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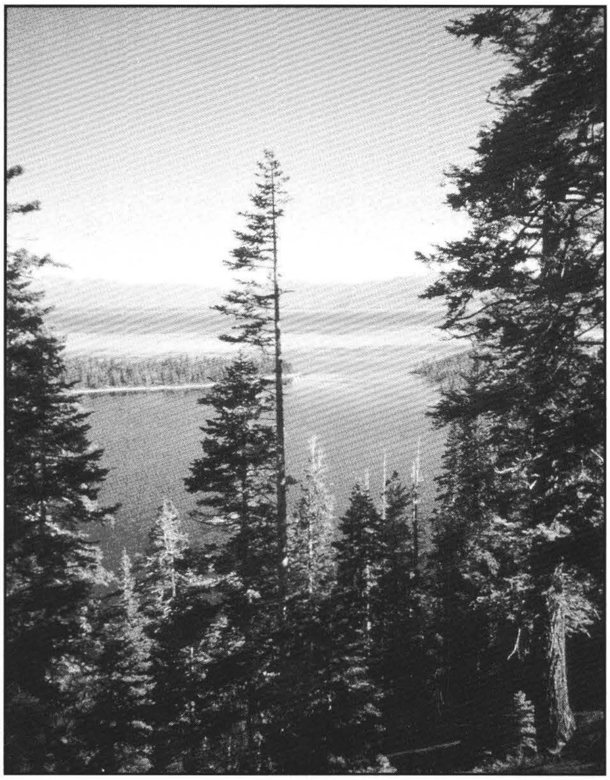
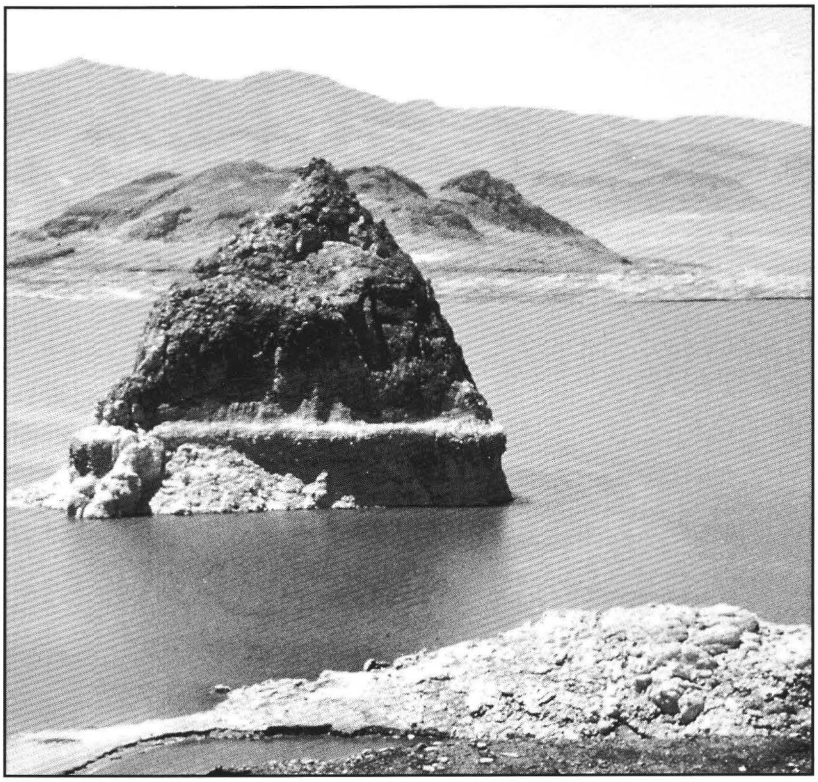
Simulation of Hourly Stream Temperature and Daily Dissolved Solids for the Truckee River, California and Nevada

Water-Resources Investigations Report 98-4064





U.S. Department of the Interior
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COVER PHOTOGRAPHS. Left picture: Emerald Bay with Lake Tahoe in the background, October 1994. Photograph by Timothy G. Rowe, U.S. Geological Survey. Right picture: The Pyramid in Pyramid Lake, July 11, 1969. Photograph by Patrick A. Glancy, U.S. Geological Survey (retired).

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Simulation of Hourly Stream Temperature and Daily Dissolved Solids for the Truckee River, California and Nevada

By **R. Lynn Taylor**

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Truckee-Carson Program

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY AND GAGING-STATION NAME ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per year
inch (in.)	25.40	millimeter
inch per year (in/yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
Langley	1.0000	calorie per square centimeter

Temperature: Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by using the formula: °C = 0.556(°F-32). Degrees Celsius (°C) or Kelvins can be converted to degrees Fahrenheit (°F) by using the formulas:

$$°F = [1.8(°C)]+32$$
$$°F = [1.8(°K)]- 459.67$$

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called "Sea-Level Datum of 1929"), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Abbreviated water-quality units used in this report:

$kcal/m^2/°C/hr$, kilocalorie per square meter per degree Celsius per hour

mg/L, milligrams per liter

Abbreviated station name used in text	Official U.S. Geological Survey gaging-station name
Above Prosser Creek gaging station	Truckee River above Prosser Creek near Truckee, Calif.
Bronco Creek gaging station	Bronco Creek at Floriston, Calif.
Clark gaging station	Truckee River at Clark, Nev.
Dog Creek gaging station	Dog Creek at Verdi, Nev.
Donner Creek gaging station	Donner Creek at Highway 89 near Truckee, Calif.
Farad gaging station	Truckee River at Farad, Calif.
Hunter Creek gaging station	Hunter Creek above Last Chance Ditch near Reno, Nev.
Marble Bluff gaging station	Truckee River at Marble Bluff Dam, Nev.
Nixon gaging station	Truckee River near Nixon, Nev.
North Truckee Drain gaging station	North Truckee Drain at Kleppe Lane near Sparks, Nev.
Sparks gaging station	Truckee River near Sparks, Nev.
Steamboat Creek gaging station	Steamboat Creek at Cleanwater Way near Reno, Nev.
Tahoe City gaging station	Truckee River at Tahoe City, Calif.
TMWRF gaging station	Reno-Sparks Sewer Treatment Plant Outfall at Reno, Nev.
Tracy gaging station	Truckee River below Tracy, Nev.
Vista gaging station	Truckee River at Vista, Nev.
Wadsworth gaging station	Truckee River at Wadsworth, Nev.

Simulation of Hourly Stream Temperature and Daily Dissolved Solids for the Truckee River, California and Nevada

By R. Lynn Taylor

ABSTRACT

Two physically based, water-quality models for simulating stream temperature and dissolved-solids concentrations in the Truckee River were developed by the U.S. Geological Survey, in support of U.S. Department of the Interior implementation of the Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990 (P.L. 101-618). The foundation of these water-quality models is the U.S. Geological Survey daily flow-routing model of the Truckee River. The flow-routing model simulates streamflow along 114 miles of the Truckee River mainstem from just downstream of Lake Tahoe, California, to Marble Bluff Dam, just upstream from Pyramid Lake, Nevada. The simulated streamflow is used to transfer heat and dissolved solids throughout the same reach. The water-quality models represent a step toward development of a "modular framework modeling system" that will provide a mechanism for integrating many hydrologic and operational analyses models into a single predictive tool.

The computer program Hydrological Simulation Program-FORTRAN (HSPF) was used to construct the stream-temperature and dissolved-solids models. HSPF was modified during this project to include a streambed heat conductance algorithm. Modification was necessary because of the shallow and wide nature of the Truckee River during periods of low flow. Construction of these models involved the collection and estimation of streamflow, stream-temperature, meteorologic, and specific-conductance data. These data were used with the channel-reach hydraulics information provided by the flow-routing model. Differences between simulations of these models and data collected at gaging stations were evaluated for the following periods: flow routing, June 1, 1993-September 30, 1995; stream temperature, June 1, 1993-May 31, 1994 (calibration period), and June 1, 1994-September 30, 1994 (validation period); and dissolved solids, October 1, 1994-September 30, 1995. The three models were evaluated at selected gaging stations. The availability of data dictated the choice of gaging stations for model evaluation. The model and data base are available in several media, including disk and computer access.

Mean absolute errors of simulated daily streamflow versus observed daily streamflow during the evaluation period ranged from 11.6 to 37.0 percent and bias ranged from -1.8 to 12.5 percent. Simulated daily maximum, daily minimum, and hourly stream temperatures during the calibration period were, on average, within 1.0°C (Celsius) of observed stream temperatures at all three model-evaluation sites. Stream-temperature model errors for daily maximum, daily minimum, and hourly stream temperatures during the validation period were within 1.8°C of observed stream temperatures for all three evaluation stations. Bias during the validation period ranged from -1.0 to 1.7°C. Mean absolute errors between observed and simulated daily dissolved-solids concentrations ranged from 6.6 to 10.8 percent and bias ranged from -7.9 to 3.1 percent. Mean absolute errors for the flow-routing, stream-temperature, and dissolved-solids

models tended to decrease with increasing simulated streamflow. For all three models, simulation results generally were best when streamflows were greater than 500 ft^3/s (cubic feet per second).

The algorithm that transfers heat to and from the streambed becomes unstable when simulated mean stream depths are 2-3 inches. For depths of that magnitude, the stream-temperature model as presently formulated may not be valid. Depths in this range correspond to a streamflow of less than 10 ft^3/s for all stream reaches. For simulated streamflows greater than or equal to 10 ft^3/s, most of the differences between observed and simulated data can be attributed to inadequacies in model input data; estimation of missing input data; and, for the stream-temperature and dissolved-solids models, errors in streamflow simulation. These models were constructed, calibrated, and checked under a specific set of conditions, and the evaluation of model results shown pertains only to those conditions. Changing conditions may require updated input data sets and recalibration to the new set of conditions.

INTRODUCTION

Truckee River water serves a variety of important economic and environmental needs. These include electric power generation upstream from Reno, municipal/industrial demands, including drinking water, of the Reno-Sparks metropolitan area (hereafter referred to as the Truckee Meadows), irrigation in the Truckee and Carson River Basins, maintenance of Pyramid Lake levels, and habitat for populations of the endangered cui-ui lakesucker and the threatened Lahontan cutthroat trout in Pyramid Lake and in the lower river reaches. Allocation of this limited resource has created long-standing and intense conflicts among economic, political, institutional, and environmental entities representing the various user interests.

In general, the demand for Truckee River water is greater than the available supply. Water rights within the basin are fully or over allocated with respect to average annual runoff volumes. Reservoir storage capacities are insufficient to supply all demands during extended periods of low precipitation. Droughts that last more than 2 years—the period during the late 1980's and early 1990's is an example—can result in significant shortages of water for irrigation and municipal use and may stress fish and wildlife ecosystems.

Adequate quantities of good-quality Truckee River water are essential to the maintenance of viable fish and wildlife habitats in the lower Truckee River and Pyramid Lake, and to the health of people in the Truckee Meadows who rely on the river for drinking-water supplies. The level of Pyramid Lake has declined during the time that Truckee River water has been diverted to the Newlands Project, a Federal reclamation program within the Truckee and Carson River Basins. Reduction of lake levels and concomitant change in stream habitat have hindered upstream migration of the cui-ui and cutthroat trout. As a result, the ability of those species to spawn in the lower Truckee River have been affected adversely.

Pyramid Lake levels also are important to wildlife other than fish. Anaho Island National Wildlife Refuge is home to a colony of American white pelicans. A land bridge that would form from the shore to Anaho Island at very low lake levels would allow predators access to the nesting area (Jones and others, 1991, p. 85).

Two factors are important indicators of Truckee River Basin ecosystem viability: (1) stream temperature and (2) concentration of dissolved solids in the water. Temperature is important because the cui-ui and cutthroat trout have narrow temperature tolerance ranges for optimum spawning, rearing, and fry survival (Hoffman and Scoppettone, 1988, p. 9-12; U.S. Fish and Wildlife Service, 1992, p. 7). In addition, other properties that characterize water quality (dissolved oxygen, pH, and algal populations) also are temperature dependent.

Salinity is a measure of the dissolved solids in water. The terminus of the Truckee River is Pyramid Lake, an evaporative sink. Thus, much of the dissolved material that enters the lake remains there while water is lost through lake-surface evaporation. As lake level drops and water volume decreases, salinity increases (Taylor, 1972).

The dissolution of minerals throughout the watershed and the discharge of treated sewage effluent at localized points are major sources of dissolved solids to the Truckee River. Mineralized ground-water inflow and treated sewage effluent in the lower Truckee River consistently have the highest concentrations of dissolved solids added to the river.

The major source of heat to the Truckee River is solar radiation. However, localized heating occurs when the temperature of influent ground water or sewage effluent is greater than stream temperatures. The major sink for heat from the Truckee River is the atmosphere with removal through evaporation and longwave radiation. Localized cooling occurs when tributary and ground-water inflow temperatures are less than stream temperatures.

Interrelated water-quantity and water-quality problems from competing objectives and limited water resources result in a wide range of alternatives for planning, allocating, and managing the water resources of the Truckee River. Title II of Public Law (P.L.) 101-618, the Truckee–Carson–Pyramid Lake Water Rights Settlement Act of 1990, provides a foundation to develop operating criteria. These criteria would be used to balance interstate and interbasin allocation and demand for water rights among the interests competing for the Truckee River water. Efficient execution of many planning, management, or environmental assessment requirements of P.L. 101-618 will require detailed water-resources and hydraulic data, coupled with sound analytical tools.

Physically based hydrologic models calibrated and evaluated with actual data and combined with reservoir/river-operations models are needed to assess alternatives for water allocation and management. The interdependence of many of the water-management issues of the Truckee River Basin, such as allocation of streamflow and maintenance of instream water-quality standards, suggests a strong need for an overall data-management and modeling framework within which individual issues can be addressed in an efficient and coordinated manner. Such a framework needs to be interbasin in scope, addressing the interrelated water-allocation and water-management issues of the Truckee and Carson River systems.

In support of U.S. Department of the Interior implementation of P.L. 101-618, the U.S. Geological Survey (USGS) began developing a data-management and computer-modeling framework to provide a mechanism for integrating various hydrologic-analysis models as modules within a single system. The strategy for constructing the modular modeling system to describe hydrologic processes of the Truckee and Carson River Basins is to initially construct models to route streamflow along the mainstems of the rivers, where water-management issues are especially critical. Other modules can be developed that will use the results of the flow-routing module to simulate selected water-quality constituents, reservoir operations, and flow allocations.

The program chosen as the framework to model the Truckee and Carson Rivers is the Hydrological Simulation Program–FORTRAN (HSPF; Bicknell and others, 1997). HSPF was selected for the Truckee River models primarily because it can (1) simulate streamflow and water-quality characteristics continuously over long periods of time including periods of storm runoff and low flows, (2) simulate streamflow and water-quality characteristics at a variety of time intervals including hourly and daily time steps, (3) simulate the hydraulics of complex natural and manmade drainage networks, (4) account for channel inflows and diversions, and (5) produce simulation results at many locations along the river. The code also is well documented, technically supported, and available within the public domain.

