celsius effluent released at RM 38.1 and RM 9.3. (Mgal/d, million gallons per day; RM, river mile; and WWTP, wastewater-treatment plant.)

Table 8. Monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario at **Golf Course Road** (river mile 51.5)

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	14.1	14.8	13.1	13.2	15.8	13.6	12.4	14.1	14.1	12.8	14.3	11.1
11	14.1	14.8	13.1	13.2	15.9	13.6	12.4	14.1	14.1	12.8	14.3	11.1
12	14	14.6	13	13.2	15.9	13.5	12.3	14	14.1	12.8	14.3	11.2
13	14.4	15.3	13.6	13.8	16.4	14.2	12.6	14.5	14.8	13.4	14.9	11.8
14	14.4	15.3	13.6	13.8	16.4	14.2	12.6	14.5	14.8	13.4	14.9	11.8
15	14.4	15.3	13.6	13.8	16.4	14.2	12.6	14.5	14.8	13.4	14.9	11.8
16	14.1	14.8	13.1	13.2	15.9	13.6	12.4	14.1	14.1	12.8	14.3	11.1
17	14.1	14.8	13.1	13.2	15.9	13.6	12.4	14.1	14.1	12.8	14.3	11.1
18	14.1	14.8	13.1	13.2	15.9	13.6	12.4	14.1	14.1	12.8	14.3	11.1
19	13.6	14.8	12.8	13.1	15.6	13.5	12	13.7	13.9	12.8	14.2	10.8
20	12.4	13.6	16.5	15.6	13.7	8.8	12.2	13.4	16.6	15.6	15	10.5
21	14.1	14.8	13.1	13.2	15.9	13.6	12.4	14.1	14.1	12.8	14.3	11.1
22	14.2	14.9	13.4	13.4	15.9	13.2	12.4	14.2	14.2	13	14.4	10.8
23	14.2	14.8	13.1	13.2	15.8	13.6	12.4	14.1	14.1	12.8	14.3	11.1
24	14.2	14.8	13.1	13.2	15.8	13.6	12.4	14.1	14.1	12.8	14.3	11.1
25	14.2	14.8	13.1	13.2	15.8	13.6	12.4	14.1	14.1	12.8	14.3	11.1
26	14.2	14.8	13.1	13.2	15.8	13.6	12.4	14.1	14.1	12.8	14.3	11.1

Table 9. Difference between the monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario and Scenario 1 at **Golf Course Road** (river mile 51.5)

[Positive values show the warming effect, while negative values show the cooling effect, of the management scenario.]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
11	0	0	0	0	0	0	0	0	0	0	0	0
12	-.1	-.1	0	0	0	-.1	0	-.1	-.1	0	0	+.1
13	+.3	+.6	+.5	+.6	+.5	+.6	+.2	+.4	+.6	+.6	+.6	+.7
14	+.3	+.6	+.5	+.6	+.5	+.6	+.2	+.4	+.6	+.6	+.6	+.7
15	+.3	+.6	+.5	+.6	+.5	+.6	+.2	+.4	+.6	+.6	+.6	+.7
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	-.5	0	-.2	-.1	-.2	-.1	-.4	-.4	-.2	0	-.1	-.3
20	-1.7	-1.2	+3.4	+2.4	-2.1	-4.8	-.2	-.7	+2.4	+2.8	+.7	-.6
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	+.2	+.3	+.2	+.1	-.4	0	+.1	+.1	+.2	+.1	-.3
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0

Table 10. Percentage of time the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature at **Golf Course Road** (river mile 51.5) exceeds 17.8 degrees Celsius for each management scenario during each month

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	29	0	0	0	0	0	19.4	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0

Table 11. Monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario at **Rood Bridge** (river mile 38.4)