Purpose and Scope of This Report

The purpose of this report is (1) to describe the data and methods used in the construction of an hourly stream-temperature model and a daily dissolved-solids concentrations (hereafter referred to as dissolved solids) model, including a brief description of the underlying daily flow-routing model, (2) to provide streamflow, stream-temperature, and dissolved-solids simulation results, (3) to discuss the differences between observed and simulated stream temperatures and dissolved solids, and (4) to discuss the limitations of these models.

The scope of the report regarding streamflow and stream temperature includes the Truckee River mainstem from near the Tahoe City gaging station, just downstream from Lake Tahoe, to Marble Bluff Dam, approximately 3.5 mi upstream from Pyramid Lake, and parts of two tributaries, Donner Creek and Martis Creek (pl. 1). The scope of the dissolved-solids model includes the Truckee River mainstem from the above Prosser Creek gaging station, just upstream from Prosser Creek, to Marble Bluff Dam (pl. 1). Streamflow, stream-temperature, meteorological, and dissolved-solids data used to calibrate, validate, or evaluate the stream-temperature and dissolved-solids models include the period from June 1993 through September 1995. A daily time step was used to simulate streamflow and dissolved-solids data, and an hourly time step was used to simulate stream-temperature data. Daily streamflow, daily dissolved-solids, and hourly stream-temperature data collected on the Truckee River mainstem were compared with simulated Truckee River flow, dissolved-solids, and stream-temperature values.

Previous Investigations

The physical and chemical characteristics of the Truckee River have been modeled by numerous investigators. Rowell (1975) constructed a one-dimensional stream-temperature model for the Truckee River for use in determining minimum streamflow required to maintain acceptable temperatures for fish spawning, specifically Lahonton cutthroat trout, in the lower Truckee River. Buchanan and Strekal (1988) developed a model to simulate the reproductive response of the cui-ui lakesucker to changes in Truckee River streamflow and Pyramid Lake levels. Model parameters included lake level, attraction flow, instream flow/temperature relation, and temperature tolerance of eggs.

A data-collection program was begun by the USGS in 1978 to assess river quality in the Truckee and Carson River Basins (Nowlin and others, 1980; La Camera and others, 1985; Brown and others, 1986). Nowlin (1987) constructed a one-dimensional nutrient and dissolved-oxygen transport model for 56 mi of the Truckee River from just downstream from Reno, Nev., to Pyramid Lake, and for the Truckee Canal. Caupp and others (1997), using parts of the Nowlin (1987) model, developed a steady-state flow model to simulate selected water-quality constituents and properties, including water temperature, dissolved oxygen, and algal dynamics, in the Truckee River from Reno to Pyramid Lake.

Bratberg and others (1982) investigated water-quality changes in the lower Truckee River by examining ground- and surface-water inputs. The impacts of agricultural practices on water quality of the lower Truckee River were investigated by Cockrum and others (1995). Smith (1981) cited relations of Pyramid Lake levels and dissolved solids with various Truckee River streamflows. Lebo and others (1994) constructed a model to predict annual Pyramid Lake levels and dissolved solids.

Acknowledgments

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DESCRIPTION OF THE STUDY AREA

The Truckee River has its headwaters in the Sierra Nevada in California, at altitudes exceeding 10,000 ft above sea level, and generally flows north and eastward into a topographically closed desert lake in Nevada. The headwaters flow into Lake Tahoe—a mountain lake with a surface area of about 192 mi^2 and an average depth of 990 ft. The terminus of the Truckee River is Pyramid Lake, in the Basin and Range Province of western Nevada. Pyramid Lake is an evaporative sink, with about 174 mi^2 of surface area at an altitude of about 3,800 ft. Drainage area for the entire Truckee River Basin is about 3,120 mi^2, but only about 1,430 mi^2 contribute flow to the 114-mi length of the Truckee River between the outlet of Lake Tahoe and Marble Bluff Dam (fig. 1), about 3.5 mi upstream from its mouth at Pyramid Lake (Berris, 1996, p. 7).

Generally, the daily stream-temperature cycle is controlled by streamflow and meteorological factors such as solar radiation, evaporation, and longwave radiation. However, a seasonal cycle of stream temperatures exists in which the coldest stream temperatures and smallest daily temperature fluctuations are during winter months and the warmest stream temperatures and largest daily temperature fluctuations are during the summer months. The daily and seasonal temperature cycles also are affected by altitude. The Truckee River Basin, between the outlet at Lake Tahoe and the Truckee River terminus at Pyramid Lake, has an altitude difference of over 2,000 vertical feet.

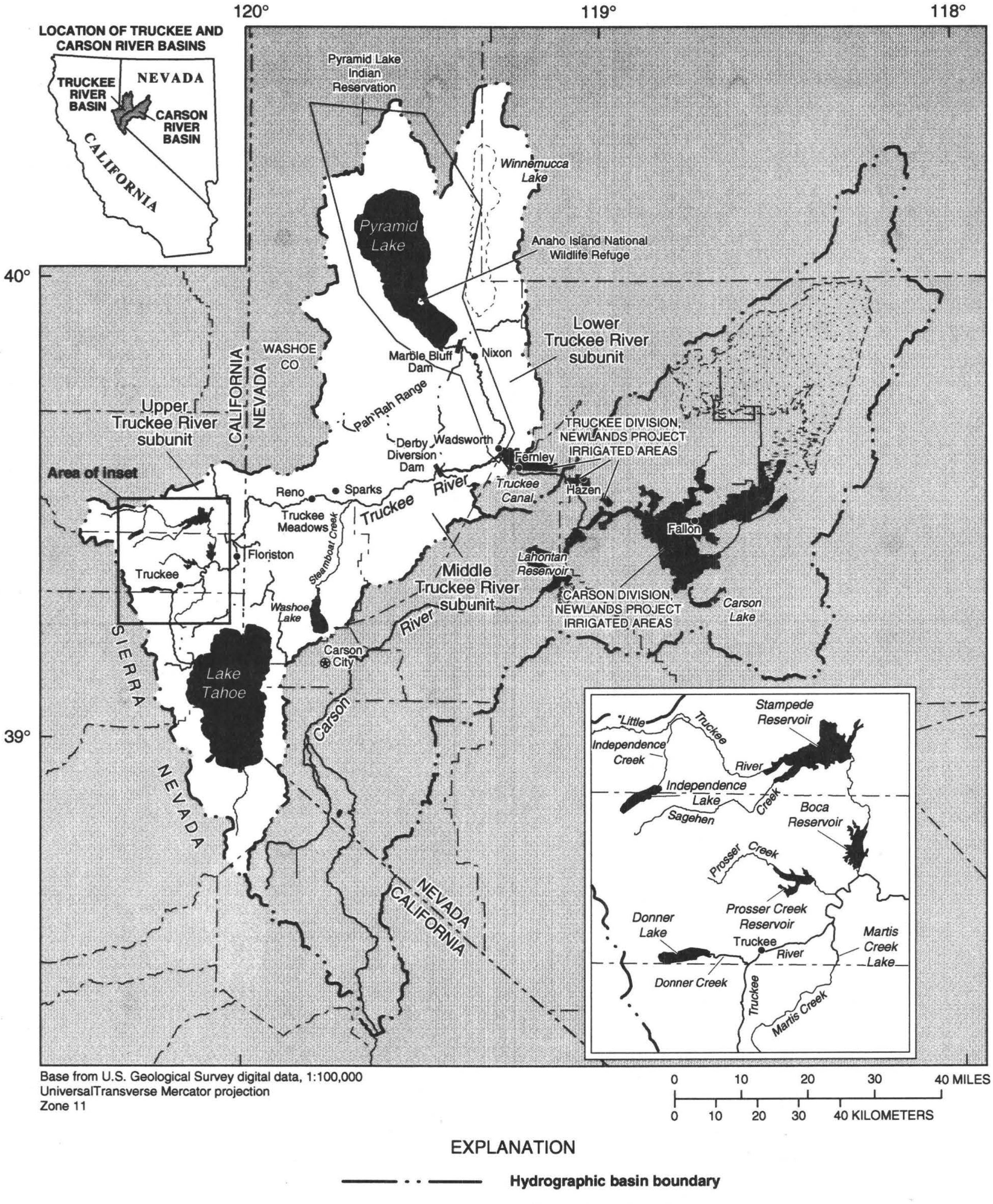

Figure 1. Location of study area, Truckee River Basin, California and Nevada.

Reservoir operations are overlaid on daily and seasonal stream-temperature cycles. Releases from reservoirs increase streamflow and potentially reduce stream temperature. Reservoir releases to the Truckee River prolong spring runoff and increase summer low flows, thus reducing daily stream-temperature fluctuations. Historically, summertime reservoir releases have been for downstream irrigation, so diversions can offset the increased flows in the lower river.

For this study, the Truckee River Basin was divided into three hydrologic subunits, the upper, middle, and lower Truckee River. These subunits are delineated on the basis of similarity in streamflow characteristics, physiography, human activities, and water quality (fig. 1). To maintain consistency with previous work (Brown and others, 1986, p. 10-12), the boundaries of these subunits generally conform to published hydrographic boundaries.

Upper Truckee River Subunit

The upper Truckee River subunit consists of the 426-mi^2 drainage area of the Truckee River between the outlet of Lake Tahoe and the Farad gaging station, near the California-Nevada State line (pl. 1, site 14). The length of the Truckee River within this subunit is 34 mi.

The mountainous upper Truckee River subunit is the coldest and wettest part of the study area. Between 30 and 60 in/yr of precipitation falls in the higher elevations of this subunit—mostly as snow during the winter and early spring months from November through April. The Sierra Nevada causes a distinct rain shadow to the east. Thus, only about 12-16 in/yr of precipitation falls in the drier parts of the subunit at lower elevations near the California-Nevada State line. Vegetation ranges from dense coniferous forests in the wet areas of the subunit to open forests mixed with grasses, sagebrush, and rabbitbrush in the drier areas.

Runoff generated in the upper Truckee River subunit, in addition to Lake Tahoe outflows, supplies most of the water to the Truckee River system. Truckee River flows are heavily dependent on the yearly snowpack characteristics of the Sierra Nevada in this subunit. High flows in the Truckee River either result as a response from snowmelt when temperatures increase in late spring or early summer, or result as a direct response to large, warm rainfalls on large winter snowpacks. In contrast, during late summer and fall after the snowpack has melted, little water enters the Truckee River and extremely low flows commonly result.

In the upper Truckee River subunit, seven reservoirs were constructed to provide flood control and to augment water supply for downstream users during low flows in summer. Three of the seven reservoirs are natural lakes (Lake Tahoe, and Donner and Independence Lakes) with control structures at the outlet. The remaining four reservoirs (Boca, Martis Creek Lake, Prosser Creek, and Stampede Reservoirs) are built on tributary streams. Attempts have been made by resource managers in recent years to use certain reservoirs to control temperatures in the lower river for spawning. Threshold streamflows, called instream flows, are necessary to provide viable habitat for fisheries and wildlife in all of the Truckee River subunits.

Urban and agricultural developments are not extensive in the upper Truckee River subunit and, therefore, have little effect on stream temperature and dissolved solids. Since 1980, effluent from the area around Truckee and from ski resorts upstream from Truckee, in addition to effluent from the north and west sides of Lake Tahoe, has been given tertiary treatment at the Tahoe-Truckee Sanitation Agency water reclamation plant near the Truckee River and the mouth of Martis Creek (pl. 1). Effluent from the plant is discharged into a leach field and sprayed on the ground surface, and is available for percolation to ground water where it may indirectly contribute to flows in Martis Creek and Truckee River after an estimated detention period of 3 to 6 months (Brown and others, 1986, p. 16).

Middle Truckee River Subunit

The middle Truckee River subunit consists of the 744-mi^2 drainage area to the Truckee River between the Farad gaging station and Derby Diversion Dam, hereafter referred to as Derby Dam (pl. 1), a distance of about 46 river miles. Large volumes of Truckee River water are diverted to about 26 diversions in this subunit for power generation, irrigation, and municipal/industrial water supply. The number of diversions is variable because diversion ditches and water intakes may not be in operation from day to day or from year to year.

The Truckee River enters the drier Basin and Range Province of Nevada in the middle Truckee River subunit. Precipitation in this subunit ranges from about 30 to 40 in/yr in the southwestern uplands to less than

8 in/yr in the Truckee Meadows and along the Truckee River corridor east of the Truckee Meadows. The mountainous southwestern part of this subunit receives ample snowfall to provide water to small tributary streams, especially during snowmelt periods from April through June. Flows from these small tributaries, directly as surface water or indirectly through irrigation systems, join the Truckee River upstream from the Vista gaging station (pl. 1, site 45). Downstream from this gaging station, the area that drains to the Truckee River consists mostly of arid terrain, and all tributary streams are ephemeral, providing little water to the Truckee River.

Urban and agricultural land use is extensive throughout the middle Truckee River subunit. The Truckee Meadows is the most populous area of the Truckee River Basin. Urban and suburban developments in this area of rapidly growing population have replaced large areas formerly devoted to agriculture. As a consequence, much of the water previously diverted for agricultural uses is now diverted for municipal and industrial needs. Some ditch systems that previously supplied water to irrigate agricultural areas now carry a part of their flows to municipal water-treatment plants. Agricultural lands, primarily devoted to pasture and alfalfa, are still irrigated in the outlying areas of the Truckee Meadows and along the Truckee River corridor east of the Truckee Meadows.

Water for municipal/industrial use, including drinking water, is taken from the Truckee River at Steamboat Ditch, Highland Ditch, and the Chalk Bluff and Glendale diversions (pl. 1) for delivery to treatment facilities. After municipal/industrial water is distributed and used, the untreated effluent is transported through a sewage collection system to the Truckee Meadows Wastewater Reclamation Facility (TMWRF). The treated effluent is then discharged into Steamboat Creek near its confluence with the Truckee River near Vista, Nev.

Agricultural diversions in the middle Truckee River subunit transport water from the river to agricultural areas. The diverted water flows through a complex pattern of lateral ditches and fields. Excess water not infiltrated to deep ground water or consumed by evapotranspiration may return to the river. This water can return indirectly through drains or ditches at discreet locations. The excess water also may run off the surface of a field at several locations or it may infiltrate to shallow ground water that subsequently may discharge directly along the river. If diverted water is never applied to fields, the water may return directly to the river through that same ditch or indirectly through tributaries of the river.

Although agricultural returns may enter the river at several locations in the Truckee Meadows, the primary agricultural returns enter the Truckee River through North Truckee Drain from the north and Steamboat Creek from the south. These two major tributaries also intercept urban runoff that does not otherwise enter the river from upstream storm drains. Steamboat Creek also receives runoff from tributary streams, such as Galena, Whites, and Thomas Creeks (pl. 1), with headwaters in the high mountains southwest of the Truckee Meadows. At Derby Dam, the downstream boundary of the middle Truckee River subunit, large volumes of water are diverted to the Truckee Canal. This water is diverted for delivery to irrigators along the canal and in the Carson River Basin near Fallon, Nev., as part of the Newlands Project (fig. 1, pl. 1). During a 20-year period (1973-92, which includes some drought years), about 32 percent of the mean annual streamflow was diverted from the Truckee River. In dry years, however, higher percentages of flow are often diverted; for example, in 1992, 88 percent of the annual streamflow was diverted (Berris, 1996, p. 10).

Water is diverted to a thermal powerplant for cooling purposes at Tracy, Nev. (pl. 1), between the Vista gaging station and Derby Dam. This powerplant is maintained such that no wastewater is discharged directly into the Truckee River. Some water from the circulating system is discharged to an unlined 220 acre/ft cooling pond adjacent to the river. Also, some water from the boiler system is discharged to an 18 acre/ft evaporation pond lined with an impervious synthetic liner (U.S. Department of Energy, 1994, p. 3-24). Thermal loading to the Truckee River, if any exists, is probably too small to be seen at the scale of the temperature model presented in this report.

The major source of heat to water in the middle Truckee River subunit is solar radiation. However, some thermal ground-water inflows impact the temperature regime in localized areas.

Lower Truckee River Subunit

The lower Truckee River subunit consists of the 261-mi^2 drainage area of the Truckee River between Derby Dam and Marble Bluff Dam (about 3.5 mi upstream from Pyramid Lake; pl. 1). The distance of this subunit of the Truckee River is about 34 river miles. Downstream from Marble Bluff Dam, the Truckee River enters Pyramid Lake across a broad delta. The interface of the delta and lake shoreline has shifted several miles during this century because of declining lake levels. Because of this shifting, Marble Bluff Dam was chosen as the downstream boundary of this subunit to provide a stable reference point for modeling and measurements.

In the lower Truckee River subunit, the Truckee River flows through arid desert terrain. Annual precipitation in this subunit ranges from about 16 in/yr in the northwest along the crest of the Pah Rah Range (fig. 1) to less than 8 in/yr along the Truckee River corridor. As a result of the arid climate, tributaries of the Truckee River are ephemeral, providing little water to the river. Therefore, when large amounts of water are diverted to the Truckee Canal nflow from the middle Truckee River subunit, the lower Truckee River subunit flow is reduced substantially. Additional inflows to the lower subunit are mostly from two major spillways from the Truckee Canal and ground-water discharge. Ground-water inflow can be as direct seepage from the Truckee Canal; as irrigation water from the canal, which has percolated to shallow ground water; or as natural springs and seeps, some of which are thermal.

Water is diverted from the river at 10 locations, including the Pyramid Lake Indian Reservation, to irrigate land along the river corridor in this subunit. However, no power generation or municipal/industrial interests require water diversions. Irrigation water may return to the river as surface-water inflows through ditches, return drains, and along fields adjacent to the river and as shallow ground-water discharge. For example, Cockrum and others (1995, p. 27) estimated that about 14 percent of total diversion to Herman Ditch, in the lower subunit, was returned to the Truckee River as surface return flow and about 27 percent was returned as subsurface return flow.

Lower Truckee River water also is used for maintaining flows for spawning of an endangered fish species, the cui-ui lakesucker, and a threatened species, the Lahontan cutthroat trout. These fish are important to the culture and economy of the Pyramid Lake Indian Reservation. Decreased flows in the Truckee River downstream from Derby Dam have caused a decline of Pyramid Lake levels and the formation of a broad, shallow river delta at Pyramid Lake. As a result of these changes in lake level, migration of both species of fish up the Truckee River to spawn is limited in dry years. In addition, decreased flows and shallow river conditions can cause stream-temperature regimes unfavorable to spawning, egg incubation, and post-emergent survival (Hoffman and Scoppettone, 1988, p. 9-12; U.S. Fish and Wildlife Service, 1992, p. 7).

Reestablishing the cui-ui lakesucker and Lahontan cutthroat trout migrations is dependent on more than just the quantity of Truckee River flows. Several interactive physical and chemical characteristics of the river—such as volume, timing, and temperature of flows during the spawning season, affect the productivity and viability of these fish.

CONSTRUCTION OF THE HOURLY STREAM-TEMPERATURE AND DAILY DISSOLVED-SOLIDS MODELS

Models built within the HSPF framework are put together in a modular fashion. Modeling a drainage network begins with flow routing as the foundation module. See Berris (1996, p. 12) for detailed information on the construction of the Truckee River flow-routing model. More complex models can be built by using water-quality modules with the flow-routing module. Temperature is a fundamental water-quality characteristic that affects many water-quality processes. Therefore, temperature is a logical first step in modeling water quality. Dissolved solids is a fundamental water-quality constituent, which is important in the Truckee River system because the terminus at Pyramid Lake is an evaporative sink. The stream-temperature and dissolved-solids models described in this report are examples of the framework concept. The following sections describe how HSPF simulates streamflow, stream temperatures, and dissolved solids; selection of model calibration and validation periods; and the data used for simulation of streamflow, stream temperatures, and dissolved solids.

Description of the HSPF Computer Program

HSPF is a set of computer codes that can simulate the hydrologic and associated water-quality processes on pervious and impervious land surfaces, within the soil profile, and in drainage networks including well mixed lakes and reservoirs (Bicknell and others, 1997). HSPF separates operations for each simulation into "blocks." Only one block, the reach reservoir (RCHRES), is used to simulate streamflow, stream temperature, and dissolved solids for the Truckee River models. Three utility blocks, EXTERNAL SOURCES, NETWORK, and EXTERNAL TARGETS, are used to transfer time-series data from the data base to the model, within the model, and back out to the data base.

The use of HSPF requires the stream system (river channels, lakes, reservoirs, wetlands, drainage ditches, and pipes) be divided into segments called reaches. General assumptions are made to use HSPF: Reaches have uniform hydraulic properties, reaches conserve mass and energy, constituents are uniformly mixed throughout a reach, each constituent in a reach moves at the same horizontal velocity as the flow (no diffusion), and flow through a reach is unidirectional (no dispersion).

In HSPF, water leaves a reach through at least one of five outlet gates or through evaporation. Typically, one of these outlet gates is defined at the downstream boundary of a channel reach. Water through this outlet gate becomes channel inflow to the upstream boundary of the adjacent downstream reach. Outlet gates also allow diversion or loss of water from a reach to ditches, canals, or ground water. HSPF is capable of producing simulation results at all locations where reach outlets exist.

The 114-mile length of the Truckee River between the outlet of Lake Tahoe and Marble Bluff Dam was divided into 45 reaches (pl. 1). Two additional reaches were designated on tributaries, Donner Creek and Martis Creek, for a total of 47 reaches (fig. 2, pl. 1). Reaches were numbered between 100 and 600 to allow numbering of other tributary reaches needed for other components of the modeling framework. Links between reaches and the inflows and outflows to each of the 47 reaches are diagrammed in figure 2 and listed in table 1. All 47 reaches were used for the stream-temperature model. But only reaches 180 through 570 were used to simulate the dissolved-solids model, because the above Prosser Creek gaging station was the most upstream station with hourly data available for estimating dissolved solids in the mainstem. Starting the dissolved-solids model near the outlet from Lake Tahoe would have required estimating all dissolved-solids inputs for the first nine reaches.

Stream-Temperature Module

HSPF can simulate stream-water temperature over a long period of time by numerically representing heat fluxes across reach boundaries and calculating changes in heat content. By assuming no significant heat sources or sinks are within a reach, change in heat content is the sum of all heat inputs minus the sum of all heat outputs for a reach. Heat inputs to a reach include water inflow from the adjacent upstream reach, tributaries and ground water, absorption and conduction from the atmosphere, and conduction from the streambed. Heat outputs from a reach include water losses through outflow gates (the next downstream reach, diversions, or ground water), losses to the atmosphere, and conduction to the streambed. Initial temperatures for water and air are provided to HSPF by the user.

The subroutine HTRCH in RCHRES accounts for inputs and outputs of heat in a reach through three major heat-transfer processes: (1) heat transfer by advection within the stream; (2) heat transfer across the air-water interface; and (3) heat transfer across the streambed-stream water interface. Diffusion and dispersion processes are not considered. Following are descriptions of these heat-transfer processes and model parameters used to adjust them. Bicknell and others (1997) includes more detailed descriptions of HSPF heat transfer processes including the algorithms used.

Advection of heat in a reach is simulated by the subroutine ADVECT in RCHRES. Water temperature is considered as a thermal concentration (heat per unit volume) which is assumed completely mixed throughout a reach and to travel at the same horizontal velocity as the water. ADVECT computes the heat leaving a reach through defined outflow gates and the heat remaining in a reach for each time step. The heat remaining is simply computed by the difference of inflow heat and outflow heat, over the time step. Total outflow of heat is a weighted mean of two estimates based on outflow conditions, one at the beginning and the other at the end of the time step. Weighting factors and how they are determined are explained in the HSPF users documentation (Bicknell and others, 1997). Inflow heat is derived from inflow stream temperatures that may either be simulated in HSPF or provided to HSPF by external time series. If an inflow does not have a corresponding stream-temperature time series, HSPF assigns temperatures of 0.0°C to that water. Therefore, all inflows are assigned temperature values.

Transfer of heat across the air-water interface is a function of meteorological inputs and stream temperature in a reach. HSPF requires five external time series of meteorological data: shortwave solar radiation in langleys per time interval, cloud cover expressed as

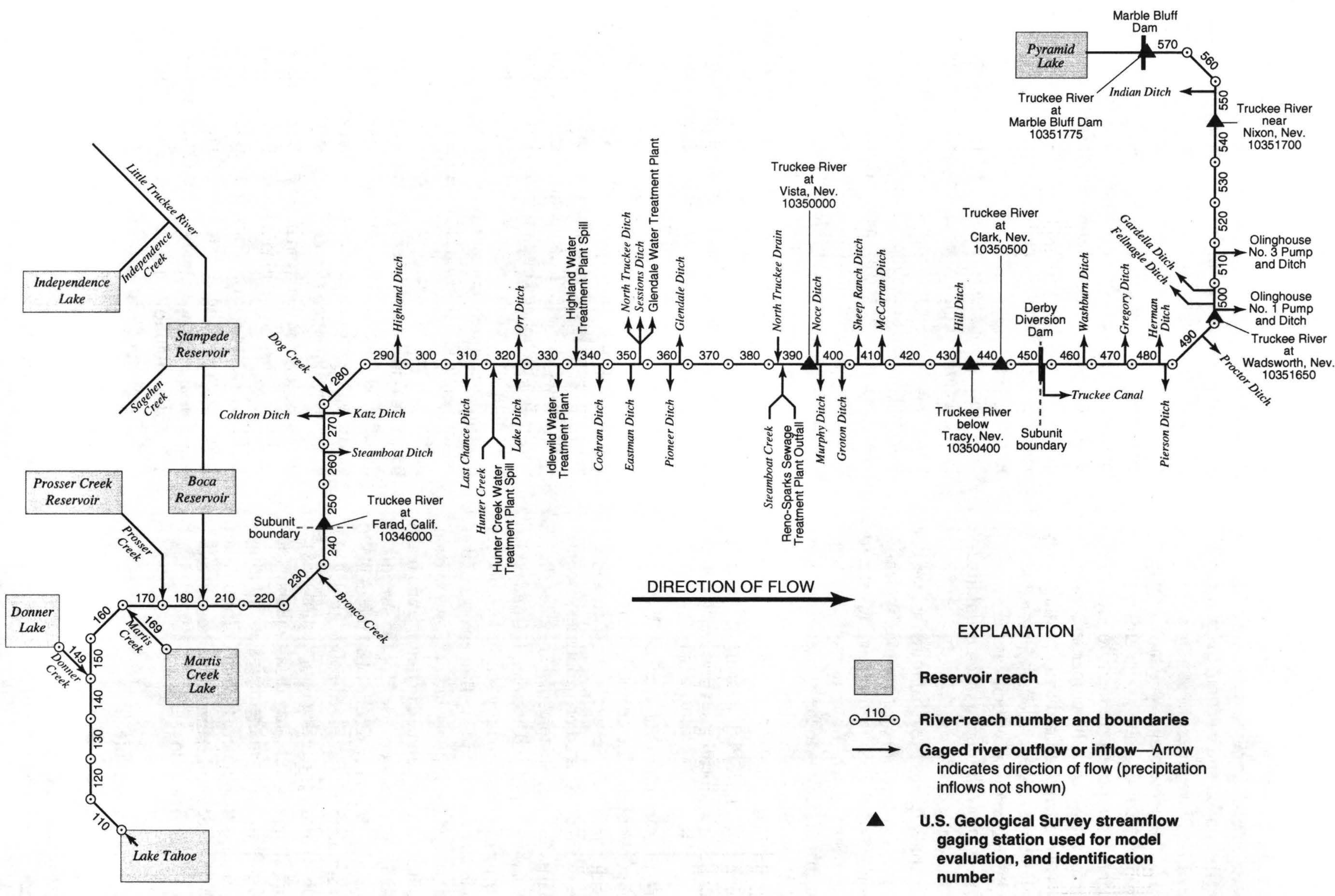

Figure 2. Schematic diagram of river reaches, gaged outflows, and gaged inflows for the Truckee River models.