[Shaded cells indicate potential violations of the 17.8 degrees Celsius State temperature standard]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	14.9	16	16.7	15.7	16	11.5	13.8	16	18.2	15.7	15.3	11
11	14.9	16	16.8	15.7	16	11.5	13.8	16	18.2	15.7	15.3	11
12	14.8	16	16.7	15.7	16	11.5	13.6	16	18.1	15.7	15.3	11
13	15.2	16.5	17.2	16.5	16.8	12.6	13.8	16.3	18.4	16.3	16	11.7
14	15.2	16.4	17.1	16.4	16.7	12.4	13.8	16.2	18.4	16.2	15.9	11.6
15	15.2	16.4	17	16.3	16.6	12.2	13.8	16.2	18.4	16.1	15.8	11.5
16	14.8	16	16.7	15.6	16	11.4	13.6	16	18.1	15.7	15.2	10.8
17	14.7	15.9	16.6	15.4	15.8	11.1	13.6	15.9	18.1	15.5	15.1	10.6
18	14.7	15.8	16.5	15.3	15.6	10.9	13.6	15.9	18	15.4	14.9	10.4
19	14.7	16	16.6	15.7	15.9	11.5	13.5	15.9	18	15.7	15.3	10.7
20	12.6	13.4	16.3	16.3	13.8	10.1	12.6	14.1	17.3	15.7	14.8	9.9
21	15	16.2	17	16.1	16.4	12	13.7	16.1	18.3	16	15.6	11.3
22	14.9	16.2	17.6	16.4	16.2	11.2	13.6	16.1	18.3	16.1	15.7	10.8
23	14.9	16.1	16.9	16	16.3	11.7	13.6	16.1	18.3	15.9	15.5	11
24	14.9	16.1	16.9	16	16.3	11.6	13.6	16.1	18.3	15.9	15.5	11
25	14.8	16.1	16.9	15.9	16.2	11.4	13.6	16	18.3	15.8	15.4	10.8
26	14.7	16	16.9	15.9	16.2	11.3	13.6	16	18.4	15.8	15.4	10.7

Table 12. Difference between the monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario averaged over each month and Scenario 1 at **Rood Bridge** (river mile 38.4)

[Positive values show the warming effect, while negative values show the cooling effect, of the management scenario.]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	-.1	0	0	0	-.1	0	-.1	0	0	0
13	+.4	+.5	+.5	+.8	+.8	+1.1	0	+.3	+.3	+.6	+.7	+.8
14	+.3	+.4	+.4	+.6	+.6	+.9	0	+.2	+.2	+.5	+.6	+.6
15	+.3	+.3	+.3	+.5	+.5	+.7	0	+.2	+.2	+.4	+.4	+.5
16	0	0	-.1	-.1	-.1	-.1	-.1	0	0	-.1	-.1	-.2
17	-.1	-.2	-.2	-.3	-.3	-.4	-.2	-.1	-.1	-.2	-.3	-.4
18	-.2	-.2	-.3	-.4	-.4	-.6	-.2	-.1	-.1	-.3	-.4	-.6
19	-.2	0	-.1	0	-.1	0	-.2	-.2	-.1	0	0	-.2
20	-2.2	-2.7	-.5	+.5	-2.2	-1.4	-1.1	-2	-.8	0	-.5	-1
21	+.1	+.2	+.2	+.4	+.3	+.5	-.1	+.1	+.1	+.2	+.3	+.3
22	0	+.2	+.8	+.7	+.2	-.3	0	+.1	+.1	+.4	+.3	-.1
23	0	+.1	+.2	+.3	+.3	+.2	0	+.1	+.2	+.2	+.2	+.1
24	0	+.1	+.2	+.3	+.3	+.1	0	+.1	+.2	+.2	+.2	0
25	-.1	0	+.2	+.2	+.2	-.1	-.1	0	+.2	+.1	+.1	-.1
26	-.1	0	+.2	+.2	+.2	-.2	-.1	0	+.2	+.1	+.1	-.3

Table 13. Percentage of time the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature at **Rood Bridge** (river mile 38.4) exceeds 17.8 degrees Celsius for each management scenario during each month

	1994						1995					
Scenario	**May**	**June**	**July**	**August**	**September**	**October**	**May**	**June**	**July**	**August**	**September**	**October**
1	0	0	6.5	0	0	0	9.7	23.3	58.1	19.4	0	0
11	0	0	6.5	0	0	0	9.7	23.3	58.1	19.4	0	0
12	0	0	3.2	0	0	0	9.7	23.3	54.8	19.4	0	0
13	0	13.3	19.4	0	20	0	9.7	26.7	74.2	22.6	0	0
14	0	3.3	16.1	0	20	0	9.7	26.7	71	19.4	0	0
15	0	0	12.9	0	13.3	0	9.7	26.7	71	19.4	0	0
16	0	0	6.5	0	0	0	9.7	23.3	58.1	19.4	0	0
17	0	0	3.2	0	0	0	9.7	23.3	48.4	16.1	0	0
18	0	0	0	0	0	0	6.5	23.3	48.4	16.1	0	0
19	0	0	3.2	0	0	0	3.2	20	54.8	19.4	0	0
20	0	0	22.6	3.2	0	0	0	0	25.8	0	0	0
21	0	0	9.7	0	3.3	0	9.7	26.7	67.7	19.4	0	0
22	0	26.7	38.7	0	0	0	9.7	26.7	64.5	19.4	0	0
23	0	0	12.9	0	3.3	0	9.7	26.7	71	19.4	0	0
24	0	0	12.9	0	3.3	0	9.7	26.7	71	19.4	0	0
25	0	0	12.9	0	3.3	0	9.7	26.7	71	19.4	0	0
26	0	0	12.9	0	3.3	0	9.7	26.7	71	19.4	0	0

Table 14. Monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario at **Scholls Bridge** (river mile 26.9)

[Shaded cells indicate potential violations of the 17.8 degrees Celsius State temperature standard]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	15.6	17.5	20.3	19.2	18.2	13.5	14.9	17.4	20.6	18.6	18	13
11	15.6	17.5	20.3	19.2	18.2	13.5	14.9	17.4	20.6	18.6	18	13
12	15.6	17.5	20.2	19.2	18.2	13.5	14.9	17.4	20.6	18.6	18	13
13	15.7	17.5	20.1	19	18.1	13.4	14.9	17.4	20.5	18.5	17.9	12.9
14	15.8	17.6	20.2	19.2	18.3	13.8	14.9	17.4	20.5	18.6	18.1	13.2
15	15.9	17.7	20.2	19.3	18.5	14.2	15	17.5	20.5	18.7	18.2	13.5
16	15.7	17.6	20.3	19.3	18.4	13.8	14.9	17.5	20.6	18.7	18.1	13
17	15.9	17.9	20.3	19.6	18.7	14.6	15	17.6	20.6	18.9	18.4	13.6
18	16.1	18.1	20.5	19.8	19	15.2	15.1	17.7	20.6	19.1	18.7	14.1
19	15.6	17.5	20.2	19.2	18.2	13.5	14.8	17.4	20.5	18.6	18	12.8
20	14.1	15.8	20.1	19.4	16.6	12	14.3	16.3	20.2	18.7	17	12
21	15.4	17.2	19.8	18.5	17.6	12.5	14.8	17.2	20.3	18.1	17.4	12.3
22	15.6	17.4	19.9	19	18.1	13.7	14.9	17.4	20.6	18.4	17.9	13.1
23	15.6	17.3	19.9	19	17.7	13.2	14.9	17.3	20.3	18.3	17.6	12.8
24	15.6	17.4	19.8	18.7	17.7	13.3	14.9	17.3	20.2	18.2	17.6	12.9
25	15.8	17.4	19.6	18.5	17.7	13.7	15	17.4	20	18.2	17.6	13.3
26	15.9	17.5	19.5	18.5	17.7	14.1	15.1	17.4	19.9	18.2	17.6	13.6

Table 15. Difference between the monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario averaged over each month and Scenario 1 at **Scholls Bridge** (river mile 26.9)