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models

[Abbreviations: C, specific conductance; F, streamflow; T, stream temperature; M&I, municipal and industrial; -- data not needed for model simulation]

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
110	inflow	Lake Tahoe outflow	measured	measured	--	Truckee River at Tahoe City, Calif., 10337500 (F,T).
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 120	simulated	simulated	--	
120	inflow	inflow from reach 110	simulated	simulated	--	
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 130	simulated	simulated	--	
130	inflow	inflow from reach 120	simulated	simulated	--	
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 140	simulated	simulated	--	
140	inflow	inflow from reach 130	simulated	simulated	--	
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 150	simulated	simulated	--	
149	inflow	Donner Creek at Highway 89 flow	measured	measured	--	Donner Creek at Highway 89 near Truckee, Calif., 10338700 (F,T).
	outflow	outflow to reach 150	simulated	simulated	--	
150	inflow	inflow from reaches 140 and 149	simulated	simulated	--	
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 160	simulated	simulated	--	
160	inflow	inflow from reach 150	simulated	simulated	--	
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 170	simulated	simulated	--	
169	inflow	Lake outflow	measured	measured	--	Martis Creek near Truckee, Calif., 10339400 (F,T).
	inflow	ungaged inflows	estimated	estimated	--	
	outflow	outflow to reach 170	simulated	simulated	--	
170	inflow	inflow from reaches160 and 169	simulated	simulated	--	
	inflow	inflow to TDS model	measured	measured	measured	Truckee River above Prosser Creek near Truckee, Calif., 10339419 (C,F,T).
	inflow	ungaged inflows	estimated	estimated	estimated	
	outflow	outflow to reach 180	simulated	simulated	simulated	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
180	inflow...	inflow from reach 170	simulated	simulated	simulated	
	inflow...	Prosser Creek Reservoir outflow	measured	measured	estimated	Prosser Creek below Prosser Creek Dam near Truckee, Calif., 10340500 (F,T).
	inflow...	ungaged inflows	estimated	estimated	estimated	
	outflow..	outflow to reach 210.	simulated	simulated	simulated	
210	inflow...	inflow from reach 180	simulated	simulated	simulated	
	inflow...	Boca Reservoir outflow	measured	measured	estimated	Little Truckee River below Boca Dam near Truckee, Calif., 10344500 (F,T).
	inflow...	ungaged inflows	estimated	estimated	estimated	
	outflow..	outflow to reach 220.	simulated	simulated	simulated	
220	inflow...	inflow from reach 210	simulated	simulated	simulated	
	inflow...	ungaged inflows	estimated	estimated	estimated	
	outflow..	outflow to reach 230.	simulated	simulated	simulated	
230	inflow...	inflow from reach 220	simulated	simulated	simulated	
	inflow...	inflow from Bronco Creek	measured	measured	estimated	Bronco Creek at Floriston, Calif., 10345700 (F,T).
	inflow...	ungaged inflows	estimated	estimated	estimated	
	outflow..	outflow to reach 240.	simulated	simulated	simulated	
240	inflow...	inflow from reach 230	simulated	simulated	simulated	
	inflow...	ungaged inflows	estimated	estimated	estimated	
	outflow..	outflow to reach 250.	simulated	simulated	simulated	Truckee River at Farad, Calif., 10346000 (C,F,T).
250	inflow...	inflow from reach 240	simulated	simulated	simulated	
	outflow..	outflow to reach 260.	simulated	simulated	simulated	
260	inflow...	inflow from reach 250	simulated	simulated	simulated	
	outflow..	diversion to Steamboat Ditch (returns measured at Steamboat Creek at Cleanwater Way near Reno, Nev.).	measured	--	--	Steamboat Ditch near Floriston, Calif. (F).
	outflow..	outflow to reach 270.	simulated	simulated	simulated	
270	inflow...	inflow from reach 260	simulated	simulated	simulated	
	outflow..	net diversion to Coldron Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Coldron Ditch at Verdi, Nev., 10347390 (F).
	outflow..	net diversion to Katz Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Katz Ditch at Verdi, Nev., 10347331 (F).
	outflow..	outflow to reach 280.	simulated	simulated	simulated	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
280	inflow...	inflow from reach 270	simulated	simulated	simulated	
	inflow...	inflow from Dog Creek	measured	measured	estimated	Dog Creek near Verdi, Nev., 10347310 (F,T).
	outflow..	outflow to reach 290.	simulated	simulated	simulated	
290	inflow...	inflow from reach 280	simulated	simulated	simulated	
	outflow..	partial net diversion to Highland Ditch (estimated spills and returns subtracted from gross diversion and some returns measured at Highland Plant Spill to Washington Street Drain).	measured and partially estimated.	--	--	Highland Ditch at Reno, Nev., 10347420 (F).
	outflow..	outflow to reach 300.	simulated	simulated	simulated	
300	inflow...	inflow from reach 290	simulated	simulated	simulated	
	outflow..	outflow to reach 310.	simulated	simulated	simulated	
310	inflow...	inflow from reach 300	simulated	simulated	simulated	
	outflow..	diversion to Last Chance Ditch (returns measured at Steamboat Creek at Cleanwater Way near Reno, Nev.).	measured	--	--	Last Chance Ditch at Hunter Creek near Reno, Nev., 10349740 (F).
	outflow..	outflow to reach 320.	simulated	simulated	simulated	
320	inflow...	inflow from reach 310	simulated	simulated	simulated	
	inflow...	inflow from Hunter Creek	measured and partially estimated.	Hunter Creek measured.	estimated.	Hunter Creek above Last Chance Ditch near Reno, Nev., 10347620 (F,T).
				Treatment plant spill estimated from Hunter Creek.		Hunter Creek Water Treatment Plant Spill (F).
	outflow..	diversion to Lake Ditch (returns measured at Steamboat Creek at Cleanwater Way near Reno, Nev.).	measured	--	--	Lake Ditch at Mayberry Drive near Reno, Nev., 10349810 (F).
	outflow..	diversion to Orr Ditch (returns measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.	measured	--	--	Orr Ditch near Reno, Nev., 10348210 (F).
	outflow..	outflow to reach 330.	simulated	simulated	simulated	
330	inflow...	inflow from reach 320	simulated	simulated	simulated	
	outflow..	diversion to Idlewild Water Plant.	measured	--	--	Idlewild Water Treatment Plant Delivery to M&I System (F).
	outflow..	outflow to reach 340.	simulated	simulated	simulated	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
340	inflow...	inflow from reach 330	simulated	simulated	simulated	
	inflow...	inflow from Highland Water Treatment Plant spill (receives some return water from Highland Ditch).	measured	estimated	estimated	Highland Plant Spill to Washington Street Drain (F).
	outflow..	diversion to Cochran Ditch (returns measured at Steamboat Creek at Cleanwater Way near Reno, Nev.).	measured	--	--	Cochran Ditch at Reno, Nev., 10349938 (F).
	outflow..	outflow to reach 350.	simulated	simulated	simulated	
350	inflow...	inflow from reach 340	simulated	simulated	simulated	
	outflow..	diversion to Eastman Ditch	measured.	--	--	Eastman Ditch at Reno, Nev., 10349974 (F).
	outflow..	diversion to North Truckee Ditch (returns measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.).	measured and partially estimated.	--	--	North Truckee Ditch at Reno, Nev., 10348270 (F).
	outflow..	partial net diversion to Sessions Ditch (estimated spills subtracted from gross diversion and some returns measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.).	measured and partially estimated.	--	--	Sessions Ditch near Reno, Nev., 10348150 (F).
	outflow..	diversion to Glendale Water Treatment Plant.	measured	--	--	Glendale Water Treatment Plant Delivery to M&I System, 10348034 (F).
	outflow..	outflow to reach 360.	simulated	simulated	simulated	
360	inflow...	inflow from reach 350	simulated	simulated	simulated	
	outflow..	diversion to Pioneer Ditch (estimated returns delivered to reach 390).	measured.	--	--	Pioneer Ditch at Reno, Nev., 10349971 (F).
	outflow..	diversion to Glendale Ditch (returns measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.).	measured and partially estimated.	--	--	Glendale Ditch near Sparks, Nev., 10348310 (F).
	outflow..	outflow to reach 370.	simulated	simulated	simulated	
370	inflow...	inflow from reach 360	simulated	simulated	simulated	
	outflow..	outflow to reach 380.	simulated	simulated	simulated	
380	inflow...	inflow from reach 370	simulated	simulated	simulated	
	outflow..	outflow to reach 390.	simulated	simulated	simulated	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
390	inflow. . .	inflow from reach 380	simulated	simulated	simulated	
	inflow. . .	estimated return from Pioneer Ditch . .	estimated	estimated	estimated	
	inflow. . .	inflow from North Truckee Drain (receives some return water from Orr Ditch, North Truckee Ditch, Sessions Ditch, and Glendale Ditch).	measured..	measured	measured	North Truckee Drain at Kleppe Drain near Sparks, Nev., 10348300 (C,F,T).
	inflow. . .	inflow from Steamboat Creek (receives some return water from Steamboat Ditch, Last Chance Ditch, Lake Ditch, and Cochran Ditch).	measured..	measured	measured	Steamboat Creek at Cleanwater Way near Reno, Nev., 10349980 (C,F,T).
	inflow. . .	inflow from Truckee Meadows Water Reclamation Facility) (receives M&I system returns from water treated at Hunter Creek, Highland, Idlewild, and Glendale Water Treatment Plants).	measured	measured	measured	Truckee Meadows Water Reclamation Facility Outfall at Reno, Nev., 10349995 (C,F,T).
	outflow. .	outflow to reach 400.	simulated	simulated	simulated	Truckee River at Vista, Nev., 10350000 (F,T).
400	inflow. . .	inflow from reach 390	simulated	simulated	simulated	
	outflow. .	net diversion to Noce Ditch (estimated spills and returns subtracted from gross diversion.	measured and partially estimated.	--	--	Noce Ditch near Vista, Nev., 10350048 (F).
	outflow. .	net diversion to Murphy Ditch (estimated and measured spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Murphy Ditch near Vista, Nev., 10350150 (F).
	outflow. .	net diversion to Groton Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Groton Ditch at Lockwood, Nev., 10350130 (F).
	outflow. .	outflow to reach 410.	simulated	simulated	simulated	
410	inflow. . .	inflow from reach 400	simulated	simulated	simulated	
	outflow. .	net diversion to Sheep Ranch Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Sheep Ranch Ditch near Lockwood, Nev., 10350140 (F).
	outflow. .	net diversion to McCarran Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	McCarran Ditch near Patrick, Nev., 10350320 (F).
	outflow. .	outflow to reach 420.	simulated	simulated	simulated	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
420	inflow...	inflow from reach 410	simulated.......	simulated.......	simulated.......	
	outflow..	outflow to reach 430..............	simulated.......	simulated.......	simulated.......	
430	inflow...	inflow from reach 420	simulated.......	simulated.......	simulated.......	
	outflow..	net diversion to Hill Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Hill Ditch opposite Tracy Powerplant at Tracy, Nev., 10350475 (F)
	outflow..	outflow to reach 440..............	simulated.......	simulated.......	simulated.......	Truckee River below Tracy, Nev., 10350400 (F,T).
440	inflow...	inflow from reach 430	simulated.......	simulated.......	simulated.......	
	outflow..	outflow to reach 450	simulated.......	simulated.......	simulated.......	Truckee River at Clark, Nev., 10350500 (C,T).
450	inflow...	inflow from reach 440	simulated.......	simulated.......	simulated.......	
	outflow..	diversion to Truckee Canal	estimated.......	--	--	Truckee River below Tracy, Nev., 10350400 (F,T). Truckee River below Derby Dam near Wadsworth, Nev., 10351600 (F,T).
	outflow..	outflow to reach 460..............	simulated.......	simulated.......	simulated.......	
460	inflow...	inflow from reach 450	simulated.......	simulated.......	simulated.......	Truckee River below Derby Dam near Wadsworth, Nev., 10351600 (F,T).
	outflow..	net diversion to Washburn Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Washburn Ditch at Orchard, Nev., 10351615 (F).
	outflow..	outflow to reach 470..............	simulated.......	simulated.......	simulated.......	
470	inflow...	inflow from reach 460	simulated.......	simulated.......	simulated.......	
	outflow..	net diversion to Gregory Ditch (estimated and measured spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Gregory Ditch near Wadsworth, Nev. (F).
	outflow..	outflow to reach 480..............	simulated.......	simulated.......	simulated.......	
480	inflow...	inflow from reach 470	simulated.......	simulated.......	simulated.......	
	outflow..	net diversion to Herman Ditch (estimated and measured spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Herman Ditch near Wadsworth, Nev., 10351635 (F).
	outflow..	net diversion to Pierson Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Pierson Ditch at I-80 Bridge at Wadsworth, Nev., 10351630 (F).
	outflow..	outflow to reach 490..............	simulated.......	simulated.......	simulated.......	

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
490	inflow...	inflow from reach 480	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	net diversion to Proctor Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Proctor Ditch at Wadsworth, Nev., 10351668 (F).
	outflow..	outflow to reach 500.	simulated	simulated	simulated	
500	inflow...	inflow from reach 490	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	net diversion at Olinghouse no. 1 Pump (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Olinghouse no. 1 Pump near Wadsworth, Nev. (F).
	outflow..	net diversion to Fellnagle Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Fellnagle Ditch near Wadsworth, Nev., 10351660 (F).
	outflow..	net diversion to Gardella Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Gardella Ditch near Wadsworth, Nev., 10351682 (F).
	outflow..	outflow to reach 510.	simulated	simulated	simulated	
510	inflow...	inflow from reach 500	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	net diversion at Olinghouse no. 3 Pump (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Olinghouse no. 3 Pump near Wadsworth, Nev. (F).
	outflow..	outflow to reach 520.	simulated	simulated	simulated	
520	inflow...	inflow from reach 510	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	outflow to reach 530.	simulated	simulated	simulated	
530	inflow...	inflow from reach 520	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	outflow to reach 540.	simulated	simulated	simulated	
540	inflow...	inflow from reach 530	simulated	simulated	simulated	
	inflow...	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow..	outflow to reach 550.	simulated	simulated	simulated	Truckee River near Nixon, Nev., 10351700 (C,F,T).

Table 1. River reaches, streamflow routes, and types of data used in Truckee River models—Continued

Reach	Inflow or outflow	Description of streamflow routing	Type of streamflow data	Type of stream-temperature data	Type of specific conductance data	Measurement gage, station no. (C, F, T)
550	inflow	inflow from reach 540	simulated	simulated	simulated	
	inflow	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow	net diversion to Indian Ditch (estimated spills and returns subtracted from gross diversion).	measured and partially estimated.	--	--	Indian Ditch near Nixon, Nev., 10351755 (F).
	outflow	outflow to reach 560	simulated	simulated	simulated	
560	inflow	inflow from reach 550	simulated	simulated	simulated	
	inflow	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow	outflow to reach 570	simulated	simulated	simulated	
570	inflow	inflow from reach 560	simulated	simulated	simulated	
	inflow	ungaged ground-water inflow	estimated	estimated	estimated	
	outflow	outflow to Pyramid Lake	simulated	simulated	simulated	Truckee River at Marble Bluff Dam, Nev., 10351775 (T).

tenths of the sky, air temperature in degrees Celsius, dewpoint temperature in degrees Celsius, and windspeed in meters per time interval. HSPF also needs the elevation differences between air temperature monitors and mean reach elevations because air temperature is corrected internally by HSPF using standard lapse rates. The lapse rate used depends on whether or not precipitation occurs during the time interval (Bicknell and others, 1997). Net transfer of heat across the air-water interface is the sum of several processes evaluated individually by HSPF. These processes are absorption of shortwave solar radiation, absorption or emission of longwave radiation, loss by evaporation, and gain or loss by conduction/convection.

Shortwave solar radiation is absorbed directly by stream water resulting in an increase in heat content within a stream reach. Solar radiation can be measured at the earth's surface with a pyranometer. Where solar radiation measurements are not available they are estimated. HSPF assumes that 3 percent of incoming solar radiation is reflected by water and 97 percent is absorbed (solar radiation x 0.97). The amount of direct solar radiation reaching the water surface can be further adjusted using the model parameter CFSAEX. CFSAEX can be used to help account for streamside shading.