[Positive values show the warming effect, while negative values show the cooling effect, of the management scenario]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	-.1	-.1	-.2	-.1	-.1	0	-.1	-.1	-.1	-.1	-.1
14	+.1	+.1	-.1	+0	+.1	+.3	0	0	-.1	0	+.1	+.2
15	+.3	+.2	0	+.1	+.3	+.7	+.1	+.1	-.1	+.1	+.2	+.5
16	+.1	+.1	+.1	+.1	+.1	+.3	0	0	0	+.1	+.1	0
17	+.3	+.3	+.1	+.4	+.5	+1.1	+.1	+.2	0	+.3	+.4	+.6
18	+.4	+.5	+.2	+.6	+.8	+1.7	+.2	+.3	0	+.5	+.7	+1.1
19	-.1	0	0	0	0	0	-.1	-.1	-.1	0	0	-.2
20	-1.5	-1.7	-.1	+.2	-1.7	-1.5	-.6	-1.1	-.4	+.1	-1	-1.1
21	-.3	-.4	-.4	-.7	-.7	-1	-.2	-.3	-.2	-.5	-.6	-.8
22	0	-.1	-.3	-.2	-.1	+.2	0	-.1	0	-.1	-.1	+.1
23	-.1	-.2	-.4	-.5	-.5	-.3	0	-.1	-.3	-.3	-.4	-.2
24	0	-.2	-.4	-.6	-.5	-.2	0	-.1	-.3	-.3	-.4	-.1
25	+.1	-.1	-.6	-.7	-.5	+.2	+.1	-.1	-.6	-.4	-.4	+.3
26	+.3	0	-.7	-.7	-.5	+.6	+.2	0	-.7	-.4	-.4	+.6

Table 16. Percentage of time the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature at **Scholls Bridge** (river mile 26.9) exceeds 17.8 degrees Celsius for each management scenario during each month

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	0	36.7	100	100	66.7	0	19.4	36.7	100	64.5	60	0
11	0	36.7	100	100	66.7	0	19.4	36.7	100	64.5	53.3	0
12	0	36.7	100	100	70	0	19.4	36.7	100	64.5	53.3	0
13	0	36.7	100	100	63.3	0	19.4	36.7	100	64.5	53.3	0
14	0	36.7	100	100	70	0	22.6	36.7	100	71	63.3	0
15	0	40	100	100	73.3	3.2	22.6	36.7	100	74.2	76.7	0
16	0	36.7	100	100	73.3	3.2	19.4	36.7	100	71	63.3	0
17	0	40	100	100	83.3	6.5	22.6	40	100	80.6	80	0
18	0	53.3	100	100	93.3	9.7	22.6	40	100	83.9	83.3	3.2
19	0	36.7	100	100	70	0	19.4	36.7	100	64.5	53.3	0
20	0	3.3	80.6	100	0	0	3.2	20	100	74.2	30	0
21	0	33.3	87.1	83.9	40	0	19.4	36.7	100	41.9	36.7	0
22	0	36.7	93.5	100	63.3	0	19.4	36.7	100	54.8	50	0
23	0	36.7	93.5	90.3	50	0	19.4	36.7	100	51.6	46.7	0
24	0	36.7	93.5	87.1	50	0	19.4	36.7	100	54.8	46.7	0
25	0	36.7	93.5	87.1	50	0	19.4	36.7	100	54.8	40	0
26	0	36.7	96.8	87.1	46.7	0	22.6	36.7	100	54.8	40	0

Table 17. Monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario at **Elsner Road** (river mile 16.2)

[Shaded cells indicate potential violations of the 17.8 degrees Celsius State temperature standard]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	16	18	21.7	20.3	18.9	13.5	15.4	18.3	21.9	19.8	18.9	13.4
11	16	18	21.7	20.3	18.9	13.5	15.4	18.3	21.9	19.8	18.9	13.4
12	16.1	18	21.7	20.3	18.9	13.5	15.4	18.3	21.9	19.8	18.9	13.4
13	16.1	18	21.6	20.2	18.8	13.5	15.4	18.3	21.9	19.8	18.8	13.3
14	16.1	18	21.6	20.2	18.9	13.7	15.4	18.3	21.8	19.8	18.9	13.5
15	16.2	18.1	21.5	20.2	19	13.9	15.4	18.4	21.8	19.8	18.9	13.7
16	16.1	18.1	21.7	20.3	18.9	13.7	15.4	18.3	21.9	19.8	18.9	13.4
17	16.2	18.1	21.6	20.3	19.1	14.1	15.5	18.4	21.8	19.9	19	13.7
18	16.3	18.2	21.5	20.4	19.2	14.6	15.5	18.4	21.7	19.9	19.1	14
19	16	18	21.7	20.3	18.9	13.5	15.3	18.3	21.9	19.8	18.9	13.2
20	15.1	16.9	21.6	20.7	18.3	13.1	15	17.6	21.8	20.1	18.6	12.7
21	15.9	17.8	21.5	20	18.6	13.1	15.3	18.2	21.8	19.6	18.6	13
22	16	18	21.6	20.2	18.8	13.6	15.4	18.3	21.9	19.7	18.8	13.5
23	16	17.9	21.5	20.1	18.6	13.4	15.4	18.3	21.8	19.6	18.7	13.3
24	16	17.9	21.5	20	18.6	13.4	15.4	18.3	21.7	19.6	18.7	13.3
25	16.1	17.9	21.2	19.8	18.6	13.7	15.4	18.3	21.5	19.5	18.6	13.5
26	16.2	17.9	21	19.6	18.5	13.9	15.5	18.2	21.3	19.4	18.5	13.7

Table 18. Difference between the monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario averaged over each month and Scenario 1 at **Elsner Road** (river mile 16.2)
[Positive values show the warming effect, while negative values show the cooling effect, of the management scenario.]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	-.1	0	0	0	0	0
13	0	0	0	-.1	0	0	-.1	0	0	-.1	-.1	-.1
14	+.1	0	-.1	-.1	0	+.2	-.1	0	-.1	0	0	+.1
15	+.2	0	-.2	-.1	+.1	+.4	0	0	-.2	0	0	+.3
16	0	0	0	0	+.1	+.2	-.1	0	0	0	0	0
17	+.1	+.1	-.1	0	+.2	+.6	0	0	-.1	0	+.1	+.3
18	+.3	+.2	-.2	+.1	+.4	+1.1	+.1	+.1	-.3	+.1	+.2	+.6
19	0	0	0	0	0	0	-.1	0	0	0	0	-.2
20	-1	-1.1	-.1	+.4	-.6	-.4	-.4	-.7	-.1	+.3	-.3	-.7
21	-.2	-.2	-.2	-.3	-.3	-.4	-.2	-.2	-.1	-.2	-.3	-.4
22	0	0	-.1	-.1	0	+.1	0	0	0	-.1	0	+.1
23	0	-.1	-.1	-.2	-.2	-.1	0	-.1	-.1	-.2	-.2	-.1
24	0	-.1	-.2	-.3	-.2	-.1	0	-.1	-.2	-.2	-.2	-.1
25	+.1	-.1	-.5	-.5	-.3	+.1	0.1	-.1	-.4	-.3	-.3	+.1
26	+.2	-.1	-.7	-.6	-.4	+.4	+.1	-.1	-.7	-.5	-.4	+.3

Table 19. Percentage of time the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature at **Elsner Road** (river mile 16.2) exceeds 17.8 degrees Celsius for each management scenario during each month

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	0	43.3	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
11	0	43.3	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
12	0	43.3	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
13	0	43.3	100	100	83.3	6.5	25.8	50	100	100	83.3	0
14	0	43.3	100	100	83.3	6.5	25.8	50	100	100	83.3	0
15	0	50	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
16	0	43.3	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
17	0	50	100	100	90	9.7	25.8	53.3	100	100	83.3	0
18	0	56.7	100	100	96.7	9.7	25.8	53.3	100	100	86.7	0
19	0	43.3	100	100	83.3	6.5	25.8	50	100	100	83.3	0
20	0	30	100	100	73.3	3.2	19.4	40	100	100	80	0
21	0	36.7	100	100	76.7	3.2	25.8	46.7	100	90.3	80	0
22	0	43.3	100	100	83.3	6.5	25.8	53.3	100	100	83.3	0
23	0	40	100	100	76.7	3.2	25.8	50	100	93.5	80	0
24	0	40	100	100	76.7	3.2	25.8	50	100	90.3	80	0
25	0	36.7	100	100	76.7	3.2	25.8	50	100	90.3	80	0
26	0	36.7	100	100	76.7	3.2	25.8	50	100	90.3	76.7	0

Table 20. Monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario at **Stafford Road** (river mile 5.5)