Longwave radiation is emitted by any surface (including water and the earth's atmosphere) with a temperature greater than 0° Kelvin (-273°C, absolute zero). Water can gain heat from or lose heat to the atmosphere by longwave radiation. Exchange of heat across the air-water interface by longwave radiation is assumed to be proportional to the difference between the water and air temperatures by HSPF. The heat-transfer coefficient KATRAD is for atmospheric longwave radiation. KATRAD can be changed by the user to adjust longwave radiation simulated.

Evaporation represents a heat loss from the water surface which is proportional to the amount of water evaporated and the latent heat of vaporization. The amount of water evaporated is proportional to the difference between the saturation vapor pressure at the water surface and the vapor pressure in the air above the water surface (calculated using the dewpoint temperature), and the windspeed. The amount of water evaporated is inversely proportional to the evaporation coefficient KEVAP. KEVAP is user defined and can be used to adjust the amount of evaporation simulated.

Heat transfer through conduction/convection is caused by a temperature difference between air and water. Conductive/convective heat transfer at the air-water interface is assumed, in HSPF, to be proportional to the air and water temperature difference, the windspeed, and an atmospheric pressure correction factor dependent on elevation. Conductive/convective heat transport is assumed to be inversely proportional to the conduction/convection heat transfer coefficient KCOND. KCOND is user defined and can be used to adjust conductive/convective heat transfer. In HSPF, a positive value for conductive/convective heat transfer indicates heat is transferring from the water to the air.

Streambed heat conductance is optional in HSPF and is turned on or off with the model flag BEDFLG. The algorithm used in this report is based on a model developed for the Truckee River by Caupp and others (1997, p. 23-24). This algorithm uses a three layer system—a water layer, a streambed layer (also termed "mud layer" in the HSPF documentation; Bicknell and others, 1997), and a ground layer.

Temperature gradients at the ground-streambed interface and the streambed-stream water interface drive the transfer of heat between the streambed and stream water. To calculate these temperature differences HSPF must have the temperatures of the ground below the streambed, the streambed, and the water. Temperature of the ground is provided by the user as the HSPF parameter TGRND and can be input as a single annual value or as monthly values. Temperatures of the streambed and water are calculated by the model at each time step for a reach. The streambed temperature is initially calculated for the center of the current time step using the streambed temperature at the end of the previous time step and the change in streambed temperature over the previous time step (slope of the streambed temperature curve). The change in streambed temperature over a time step is assumed to be linear. The ground, streambed, and water temperatures are used to calculate the heat transfers between the ground and streambed and between the streambed and water. These heat transfers are controlled within the model by the user defined HSPF model parameters KGRND and KMUD. The results of these heat transfers are then used to update streambed and stream-water temperatures at the end of the current time step.

Stream-water temperature in a reach at the end of a time step is calculated from the net heat exchange across all reach boundaries (including upstream/downstream, air/water, and water/streambed); a factor to convert total heat to temperature; and a sum consisting of partial derivatives, with respect to water temperature, of the heat exchange terms which depend on water temperature. Heat exchange calculations become unrealistic when the stream becomes very shallow. Therefore, heat transfer calculations are not made when the simulated average water depth is less than 2 in. Under these conditions, water temperature is set equal to air temperature (Bicknell and others, 1997).

Dissolved-Solids Module

Dissolved solids principally is a measure of the inorganic material dissolved in water. Most of this material is composed of eight major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, and Cl^{-}). These inorganic ions are assumed by the model to be conservative with respect to physical and biochemical transformations, that is, mass is conserved within a reach. In HSPF, the only way a conservative constituent can be lost from a reach is through active outflow gates. A conservative constituent is assumed to be completely mixed throughout the reach and to move at the same horizontal velocity as the water. Following is a brief description of the way in which HSPF moves conservative constituents through a stream system. Bicknell and others (1997) includes a more detailed description including the algorithms used.

Movement of conservative constituents is continuously simulated in HSPF by numerically representing the flow of material into and out of each reach. Mass balance of material is checked, so that the change in mass of material within a reach at the end of a time step is equal to the difference of the inflow mass and the outflow mass during that time step. Input dissolved-solids data can be simulated by HSPF or provided as external data sets. If an inflow does not have a corresponding dissolved-solids concentration, HSPF sets the concentration to zero, which is why all inflows are assigned values. The two HSPF subroutines used to route a conservative constituent are CONS and ADVECT.

Input data are passed to CONS either as simulation results or as external time series. CONS then converts the input data to internal units, calls the subroutine ADVECT, and finally calculates the mass of constituent left in the reach after advection. The subroutine ADVECT simulates movement of a conservative constituent through a reach in the same manner as previously described for the stream-temperature module.

Selection of Calibration and Validation Periods

Model calibration provides a means to adjust model parameter values, so that model outputs are as close as possible to observed data. Model validation provides a check on how well the model works under a set of conditions other than those in the calibration period. June 1, 1993, through May 31, 1994, is the calibration period for the hourly stream-temperature model. The beginning date was chosen to balance between existing data and missing data. The end date was chosen to have a calibration period of 1 year. The validation period is from June 1 through September 30, 1994.

The dissolved-solids model does not have any calibration parameters. The only adjustments possible are in the estimates of ungaged input data and the estimates of dissolved solids from measurements of specific conductance. When more than one method was applied to estimate input data, those estimated data that gave the best result were used. The dissolved-solids model was constructed and the results checked using data collected during the 1995 water year[1].

Input Data for Flow-Routing, Stream-Temperature, and Dissolved-Solids Models

The Truckee River stream-temperature and dissolved-solids models require all of the hydraulic and streamflow data necessary to route streamflow via the flow-routing module. In addition, these models require stream-temperature and meteorological input data for the temperature module and dissolved-solids input data for the dissolved-solids module. For a detailed discussion of the hydraulic and streamflow data used to construct the flow-routing model see Berris (1996).

The hydraulic data used by the flow-routing module of the temperature and dissolved-solids models are the same as those described by Berris (1996). However, a slight change in streamflow input data was made with the addition of three streamflow gaging stations.

Data collected at established gaging stations were used, when possible, for input to the model. However, because HSPF requires complete time series at the specified time step, intermittent or missing data from

[1]A water year is the 12-month period October 1 through September 30 and is designated by the calendar year in which it ends.

continuous collection stations had to be estimated. Observed data are collected by field personnel or recorded by in-place instruments. Estimated data are derived by mathematical, statistical, graphical, or other means to fill gaps in the record of observed data. Only data necessary for model input were estimated. Model evaluation used only observed data.

Observed Data

Streamflow, stream-temperature, meteorological, and specific-conductance data for the Truckee River stream-temperature and dissolved-solids models were collected at stations listed in table 2 and shown on plate 1. Measurements were made at time intervals of 1 hour or less. Instantaneous measurements of streamflow, stream temperature, and specific conductance made at time intervals less than 1 hour were aggregated to an hour time interval by calculating the mean of all values collected in a particular hour and assigning that value to the beginning of the hour. The observed data were used for estimating missing data, model simulation, and model evaluation.

Streamflow

Simulation of Truckee River streamflow requires input time series of flow data that describe inflow to and diversions from the river. The input time series usually consist of flow records from gaging stations. Three general types of gaging stations are used for the production of flow records—continuous-recording stage gaging stations, continuous-recording flowmeters, and manual observation of staff gages.

Inflows to and diversions from the Truckee River are gaged by several agencies. Gaged inflows generally are major tributaries, but occasionally agricultural and municipal returns are gaged. Most tributary gaging stations are operated by the USGS (U.S. Geological Survey, 1994-96), but the U.S. Army Corps of Engineers, Westpac Utilities, and the U.S. District Court Water Master also operate or have operated gaging stations on some tributaries. These gaging stations generally record continuously.

Gaged diversions include most irrigation ditches, the Truckee Canal, and diversions to water treatment plants. Most gaging stations on irrigation ditches are operated and maintained by the Federal Water Master. These gaging stations consist of continuously recording gages and nonrecording staff gages.

Agricultural users commonly return unused diverted irrigation water to the Truckee River, but only a few of these returns are gaged. Beginning in about 1985, the Federal Water Master has operated and maintained gages on some of these returns. In general, these are nonrecording staff gages. Two major point sources of agricultural return water are continuously gaged—North Truckee Drain and Steamboat Creek gaging stations. Not all the other agricultural returns are included in the models because little or no data were available to estimate these inflows and their associated water-quality characteristics.

Continuous-recording gaging stations on the Truckee Canal are operated by the Federal Water Master and the USGS. However, the gages are subjected to backwater conditions which reduce the accuracy of the daily flow records. Therefore, the Truckee Canal flow record was estimated using the mass-balance estimation procedure as presented by Berris (1996, p. 19). Gages that measure the water diverted to water-treatment plants and the volume of water treated at those plants are operated and maintained by Westpac. These gages consist of continuous-recording stage gaging stations, continuous-recording flowmeters, and manual observation of staff gages.

Three streamflow gaging stations were added to the stream gage network during the 1993 water year—Donner Creek, above Prosser Creek and Bronco Creek (tables 1-2, pl. 1). The Donner Creek and Bronco Creek gaging stations provided measured streamflow at locations where streamflow was previously estimated (Berris, 1996, p. 19-20). Estimates of streamflow in the ungaged part of the upper Truckee River subunit were adjusted to reflect the presence of these new gages.

Stream Temperature

Simulation of Truckee River stream temperature using HSPF requires stream-temperature time-series data for every inflow included in the flow-routing module. Continuous stream-temperature data are collected using electronic thermistors connected to electronic data loggers. These temperature monitors generally are serviced and the calibration checked every 2 to 4 weeks. The data from stream-temperature monitors on major tributaries, major agricultural returns, and the Truckee Meadows municipal/industrial return were used as direct input to the temperature model and were used to estimate temperature for inflows where temperature monitoring was not done (tables 1-2, pl. 1).

Table 2. Data-collection sites for the Truckee River streamflow-routing, stream-temperature, and dissolved-solids models, 1993-95

Operating Agency: FWM, U.S. District Court Water Master; NWS, National Weather Service; SPPC, Sierra Pacific Power Company; TMWRF, Truckee Meadows Wastewater Treatment Facility; USACE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey; Washoe, Washoe County; Westpac, Westpac Utilities.

Purpose: E, estimation (c-specific conductance, f-streamflow, t-stream temperature); M&I, municipal and industrial; S, model simulation; V, simulation evaluation point.

Station Type: C, specific conductance; F, streamflow; M, meteorologic (b-atmospheric pressure, c-cloud cover, d-dewpoint temperature, r-relative humidity, s-solar radiation, t-air temperature, w-windspeed); T, stream temperature.

Site number (pl. 1)	Agency assigned station number [1]	Station name	Operating agency	Station type	Purpose	Site number (Berris, 1996)
		Upper Subunit				
1	USGS 10336660	Blackwood Creek near Tahoe City, Calif.	USGS. . . .	F	E(f)	1
2	USGS 10336676	Ward Creek at State Highway 89 near Tahoe Pines, Calif.	USGS. . . .	F	E(f)	2
3	USGS 10337500	Truckee River at Tahoe City, Calif.	USGS. . . .	F,T	S	3
4	USGS 10338000	Truckee River near Truckee, Calif..	USGS. . . .	F,T	V	4
5	USGS 10338700	Donner Creek at Hwy 89 near Truckee, Calif.	USGS. . . .	F,T	S	--
6	NWS, USGS	Truckee Airport.	NWS, USGS. . . .	M(c,d,s,t,w)	S	--
7	USGS 10339400	Martis Creek near Truckee, Calif..	USGS	F,T	S	6
8	USGS 10339419	Truckee River above Prosser Creek near Truckee, Calif.	USGS. . . .	F,C,T	S,V	--
9	USGS 10340500	Prosser Creek below Prosser Creek Dam near Truckee, Calif.	USGS. . . .	F,T	S	7
10	USGS 10343500	Sagehen Creek near Truckee, Calif.	USGS. . . .	C,F	E(c,f)	8
11	USGS 10344500	Little Truckee River below Boca Dam near Truckee, Calif.	USGS. . . .	F,T	S	9
12	USGS 10345700	Bronco Creek at Floriston, Calif.	USGS. . . .	F,T	E(t),S	--
13	Washoe	Truckee River at Floriston, Calif	Washoe. . .	T	V	--
14	USGS 10346000	Truckee River at Farad, Calif..	USGS. . . .	C,F,T	V	10
		Middle Subunit				
15	USGS 10347310	Dog Creek at Verdi, Nev.	USGS. . . .	F,T	E(f),S	11
16	FWM USGS 10347331	Katz Ditch near Verdi, Nev.	FWM	F	S	12
17	FWM T2 USGS 10347390	Coldron Ditch at Verdi, Nev..	FWM	F	S	13
18	Westpac FWM T4 USGS 10347420	Highland Ditch at Reno, Nev..	Westpac . .	F	S	14
19	USGS 10347620	Hunter Creek above Last Chance Ditch near Reno, Nev.	Westpac . .	F,T	E(f),S	--
20	NWS	Reno Airport Meteorologic Station	NWS	M(c,d,t,w)	S	--
21	Washoe	South Reno Meteorologic Station.	Washoe. . .	M(s)	S	--
22	Westpac	Hunter Creek Water Treatment Plant Spill	Westpac . .	F	S	--
23	Westpac	Hunter Creek Water Treatment Plant Delivery to M&I System.	Westpac . .	F	S	17

Table 2. Data-collection sites for the Truckee River streamflow-routing, stream-temperature, and dissolved-solids models—Continued