[Shaded cells indicate potential violations of the 17.8 degrees Celsius State temperature standard]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	16.5	18.5	22.3	21.3	19.3	14.2	16.1	19	22.6	20.9	19.6	14.2
11	16.5	18.5	22.3	21.3	19.3	14.2	16.1	19	22.6	20.9	19.6	14.2
12	16.5	18.5	22.3	21.3	19.3	14.2	16.1	19	22.6	20.9	19.7	14.2
13	16.6	18.5	22.3	21.2	19.3	14.2	16.1	19	22.6	20.9	19.6	14.1
14	16.6	18.5	22.3	21.2	19.3	14.2	16.1	19	22.6	20.8	19.6	14.2
15	16.6	18.5	22.2	21.1	19.3	14.3	16.1	19	22.6	20.8	19.6	14.3
16	16.6	18.6	22.3	21.3	19.5	14.5	16.1	19.1	22.6	20.9	19.7	14.1
17	16.8	18.6	22.2	21.3	19.7	15.1	16.3	19.2	22.6	21	20	14.7
18	17	18.8	22.1	21.3	19.9	15.6	16.4	19.3	22.5	21.1	20.1	15
19	16.5	18.5	22.3	21.3	19.3	14.2	16	19	22.6	20.9	19.6	14
20	16.3	17.9	22.4	21.4	18.9	13.3	16	18.8	22.4	20.7	19	13.3
21	16.3	18.3	22.3	21	18.9	13.5	15.8	18.7	22.5	20.5	19.2	13.3
22	16.5	18.5	22.3	21.2	19.3	14.2	16.1	19	22.6	20.9	19.6	14.2
23	16.5	18.4	21.9	20.7	18.8	14	16	18.8	22.1	20.3	19.1	13.8
24	16.5	18.3	21.8	20.6	18.8	14.1	16	18.7	21.9	20.2	19	13.9
25	16.7	18.3	21.4	20.2	18.7	14.3	16.1	18.7	21.5	19.9	18.9	14.2
26	16.9	18.2	21.1	20	18.6	14.6	16.3	18.8	21.2	19.7	18.7	14.5

Table 21. Difference between the monthly means of the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature in degrees Celsius for each management scenario averaged over each month and Scenario 1 at **Stafford Road** (river mile 5.5)

[Positive values show the warming effect, while negative values show the cooling effect, of the management scenario.]

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	-.1	0	0	0	0	0
13	+.1	0	0	0	0	0	-.1	0	0	0	0	0
14	+.1	0	0	-.1	0	0	-.1	0	0	-.1	0	0
15	+.1	0	0	-.1	0	+.1	-.1	0	-.1	-.1	0	+.1
16	+.1	0	0	0	+.2	+.3	-.1	+.1	0	0	+.1	-.1
17	+.3	+.1	-.1	0	+.4	+.9	+.1	+.2	-.1	+.2	+.3	+.5
18	+.5	+.2	-.2	+.1	+.6	+1.3	+.3	+.3	-.1	+.2	+.4	+.8
19	0	0	0	0	0	0	-.1	0	0	0	0	-.2
20	-.3	-.6	+.1	+.1	-.4	-.9	-.1	-.1	-.2	-.2	-.7	-.9
21	-.2	-.2	0	-.2	-.4	-.7	-.3	-.2	-.1	-.4	-.5	-.9
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	-.2	-.4	-.5	-.4	-.3	-.1	-.2	-.5	-.6	-.6	-.4
24	0	-.2	-.5	-.6	-.5	-.2	0	-.2	-.7	-.7	-.6	-.4
25	+.2	-.3	-.9	-1	-.6	+.1	+.1	-.3	-1.1	-1	-.8	0
26	+.4	-.3	-1.2	-1.3	-.7	+.4	+.2	-.2	-1.4	-1.2	-1	+.3

Table 22. Percentage of time the 7-day moving average of daily maximum simulated 1994 and 1995 water temperature at **Stafford Road** (river mile 5.5) exceeds 17.8 degrees Celsius for each management scenario during each month