Site number (pl. 1)	Agency assigned station number [1]	Station name	Operating agency	Station type	Purpose	Site number (Berris, 1996)
24	Westpac	Idlewild Water Treatment Plant Delivery to M&I System.	Westpac. .	F	S	18
25	Westpac	Highland Water Treatment Plant Delivery to M&I System.	Westpac. .	F	S	19
26	Westpac	Highland Plant Spill to Washington Street Drain. .	Westpac. .	F	S	20
27	USGS 10348000	Truckee River at Reno, Nev.	USGS . . .	F,T	V	21
28	Westpac USGS 10348034	Glendale Water Treatment Plant Delivery to M&I System.	Westpac. .	F	S	22
29	FWM USGS 10348150	Sessions Ditch near Reno, Nev.	FWM. . . .	F	S	23
30	USGS 10348200	Truckee River near Sparks, Nev.	USGS . . .	C,F,T	V	24
31	FWM T7 USGS 10348210	Orr Ditch near Reno, Nev.	FWM. . . .	F	S	25
32	Westpac	Chalk Bluff Water Treatment Plant Delivery to M&I System.	Westpac. .	F	S	--
33	FWM T9, T9a, T9b USGS 10348270	North Truckee Ditch at Reno, Nev.	FWM. . . .	F	S	26
34	USGS 10348300	North Truckee Drain at Kleppe Lane near Sparks, Nev.	USGS . . .	C,F,T	E(t),S	27
35	FWM T12 USGS 10348310	Glendale Ditch near Sparks, Nev.	FWM. . . .	F	E(f),S	28
36	USGS 10348900	Galena Creek near Steamboat, Nev.	USGS . . .	F	E(f)	29
37	FWM T1 USGS 10349350	Steamboat Ditch near Floriston, Calif.	FWM. . . .	F	S	30
38	FWM T5 USGS 10349740	Last Chance Ditch at Hunter Creek near Reno, Nev.	FWM. . . .	F	S	31
39	FWM T6 USGS 10349810	Lake Ditch at Mayberry Drive near Reno, Nev. . .	FWM. . . .	F	S	32
40	FWM T8 USGS 10349938	Cochran Ditch at Reno, Nev.	FWM. . . .	F	S	33
41	FWM T11 USGS 10349971	Pioneer Ditch at Reno, Nev.	FWM. . . .	F	S	34
42	FWM USGS 10349974	Eastman Ditch at Reno, Nev.	FWM. . . .	F	S	35
43	USGS 10349980	Steamboat Creek at Cleanwater Way near Reno, Nev.	USGS . . .	C,F,T	S	36
44	Washoe USGS 10349995	Reno-Sparks Sewer Treatment Plant Outfall at Reno, Nev.	Washoe, USGS.	C,F,T	S	37
45	USGS 10350000	Truckee River at Vista, Nev.	USGS . . .	F,T	E(f),V	38
46	FWM T16 USGS 10350048	Noce Ditch near Vista, Nev.	FWM. . . .	F	S	39
47	FWM USGS 10350130	Groton Ditch at Lockwood, Nev.[2]	FWM. . . .	F	S	40

Table 2. Data-collection sites for the Truckee River streamflow-routing, stream-temperature, and dissolved-solids models—Continued

Site number (pl. 1)	Agency assigned station number [1]	Station name	Operating agency	Station type	Purpose	Site number (Berris, 1996)
48	FWM USGS 10350140	Sheep Ranch Ditch near Lockwood, Nev.	FWM	F	S	41
49	FWM T17 USGS 10350150	Murphy Ditch near Vista, Nev.[2]	FWM	F	S	42
50	FWM T19 USGS 10350320	McCarran Ditch near Patrick, Nev.	FWM	F	S	43
51	TMWRF USGS 10350400	Truckee River below Tracy, Nev.	TMWRF, USGS.	F,T	E(f),V	44
52	SPPC	Tracy Powerplant Meteorologic Station	SPPC	M(b,r,s,t,w)	S	--
53	FWM USGS 10350475	Hill Ditch opposite Tracy Powerplant at Tracy, Nev.	FWM	F	S	45
54	USGS 10350500	Truckee River at Clark, Nev.	USGS	C,T	V	--
		Lower Subunit				
55	USGS 10351600	Truckee River below Derby Dam near Wadsworth, Nev.	USGS	F,T	E(f),S,V	48
56	FWM T20 USGS 10351615	Washburn Ditch at Orchard, Nev.	FWM	F	S	49
57	FWM T23 USGS 10351630	Pierson Ditch at I-80 Bridge at Wadsworth, Nev.	FWM	F	S	50
58	FWM T22 USGS 10351635	Herman Ditch near Wadsworth, Nev.	FWM	F	S	51
59	FWM T21	Gregory Ditch near Wadsworth, Nev.	FWM	F	S	52
60	USGS 10351650	Truckee River at Wadsworth, Nev.	USGS	F,T	V	53
61	FWM T25 USGS 10351660	Fellnagle Ditch near Wadsworth, Nev.	FWM	F	S	54
62	FWM T24 USGS 10351668	Proctor Ditch at Wadsworth, Nev.	FWM	F	S	55
63	FWM T26 USGS 10351682	Gardella Ditch near Wadsworth, Nev.	FWM	F	S	56
64	FWM	Olinghouse #1 Pump near Wadsworth, Nev.	FWM	F	S	57
65	FWM	Olinghouse #3 Pump near Wadsworth, Nev.	FWM		S	58
66	Washoe	S Bar S Ranch Meteorologic Station	Washoe	M(r,t,s,w)	S	--
67	USGS 10351700	Truckee River near Nixon, Nev.	USGS	C,F,T	V	59
68	TMWRF	Truckee River at Hwy 447 near Nixon, Nev.	TMWRF	C,T	V	--
69	FWM T27 USGS 10351755	Indian Ditch near Nixon, Nev.	FWM	F	S	60
70	USGS 10351775	Truckee River at Marble Bluff Dam	USGS	T	V	--

[1] If station numbers are not provided by the primary reporting agency, that agency is listed without the station number.

2 Groton Ditch at Lockwood, Nev., and Murphy Ditch near Vista, Nev., combined in 1985 and are currently known as Groton Ditch.

All 10 temperature monitors on tributaries to the Truckee River are operated by the USGS (table 2, pl. 1). These gages were installed where little or no thermal input exists between the gage and the Truckee River, with the exception of the Steamboat Creek gaging station. Because the Steamboat Creek gaging station is just upstream of the effluent discharge from the TMWRF, effluent-temperature data are necessary. Hourly temperature data have been collected at the TMWRF gaging station since June 1993.

Stream-temperature monitors on the Truckee River mainstem are operated by the USGS, Washoe County Department of Comprehensive Planning (Leonard Crowe, Washoe County Department of Comprehensive Planning, written commun., 1993-94), and the TMWRF (Rick Warner and Tom Swan, written commun., 1993-94). The USGS operated 12 stream-temperature monitors on the mainstem from Tahoe City, Calif., to Marble Bluff Dam, Nev., during the 1993 and 1994 water years. Washoe County operated a stream-temperature gage on the mainstem near Floriston, Calif. TMWRF collected hourly stream-temperature data (as well as conductance data using a four-constituent monitor) from stations near the Tracy and Nixon gaging stations during the same period (table 2, pl. 1). Data from the Tahoe City temperature gage were used as input to the model. The rest of the above-mentioned mainstem gages were available for evaluating the stream-temperature model.

Meteorology

Time-series data from five meteorological stations within the Truckee River Basin initially were used in the Truckee River stream-temperature model (table 2, pl. 1). The data included are air temperature, atmospheric pressure, cloud cover, dewpoint temperature, relative humidity, solar radiation, and windspeed. These data were obtained from the National Weather Service (NWS) stations at the Truckee Airport and Reno/Tahoe International Airport, the Washoe County stations in south Reno about 5 mi south of the airport and S Bar S Ranch north of Wadsworth, Nev., and a Sierra Pacific Power Company station at Tracy Powerplant.

Data are collected at NWS meteorological stations in Truckee and Reno by NWS personnel, with the exception of solar radiation. The USGS installed an Epply precision pyranometer connected to an electronic data logger at Truckee Airport in June 1993 to measure solar radiation in the upper Truckee River Basin. Because of problems associated with snow, the pyranometer was removed in October 1993 and reinstalled May 1994. The Washoe County Health Department meteorological station in south Reno collects solar-radiation data year round using a Spectral Physics Spectra Sun pyranometer. The solar radiation instruments at both of those stations take continuous radiation readings and are set to record the hourly average of shortwave solar radiation. The NWS station in Reno and Washoe County Health Department station will be referred to collectively as the meteorological station at Reno airport.

NWS personnel record instrument readings for air temperature, dewpoint temperature, and windspeed each hour during daylight hours at the Truckee Airport and 24 hours a day at the Reno airport. The air-temperature data are single instantaneous readings taken each hour. Windspeed is a mean of instantaneous readings made every 2 minutes (readings and averaging are made by the instrument). Hourly cloud cover is obtained by visual observation of current sky conditions.

Sierra Pacific Power Company operates a meteorological station at its Tracy Powerplant on the south bank of the Truckee River near Tracy, Nev., about 20 mi downstream from Reno (table 2, pl. 1). Air temperature, atmospheric pressure, relative humidity, solar radiation, and windspeed were obtained from this station. Air-temperature, atmospheric-pressure, and relative-humidity data used in this report were measured near the ground at 1- to 2-minute intervals and hourly means were recorded. Dewpoint temperature was estimated from the air temperature, atmospheric pressure, and relative humidity using a computer program written by Kelly Redmond (Western Region Climate Center, Reno, Nev., written commun., 1993). This program uses the Groff-Gratch formulation. Solar-radiation data used in this report were measured continuously near the ground and the hourly means recorded. Windspeed data used in this report were measured at 33 ft above ground surface at 1- to 2-minute intervals and hourly means were recorded. All data were recorded hourly by electronic data loggers.

Washoe County Department of Comprehensive Planning operates a meteorological station at S Bar S Ranch adjacent to the Truckee River about 4 mi north of Wadsworth, Nev. (table 2, pl. 1). The station has been in operation since mid-June 1993 and provided air temperature, relative humidity, solar radiation, and windspeed for the lower Truckee River Basin. The instrumentation measured air temperature and relative humidity instantaneously at the beginning of each hour. Atmospheric-pressure data were not available at S Bar S Ranch so the data were assumed to be the same as atmospheric pressure at Tracy. Dewpoint temperature was estimated for this station using the same procedures as those used for Tracy station data. Solar radiation was measured continuously, and windspeed was measured about every 5 minutes. Hourly means were recorded for all three variables. Cloud-cover data were not available for the lower subunit, so cloud-cover data for Reno airport were used.

Dissolved Solids

All dissolved-solids concentrations used in the model are estimated from observed or estimated specific conductance values. Specific conductance is a measure of the ability of water to conduct an electric current. Because the ability of water to carry an electric current is dependent on the concentration of inorganic ions (salts) dissolved in the water, specific conductance is an indirect measure of dissolved-solids concentration. The linear relation that exists between dissolved solids and specific conductance in many stream systems (Hem, 1985, p. 67), allows the estimation of dissolved solids from specific conductance.

On the mainstem of the Truckee River, during the 1994 water year (U.S. Geological Survey, 1995-96), specific-conductance data were recorded at 1-hour intervals at five USGS gaging stations—above Prosser Creek, Farad, Sparks, Clark, and Nixon (table 2, pl. 1). On the major tributaries contributing dissolved solids to the Truckee River, three additional stations also recorded hourly conductance data—North Truckee Drain, Steamboat Creek, and TMWRF. Instantaneous conductance measurements made at the beginning of each hour were aggregated to daily means which were then converted to estimated dissolved-solids concentrations for input to the model.

Estimated Data

HSPF requires complete time-series data (no missing data at the selected time step) for simulating streamflow, stream temperature and dissolved solids. Therefore, estimating missing data was necessary. Techniques used to estimate missing streamflow, stream-temperature, meteorological, and dissolved-solids data included direct substitution, linear interpolation, and regression analyses. The technique chosen depended upon the type of missing data, the length of missing record, and other data available from which to make estimations.

Streamflow

To quantify inflows to and outflows from the Truckee River, streamflow and ground-water data were estimated when continuous or accurate tributary, diversion, or return flow data were not available. Data accuracy was affected by backwater conditions and by the absence of gaging stations at all Truckee River inflow locations.

For the original streamflow model (Berris, 1996), missing streamflow records were estimated by (1) linear interpolation between streamflow measurements, (2) comparisons of hydrographs from nearby gaging stations on tributaries of the Truckee River, (3) regression analyses using hydrographs of observed tributary and mainstem streamflow, and (4) water balance computations with hydrographs of observed mainstem streamflow. When necessary, these estimation techniques were used in this report. A detailed description of streamflow and ground-water inflow estimation techniques for the Truckee River flow-routing model is given by Berris (1996).

Stream Temperature

Estimates of missing hourly stream-temperature data were necessary because of instrument malfunctions or environmental conditions; temperature monitors were not installed until after June 1, 1993; and temperature monitors were not included on all inflows to the flow-routing model, including ground-water inflows. Missing stream-temperature data were estimated by linear interpolation, direct substitution of observed data from a similar time period, or a combination of the two. When data gaps were a few hours or less, linear interpolation was used to fill in the missing data. Data gaps of more than a few hours to about a week generally were estimated by substituting observed data at the same station from days before or after the missing period.

Bronco Creek gaging station stream-temperature data were directly substituted for all ungaged surface-water inflows to the Truckee River in the upper subunit. Bronco Creek enters the Truckee River at reach 230 and the upper subunit ends at reach 240 (pl. 1). Bronco Creek gaging station was chosen because the headwaters are at a similar altitude to the other upper subunit tributaries, and because Bronco Creek is the only unregulated stream in the subunit with hourly data available.

Missing data for the first week of the simulation period (June 1-7, 1993) at the Dog Creek gaging station were estimated using data from Hunter Creek gaging station. A comparison of the temperature records for the two gaging stations during mid-June indicated that maximums at Hunter Creek were about 3°C cooler and minimums about 2°C cooler than Dog Creek. Therefore, the maximum and minimum temperatures for Hunter Creek during the missing period were used for Dog Creek after adding 3°C to the maximums and 2°C to the minimums. Linear interpolation then was used to fill in the rest of the missing values.

Stream-temperature estimates were necessary for Steamboat Creek and North Truckee Drain gaging stations, and the ungaged inflows to the middle subunit. Missing data at Steamboat Creek station during the first half of June 1993 were estimated by substituting the station temperature record from the last half of June. This was possible because stream temperatures generally did not increase during the last half of June. Missing temperature data for North Truckee Drain during June 1993 were estimated by substituting the Steamboat Creek record for June. The North Truckee Drain record, including the substituted Steamboat Creek data, subsequently was used for ungaged inflows in the middle Truckee River Basin.

The flow-routing model includes ground-water inflows for the lower Truckee River subunit, reaches 490-570 (fig. 2, pl. 1). Because no temperature data were available for these inflows, they had to be estimated. The estimate was made from previous work done in lower Carson River (Whitney, 1994), where measurements of ground-water temperature near the Carson River averaged about 15.5°C. This estimate was used for ground-water inflow to the lower Truckee River subunit.

The present methods of inflow stream-temperature estimation are deemed adequate as a first approximation of missing data. Different, more mathematically complex estimates, such as air temperature/stream temperature regression analysis, could be made if model results show the present methods to be unsatisfactory.

Meteorology

Hourly time series of meteorological data also were used as input to the stream-temperature model. Meteorological data were estimated when complete hourly time series were not available due to interval of data collection, instrument malfunction, absence of instrumentation or observations, or unfavorable environmental conditions. In general, meteorological data were collected at 1- to 3-hour intervals. The gaps were filled using linear interpolation except as noted.

Truckee Airport solar radiation was estimated from potential solar radiation from June 1 through July 15, 1993, and from October 1, 1993, through May 31, 1994. A FORTRAN program (Timothy Liebermann, U.S. Geological Survey, written commun., 1994) was used to calculate hourly maximum potential solar radiation for 1 day each week throughout the year. This program assumes a solar constant of 2 langleys/min for the maximum potential solar radiation striking the earth's outer atmosphere. The calculated values were then substituted for the other weekdays, which resulted in a complete hourly time series of maximum potential solar radiation for a year. This time series was corrected for the effects of the earth's atmosphere, cloud cover, and topographic shading. Solar radiation was multiplied by 0.81 to account for attenuation by the earth's atmosphere and to give potential solar radiation at the earth's surface under clear sky conditions (RADclear). The value 0.81 is a typical value for atmospheric attenuation in northwestern Nevada (William D. Nichols, U.S. Geological Survey, oral commun., 1994). Solar radiation attenuation due to cloud cover (RADcloudy) was estimated using the following equation:

$$\text{RADcloudy} = (\text{RADclear})\left(1 - 0.65*\text{C}^2\right)$$

where C is the decimal fraction (between 0 and 1) of sky covered by clouds (Tennessee Valley Authority, 1972, p. 2-19).

A geographic information system utilizing digital elevation mapping data was used to calculate the percent of river channel shaded hourly throughout the year. For many mountainous reaches with mountains to the east and west, this estimate of topographic shading did not affect solar radiation reaching the water surface during the middle of the day when solar radiation was highest (fig. 3) regardless of the season. However, the

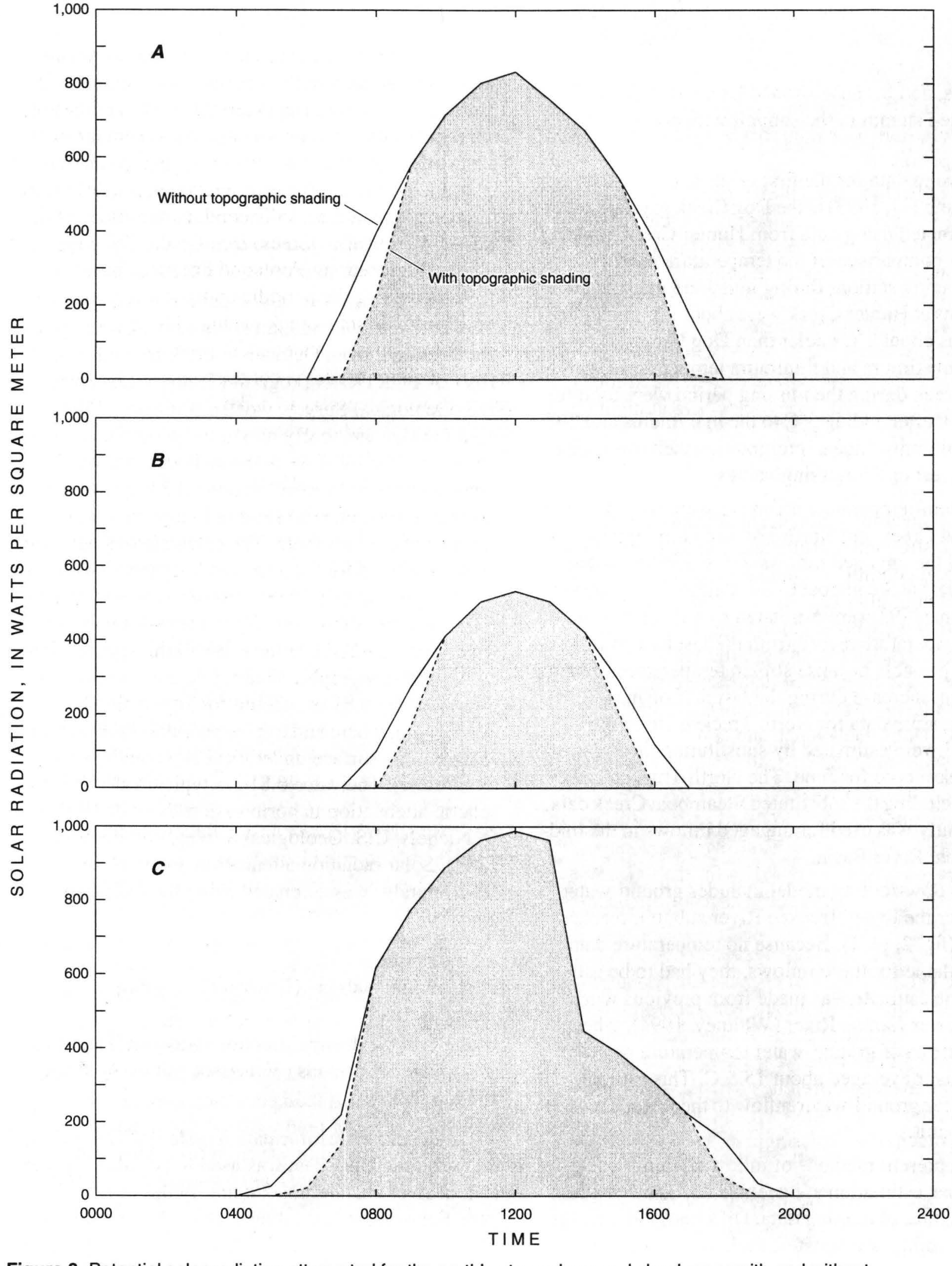

Figure 3. Potential solar radiation attenuated for the earth's atmosphere and cloud cover with and without topographic shading in a mountainous reach (reach 130) for (*A*) October 1, 1993, (*B*) December 21, 1993, and (*C*) May 31, 1994.

solar radiation reaching the water surface was reduced by topographic shading in some mountainous reaches even in the middle of the day. The estimated solar-radiation data then were combined with measured data at Truckee Airport to provide a complete time series of hourly solar-radiation data for the calibration/validation period.

NWS collected data at the Truckee Airport during daylight hours only. Linear interpolation was used to fill in missing data for cloud cover, daytime windspeed, air temperature, and dewpoint temperature. Typically in the study area, windspeed increases in the late afternoon and early evening and then decreases at night. Under these conditions linear interpolation would overestimate windspeed; therefore, windspeed for the upper subunit was assumed to be zero at night.

Dissolved Solids

Hourly specific-conductance data are missing because of instrument malfunctions, unfavorable environmental conditions, conductance monitors were not installed until after October 1, 1994, and conductance monitors were not included on all inflows to the flow-routing model, including ground-water inflows. Missing specific-conductance data were estimated using linear regression of conductance and streamflow (same station), or conductance and conductance (two stations), linear interpolation, and direct substitution.

Missing data for the above Prosser Creek gaging station were estimated using a linear relation developed between conductance and streamflow for that station (table 3). Missing conductance data for the Clark gaging station were filled by direct substitution using TMWRF data collected below Tracy. Missing data are from March 4-23 and May 19-September 25, 1995. The TMWRF data were used because Clark and TMWRF stations are only about 1 mi apart and have very little inflow between them. A statistical comparison of remaining 1995 water year specific-conductance data shows an average difference between the stations of only 5 percent. The TMWRF data, also not complete, filled much of the missing data at Clark between May and September.

Monthly and bimonthly measurements of specific conductance were made on tributaries to the Truckee River from Hunter Creek upstream to Martis Creek between February and November 1995. Bimonthly measurements were taken during the snowmelt runoff period March through July. These measurements were used to estimate specific conductance for the ungaged upper Truckee River tributaries, and for Hunter and Dog Creeks in the middle subunit.

A linear relation was determined, where possible, between specific conductance and streamflow for use in estimating ungaged and missing specific conductance in future years. A linear relation was determined using the combined periodic conductance measurements for the Bronco Creek, Dog Creek, and Hunter Creek gaging stations. A second linear relation was determined using the periodic conductance measurements for the Martis Creek gaging station. Use of a log-log (log[conductance] and log[streamflow]) transformation for all the conductance and streamflow relations was necessary to make them linear. No linear relation was found between specific conductance and streamflow at Steamboat Creek gaging station, but a linear relation was found between specific conductance at Steamboat Creek and specific conductance at Clark gaging stations. Estimates of missing specific-conductance data for Steamboat Creek were made using this relation with specific conductance at Clark. Table 3 provides the nontransformed relations and coefficients of determination (r^2) used to estimate specific conductance from streamflow.

Because no linear relations between specific conductance and streamflow were found for the USGS stations at Prosser Creek below Prosser Creek Dam near Truckee, Calif., and Little Truckee River below Boca Dam near Truckee, Calif., or the North Truckee Drain and TMWRF, the missing data were filled using periodic specific-conductance measurements. During the 1995 water year, instantaneous measurements made at Prosser Creek below Prosser Creek Dam indicated some seasonal change in the conductivity. Therefore, all missing data points between measurements were estimated by filling the first half of the missing days between one measurement and another with the first measured value and the second half of the missing days with the second measured value. During 1995 water year, instantaneous measurements made at Little Truckee River below Boca Dam indicated conductivity changed little year round. Therefore, the mean of all measurements taken was used for each day of missing data. Specific-conductance data were missing for the North Truckee Drain because the monitor was not installed until October 28, 1994. However, three instantaneous measurements were made during October 1994 and missing data were estimated

Table 3. Regression equations and coefficients of determination used to estimate specific conductance and dissolved-solids concentrations for the dissolved-solids model

[Abbreviations: (1), equation number; Cond, specific conductance, in microsiemens per centimeter at 25° Celsius; DS, dissolved-solids concentration, in milligrams per liter; Flow, streamflow, in cubic feet per second; r^2, coefficient of determination]

Dissolved-solids model inflows and Truckee River check sites		Specific-conductance/ streamflow relation and specific-conductance/ specific-conductance relation [1]	Specific-conductance/ dissolved-solids relation[1]
Model inflows	Truckee River above Prosser Creek, Truckee, Calif.	(1) $Cond = 1096(Flow)^{-0.39}$ $r^2 = 0.90$	(2) $DS = 10.4 + 0.57(Cond)$ $r^2 = 0.996$
	Upper and middle subunit ungaged inflows.	(3) $Cond = 236(Flow)^{-0.19}$ $r^2 = 0.74$	(4) $DS = 13.2 + 0.64(Cond)$ $r^2 = 0.85$
	Bronco Creek at Floriston, Calif.		(4) $DS = 13.2 + 0.64(Cond)$ $r^2 = 0.85$
	Dog Creek at Verdi, Nev.		(4) $DS = 13.2 + 0.64(Cond)$ $r^2 = 0.85$
	Hunter Creek above Last Chance Ditch near Reno, Nev.		(4) $DS = 13.2 + 0.64(Cond)$ $r^2 = 0.85$
	Bronco + Dog + Hunter Creeks	(5) $Cond = 218(Flow)^{-0.31}$ $r^2 = 0.65$	
	North Truckee Drain at Kleppe Lane near Sparks, Nev.		(6) $DS = 39.0 + 0.58(Cond)$ $r^2 = 0.89$
	Steamboat Creek at Cleanwater Way near Reno, Nev.	(7) $Cond = 467 + 0.69(Cond)$ $r^2 = 0.56$	(6) $DS = 39.0 + 0.58(Cond)$ $r^2 = 0.89$
	Reno-Sparks Sewer Treatment Plant Outfall at Reno, Nev. (Truckee Meadows Waste Reclamation Facility).		(8) $DS = 70.0 + 0.50(Cond)$ $r^2 = 0.50$
Mainstem check sites.	Truckee River at Farad, Calif.		(2) $DS = 10.4 + 0.57(Cond)$ $r^2 = 0.996$
	Truckee River near Sparks, Nev.		(2) $DS = 10.4 + 0.57(Cond)$ $r^2 = 0.996$
	Truckee River at Clark, Nev.		(2) $DS = 10.4 + 0.57(Cond)$ $r^2 = 0.996$
	Truckee River near Nixon, Nev.		(2) $DS = 10.4 + 0.57(Cond)$ $r^2 = 0.996$

[1] Relations used to develop regression equations are as follows:

Equation (1): Linear relation determined using specific-conductance and streamflow data for Truckee River above Prosser Creek near Truckee, Calif.

Equation (2): Linear relation determined using dissolved-solids and specific-conductance data for Truckee River at Farad, Calif; Truckee River at Clark, Nev., and Truckee River near Nixon, Nev.

Equation (3): Linear relation determined using specific-conductance and streamflow data for Martis Creek near Truckee, Calif.

Equation (4): Linear relation determined using dissolved-solids and specific-conductance data for Sagehen Creek near Truckee, Calif., Prosser Creek below Prosser Creek Dam near Truckee, Calif., and Little Truckee River below Boca Dam near Truckee, Calif.

Equation (5): Linear relation determined using specific-conductance and streamflow data for Bronco at Floriston, Calif., Dog Creek at Verdi, Nev., and Hunter Creek above Last Chance Ditch near Reno, Nev.

Equation (6): Linear relation determined using dissolved-solids and specific-conductance data for North Truckee Drain at Kleppe Lane near Sparks, Nev., and Steamboat Creek at Cleanwater Way near Reno, Nev.

Equation (7): Linear relation determined using specific-conductance data for Steamboat Creek at Cleanwater Way near Reno, Nev. (Cond.), and Truckee River at Clark, Nev. (Cond.).

Equation (8): Linear relation determined using dissolved-solids and specific-conductance data for the Reno-Sparks Sewer Treatment Plant Outfall at Reno, Nev. (Truckee Meadows Waste Reclamation Facility), effluent.

using the same method as described above for Prosser Creek. The TMWRF station never had more than 10 consecutive days of missing data, so missing data were estimated using linear interpolation.

The dissolved-solids data are considered observed for model evaluation, even though all dissolved-solids data are estimated from observed or estimated specific conductances. Dissolved-solids concentrations were estimated from specific-conductance values using linear relations developed for the Truckee River Basin (table 3). Linear relations were determined for the mainstem using historical data of dissolved-solids concentrations and specific conductance for the Farad and Nixon gaging stations. The results of these two relations were similar; thus; all specific-conductance/dissolved-solids data pairs for the mainstem were combined and a single relation was determined for the mainstem (table 3, eq. 2).

For mountainous tributaries in the upper and middle subunits, a linear relation was determined using historical specific-conductance/dissolved-solids data predominantly from the USGS station Sagehen Creek near Truckee Calif., but including Prosser Creek below Prosser Creek Dam and the Little Truckee River below Boca Dam (table 3, eq. 4). This relation, different from that of the mainstem, was used to calculate dissolved solids for all tributaries in the upper subunit and the upstream end of the middle subunit (Dog and Hunter Creeks).

Linear relations were determined for the Truckee River at three main returns—North Truckee Drain, Steamboat Creek, and TMWRF. Historical specific-conductance/dissolved-solids data from the North Truckee Drain and Steamboat Creek gaging stations, the two major agricultural returns, were combined for one relation (table 3, eq. 6). A separate relation was determined from data collected by TMWRF personnel for the TMWRF station (table 3, eq. 8). The TMWRF station relation was not very strong ($r^2 = 0.50$) and the slope falls outside the normal range given by Hem (1985, p. 67). This weak relation probably is because specific conductance and dissolved solids were not always sampled at the same time of day. A second estimate was made using the linear relation developed for upper and middle subunit ungaged inflows.