Scenario	1994						1995					
	May	June	July	August	September	October	May	June	July	August	September	October
1	0	70	100	100	83.3	9.7	29	66.7	100	100	93.3	0
11	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
12	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
13	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
14	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
15	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
16	0	70	100	100	100	12.9	29	66.7	100	100	93.3	0
17	6.5	73.3	100	100	100	16.1	29	73.3	100	100	100	0
18	25.8	73.3	100	100	100	19.4	32.3	73.3	100	100	100	3.2
19	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
20	0	40	100	100	86.7	3.2	29	63.3	100	100	83.3	0
21	0	53.3	100	100	90	6.5	25.8	60	100	100	86.7	0
22	0	70	100	100	100	9.7	29	66.7	100	100	93.3	0
23	0	63.3	100	100	90	6.5	29	63.3	100	100	86.7	0
24	0	60	100	100	90	6.5	29	63.3	100	100	86.7	0
25	0	63.3	100	100	90	6.5	29	66.7	100	100	83.3	0
26	6.5	56.7	100	100	90	6.5	32.3	66.7	100	100	83.3	0

SUMMARY AND CONCLUSIONS

In 1994, the USGS and the Unified Sewerage Agency of Washington County, Oregon, began a cooperative study whose objectives were:

(1) To quantify the temporal and spatial patterns of water temperature in the main stem of the Tualatin River and the lower reaches of its major tributaries.

(2) To determine the relation of water temperature in the Tualatin River and its major tributaries to climatic conditions, seasonal and diel variations, and human-caused factors.

(3) To assess the effects of various flow-management practices on water temperature during the low-flow season (May through October).

Streamflow, water-temperature and meteorological data were collected at various locations on the main stem of the Tualatin River from RM 63.9 to RM 3.4 from May through November during 1994 and 1995.

The data were used to calibrate two dynamic-flow heat-transport models, DAFLOW-BLTM and CE-QUAL-W2. The DAFLOW-BLTM models are one-dimensional; they were applied to the section of the river upstream of Rood Bridge (RM 63.9 to RM 38.4). The CE-QUAL-W2 model is a laterally averaged two-dimensional model; it was applied to the lower river section (RM 38.4 to RM 3.4). A variety of hypothetical water-management scenarios were assessed through model simulations, which included changes in Henry Hagg Lake operation, riparian shading along the main stem, wastewater-treatment plant operation, and the Oswego diversion dam operation. The results of modeling simulations for 10 different scenarios, using data from the 1994 low-flow season, were documented by Risley (1997).

This report presents model simulation results of 16 additional hypothetical water-management scenarios that were made after completion of the original study. Simulations for these scenarios used data collected in 1995 in addition to that from 1994. Although the 16 additional scenarios showed varying effects on the water temperature of the river system, the State of Oregon temperature standard was still exceeded in most of the lower river reaches during the warmer months in both years. Also, the most extreme cooling (or warming) effect of any of the scenarios was never greater than 2.0^{o}C (degrees Celsius) at any location along the whole reach. The results of these scenarios included:

Scenario 11: Existing conditions with 1.33 ft^3/s decrease in Rock Creek WWTP effluent

The effect of diverting 1.33 ft^3/s of Rock Creek wastewater-treatment plant (WWTP) effluent for irrigation was evaluated. Temperatures downstream of that WWTP (RM 38.1) for most months decreased about 0.05^{o}C or less. Farther downstream, the effect was almost negligible near RM 10.0. The effect of thisscenario is slightly more apparent in the 1994 simulation than the 1995 simulation.

Scenario 12: Existing conditions with 1.33 ft^3/s river withdrawal and 2.0 ft^3/s Henry Hagg Lake release

In a follow-up scenario, a constant flow of 1.33 ft^3/s was withdrawn from the river at RM 37.3 and an additional constant flow of 2.0 ft^3/s was released from Henry Hagg Lake to compensate. Again the effect of this scenario on the river system was fairly minimal for in 1994 and 1995. Temperatures generally decreased from RM 60.0 to RM 3.4 by about 0.05 to 0.1^{o}C. For most months the overall cooling effect of scenario 12 was slightly greater than the cooling effect of scenario 11.

Scenarios 13–15: Existing conditions with effluent releases of 5 Mgal/d at RM 55.2 and RM 43.8 and 10, 20, and 30 Mgal/d at RM 38.1

In another set of scenarios, the effect of piping and then releasing Rock Creek WWTP effluent at two upstream locations (RM 43.8 and RM 55.2) was evaluated. A constant flow of 5 million gallons per day (Mgal/d) was released at each upstream location, in addition to a constant release of either 10, 20, or 30 Mgal/d of effluent at RM 38.1. Temperatures increased between RM 55.2 and RM 38.1 by about 1.0^{o}C or less, but were still in compliance with the water-quality standard. Downstream of RM 38.1, the river temperature decreased (generally 0.6^{o}C or less) if the release from Rock Creek WWTP was only 10 Mgal/d. If the releases from Rock Creek WWTP were 20 and 30 Mgal/d, temperatures downstream of RM 38.1 generally increased; however, the magnitude of the increase was almost entirely less than 1.0^{o}C.

Scenarios 16–18: Existing conditions with 25, 45, and 65 Mgal/d of effluent at RM 38.1 and RM 9.3

The temperature effect resulting from constant 25, 45, or 65 Mgal/d effluent releases from the Rock Creek (RM 38.1) and Durham (RM 9.3) WWTPs was evaluated. Temperatures throughout the reach downstream of Rock Creek WWTP, and to a lesser extent downstream of Durham WWTP, increased proportionately. The magnitude of the increases were by as much as 0.6, 1.5, and 2.2^{O}C for the three scenarios, respectively.

Scenarios 19–20: Existing and "natural" conditions with Gaston temperature data replaced with Lee Falls data

In another scenario, a cooler water-temperature data set, representing more shaded, "natural" background conditions, was used as input to the model upper boundary at Gaston (RM 63.9). Water temperatures decreased substantially between RM 63.9 and the confluence with Scoggins Creek (RM 60.0) by as much as 4.0^{O}C. However, the effect of the temperature decrease was overwhelmed by the large volume of colder water flowing from Scoggins Creek as a result of releases from Henry Hagg Lake. For most of the reach downstream of RM 60.0, the overall cooling effect of this scenario was less than 0.5^{O}C. In a follow-up scenario, the same model upper boundary condition was used in conjunction with the "natural" background conditions scenario from Risley (1997). Water temperatures again decreased substantially between RM 63.9 and the confluence with Scoggins Creek (RM 60.0); however, between Scoggins Creek and the Dairy Creek confluence (RM 44.8), water temperatures gradually increased because the unnaturally cool water released from Henry Hagg Lake was not present. Nonetheless, almost all of the reach above Rood Bridge (RM 38.4) was within compliance of the water-quality standard. Below RM 38.4, temperatures increased (1.0^{O}C or less) for July and August, and decreased for other months.

Scenario 21: Existing conditions with WWTP effluent temperature equal to receiving river temperature

The effect of setting the temperature of effluent released at RM 38.1 and RM 9.3 equal to the temperature of the river was evaluated. Temperatures downstream of RM 38.1 decreased by as much as 2.4^{O}C. The reduction then tapers off to 0.5^{O}C upstream of RM 9.3. Downstream of RM 9.3, temperatures decreased by as much as 1.2^{O}C.

Scenario 22: Existing conditions with up to 10 Mgal/d of USA flow augmentation released near Rock Creek WWTP outfall

Another scenario was used to evaluate the effect of releasing a purchased allotment of Scoggins Dam flow (up to, but not exceeding 10 Mgal/d) at RM 38.1 instead of into Scoggins Creek. Observed Scoggins Dam temperature data were used for the allotted flow. Temperatures increased for all months except October from RM 60.0 to RM 38.1 by as much as 0.6^{O}C. However, downstream of RM 38.1, temperatures decreased from as much as 0.7^{O}C for all months except October. However, the effect of the supplemental release became less pronounced moving downstream.

Scenarios 23–26: Existing conditions with 20, 25, 45, and 65 Mgal/d of 17.8 degrees Celsius effluent released at RM 38.1 and RM 9.3

The effect of constant effluent releases of 20, 25, 45, and 65 Mgal/d at two WWTPs (RM 38.1 and RM 9.3) was evaluated. The 1994 and 1995 measured effluent-temperature data from the WWTPs were used, except that the temperatures were not permitted to be greater than 17.8^{O}C. For most months, the temperature in the reach downstream of both WWTPs decreased in all four scenarios. From RM 38.1 to RM 9.3, the temperature decrease was less than 1.0^{O}C. Downstream of the Durham WWTP (RM 9.3), temperatures decreased by almost 2.0^{O}C.

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