During the 1995 water year, estimates of dissolved solids in ground-water inflow to reaches 490-570 (table 4, pl. 1) were derived from ground-water-quality data collected by TMWRF personnel in the lower Truckee River subunit, and Bratberg and others (1982) and Nowlin (1987). Bratberg and others (1982) used measured dissolved solids and a mass balance approach to estimate concentrations where measurements were not available. Nowlin (1987) summarized ground-water data available at that time. For this report, inputs of dissolved solids through ground-water inflow were estimated as constant values throughout the year. The TMWRF data consisted of specific-conductance measurements taken from a well adjacent to the river and a well away from the river at each sampling location. The mean values of the measurements from the wells adjacent to the river in a reach were calculated for this report and used for the input of dissolved solids for that reach. When samples from the well adjacent to the river indicated the water was coming from the river, samples from the well away from the river were used. Some reaches had no wells.

SIMULATION OF DAILY FLOW ROUTING, HOURLY STREAM TEMPERATURE, AND DAILY DISSOLVED SOLIDS

Flow Routing

Simulated daily streamflow was necessary to transport heat and dissolved solids down the Truckee River. The data base used by Berris (1996) contained streamflow data through September 1992. This data

Table 4. Lower Truckee River subunit estimates of dissolved-solids concentrations in ground water, by reach

Property	Reach (see pl.1)								
	490	500	510	520	530	540	550	560	570
Estimated dissolved-solids concentrations, in milligrams per liter.	[1]1,000	[1]1,000	[1]1,000	[2]1,270	[3]1,280	[3]2,600	[2]1,270	[2]1,270	[2]1,270

[1] Modified from Bratberg and others, 1982, based on earlier model results.

[2] From Bratberg and others, 1982.

[3] Truckee Meadows Water Reclamation Facility, Reno, Nev., oral commun., 1996.

base was updated through September 1995 to coincide with the stream-temperature and specific-conductance data used to calibrate the water-quality models in this report. Flow-routing results for the additional 2 years are presented for the Farad, Tracy, and Nixon gaging stations. For flow-routing results prior to 1993 see Berris (1996).

Stream Temperature

The stream-temperature model was constructed, calibrated, and validated within the framework of the existing flow-routing model. In addition to calibrating model parameters, some adjustments were made to estimated model input data where data were poorly defined, such as ungaged ground-water or surface-tributary inflows. The inclusion of different estimates for poorly defined model inputs indicates model sensitivity to a particular input and indicates which estimates result in the best simulations under the given conditions.

Meteorological conditions vary greatly from one end of the basin to the other, but the minimum number of stations needed to adequately characterize conditions for input to the stream-temperature model was unknown at the outset of this study. Sensitivity of the model to meteorological data was checked to determine the most efficient number and locations for meteorological inputs. The model parameters and input data determined to give the best simulated results were used to validate the model at Farad, Vista, and Marble Bluff gaging stations (fig. 2, pl. 1).

Calibration of the Stream-Temperature Model

Initial calibration of the stream-temperature model was accomplished using input data from June 1 through September 30, 1993, and HSPF (Bicknell and others, 1993). This version of HSPF provides four model parameters for adjusting the heat transfer processes of shortwave radiation (CFSAEX), longwave radiation (KATRAD), evaporation (KEVAP), and conduction/convection (KCOND) (table 5). This initial calibration of the stream-temperature model was unsatisfactory. Simulated stream temperatures matched observed temperatures well during June, but the daily variation between simulated maximum and minimum stream temperatures increased more than the observed from July through September. Part of this variation probably was due to simulated streamflow and, thus, simulated stream depths being less than observed in some reaches. However, the problem also occurred when simulated streamflow was not less than observed. No combination of model parameters would decrease the simulated daily variation in maximum and minimum stream temperatures to more closely reflect observed stream temperatures. Another term may need to be incorporated into HSPF's energy budget calculations to even out the daily variation in maximum and minimum simulated temperatures.

HSPF typically has been applied to large, deep river channels and, therefore, did not have a streambed heat conductance term. In a river system like the Truckee River, where low flows typically are shallow and wide, being able to simulate the storage and release of heat in the streambed might provide the means to reduce the daily variation in simulated maximum and minimum stream temperatures. Therefore, the streambed conductance algorithm, including three model parameters (MUDDEP, KMUD, and KGRND) (table 5), was added to HSPF (Bicknell and others, 1997). The stream-temperature model with streambed conductance was calibrated from June 1, 1993, through May 31, 1994.

A separate model was calibrated for each of the three subunits, starting with the upper subunit and progressing downstream. HSPF documentation (Bicknell and others, 1997) provides maximum and minimum values and a default value for each model parameter (table 5). In many instances, the documentation provides typical or recommended values. Model parameter values generally were set at default or recommended values initially and kept within typical or recommended ranges. The best model parameters determined during upper subunit calibration were used as a guide to start calibration for the middle and lower subunits.

Adjustment of Model Parameters

CFSAEX was used to adjust direct solar radiation inputs to the Truckee River. Typical values used are between 0.7 and 1.0 (Brian Bicknell, Aqua Terra Consultants, oral commun., 1994). A CFSAEX value of 1.0 would mean that 100 percent of the radiation reaching the measurement device at the meteorological data collection station was reaching the stream surface. A CFSAEX value of 0.7 would mean that 70 percent of measured solar radiation was reaching the stream surface, or that effectively 30 percent of the stream is

Table 5. Stream-temperature model parameters and values used for simulation and analysis

[Abbreviation: kcal/m²/°C/hr, kilocalorie per square meter, per degree Celsius, per hour. Symbols: --, not applicable; ∞ , infinity]

Model parameter	Parameter definition	Parameter range	Default value [1]	Final value Subunit: Upper Reaches: (110-240)	Middle (250-450)	Lower (460-570)
CFSAEX	Ratio of radiation at the stream surface to radiation at the measurement device.	0.001-2.0	--	0.8	0.8	0.8
KATRAD	Atmospheric longwave radiation heat transfer coefficient	1.0-20	9.37	10.5	9.5	9.0
KEVAP	Controls the transfer of hear due to evaporation losses	1.0-10	2.24	1.8	1.0	1.0
KCOND	Conduction/convection heat transfer coefficient	1.0-20	6.12	6.12	6.12	6.12
MUDDEP	Streambed layer depth, in feet	.01- ∞	.33	1.0	2.0	2.0
KMUD	Controls the transfer of heat between the stream water and streambed, in kcal/m²/°C/hr.	.0- ∞	50	25.0	75.0	75.0
KGRND	Controls the transfer of heat between ground and mud, in kcal/m²/°C/hr.	.0- ∞	1.4	1.4	1.4	1.4
TGRND	Ambient ground temperature, in degrees Celsius, simulates heat transfer at the ground-streambed interface	-10-45	--	(2)	10.0	10.0

[1] Bicknell and others, 1997.

[2] Monthly values are as follows: Jan., 0.0; Feb., 0.0; Mar., 1.7; Apr., 10.0; May, 10.0; June, 10.0; July, 12.8; Aug., 12.8; Sept., 12.8; Oct., 1.7; Nov., 0.0; Dec., 0.0.

shaded. Increasing CFSAEX increased simulated stream temperatures and decreasing CFSAEX decreased simulated stream temperatures. Final calibration values are listed in table 5.

KATRAD has a typical value of 9.0 according to the HSPF documentation (Bicknell and others, 1997). The value of KATRAD was varied between 8.5 and 12.0 during calibration of the three subunits. In general, increasing KATRAD increased stream temperature for the entire simulation, decreasing KATRAD decreased stream temperature for the entire simulation, and the effect appeared greater during the winter months. Final calibration values for KATRAD are listed in table 5.

KEVAP has a typical value range between 1.0 and 5.0 (Bicknell and others, 1997). KEVAP was adjusted between 1.0 and 2.5 during the calibration of the three subunits. Increasing KEVAP increased evaporation and generally caused stream temperatures to decrease. Decreasing KEVAP decreased evaporation and generally caused stream temperatures to increase. As with KATRAD, KEVAP generally caused stream temperature to increase or decrease for the entire simulation. Final calibration values for KEVAP are listed in table 5.

KCOND has typical values which include the entire parameter range (table 5; Bicknell and others, 1997). Changes to KCOND produced results similar to those seen with changes to KATRAD, but to a lesser degree. A large change in the value of KCOND (doubling the default value to 12.0) did not produce much change in simulated stream temperatures. Therefore, KCOND was left at the default value for all three subunits (table 5).

The upper subunit MUDDEP, the thickness of the mud layer, had an initial value of 0.3 ft, then varied between 0.3 and 2.0 ft. A MUDDEP value of 1.0 ft provided better results than smaller depths and when MUDDEP was changed from 1.0 to 2.0 ft, simulated stream temperatures changed little. MUDDEP had values of 1.0, 2.0, and 4.0 ft for three different runs with mixed results. In general, simulated stream temperatures changed little between the three values. The lower subunit MUDDEP had an initial value of 2.0 ft, similar to the 2.3 ft used by Caupp and others (1997, p. 90) in a stream-temperature model of the lower Truckee River Basin. Final values used are listed in table 5.

For the coefficient, KMUD, Caupp and others (1997, p. 90) used about 72 kcal/m²/°C/hr for a model of the lower Truckee River and 50 kcal/m²/°C/hr for a river in Canada. KMUD had an initial calibration run value of 75 kcal/m^2/°C/hr, then was varied between 25 and 125 kcal/m^2/°C/hr. In general, increasing the value of KMUD caused the daily range between minimum and maximum stream temperature to decrease, but decreasing the value of KMUD increased this range. An exception was during spring runoff when flows increased and the effects of KMUD diminished. Final values for KMUD are listed in table 5.

The effect of KGRND on simulated stream temperatures was tested using values of 0.5 and 10.0 on successive runs. Increasing KGRND increased stream temperatures during mid-June through October and decreased stream temperatures from the end of November through February. November was a transition month between increasing and decreasing simulated stream-temperature distributions. March through May had little difference in the two runs. KGRND could be used to change the simulated stream-temperature distribution; however, the desired change was generated when KGRND was made smaller. Since the initial value was the default value of 1.4, little room for adjustment (from 1.4 to 0) existed. For this reason, the default value was used (table 5).

Ambient ground temperature, TGRND, is necessary to simulate heat transfer at the ground-streambed interface. Three ways to input TGRND are time series, single annual value, or monthly values. No measured time series of ground temperature is available for the Truckee River Basin. TGRND had an initial single annual value of 10.0°C, based on the mean annual air temperature at Wadsworth, Nev., for all three subunits. This value worked well for the middle and lower subunits, but during the winter months, for the upper subunit, simulated daily maximum stream temperatures were overestimated. To bring these simulated temperatures closer to observed, monthly values were used (table 5).

For the middle and lower subunits, the initial temperature of 10.0°C was used for TGRND. However, in the lower subunit at Nixon gaging station, a temperature 15.6°C was input to compare with the initial simulation. On average, only a few tenths of a degree difference was observed. Consequently, because the initial value of 10°C produced slightly better simulation results, it was used. Final values used for TGRND are listed in table 5.

Validation of the Stream-Temperature Model

The stream-temperature model was validated using input data from June 1 through September 30, 1994. For the validation period, model parameters were set to the final values given in table 5. These values were determined, during model calibration, to give simulation results that were closest to observed data.

Dissolved Solids

The dissolved-solids model was constructed within the framework of the existing flow-routing model (Berris, 1996). No parameters can be adjusted to calibrate the dissolved-solids module. Different estimates of dissolved solids in surface- and ground-water inflows were used during the construction of the model and the best combination was used in the final model. The dissolved-solids model was not validated because the entire yearlong record of specific-conductance data used to estimate dissolved solids also was used for model testing.

Sensitivity of the Stream-Temperature Model to Selected Input Data

Selected model input data were varied to check the sensitivity of the calibrated stream-temperature model during the calibration period for three reasons. (1) The stream-temperature model was run using daily and hourly streamflow inputs to determine if hourly streamflow inputs were necessary. (2) Several water-temperature estimates for ungaged model inflows were made to determine the best estimates for ungaged surface- and ground-water inflows. (3) The meteorological stations used and the stream reaches covered by each station were changed to determine the geographical coverage of meteorological data necessary for adequate stream-temperature simulation.

Streamflow

The stream-temperature model is run using an hourly time step. However, the streamflow data are input at a daily time step. These daily flow data are converted by the model to hourly values by assuming a constant flow each hour of the day equal to the daily mean. Tests were run to check the sensitivity of using converted daily mean flow data and observed hourly flow data in the middle and lower subunits. For the middle subunit test, daily mean and hourly flow data were input at the TMWRF effluent and the results were checked for the Vista gaging station. For the lower subunit test, measured hourly streamflow data were input below Derby Dam and the results compared, at the Marble Bluff gaging station, with a model run using daily mean streamflow data below Derby Dam. Little or no difference in simulated stream temperatures was shown at either the Vista or Marble Bluff gaging stations.

Water Temperature

For all model inflows, HSPF requires time-series, water-temperature data. HSPF assigns 0.0°C to any model inflow that does not have an assigned water temperature; therefore, all missing input data were estimated. Estimated water temperatures are necessary for ungaged surface-water inflow and ground-water inflow. More than one estimate for each of these types of inflow was necessary to determine which estimates provided the best stream-temperature simulations.

Most ungaged surface-water inflows are in the upper subunit. Temperatures of ungaged surface water were estimated by substitution of temperatures measured at tributary gaging stations. The measured time series chosen to estimate ungaged surface-water inflows in the upper subunit was Bronco Creek. Three additional estimates were made to test the sensitivity of the calibrated model to stream-temperature estimates of ungaged upper subunit tributaries. The measured time series from Donner Creek and Martis Creek gaging stations and the mean stream temperature over the calibration period of 5.5°C for Bronco Creek were substituted for each hour of the calibration period. Results from these three runs were compared with the results of the calibrated model using the Bronco Creek time series. Comparison of daily maximum, daily minimum, and hourly mean absolute error between observed and simulated stream temperatures for the Farad and Marble Bluff gaging stations shows little or no difference between using Bronco Creek time-series data and the other estimates. The smallest difference in mean absolute error was 0.0°C and the greatest difference was 0.2°C. Therefore, the Bronco Creek time series was used as the temperature estimate for ungaged tributary inflow in the upper subunit.

Most ground-water inflows to the stream-temperature model are in the lower subunit and neither ground-water inflows nor ground-water temperatures were measured. The total ground-water inflow to the lower Truckee River was estimated to be 23 ft^3/s (Berris, 1996, p. 21 and model code, see appendix, p. 83). This flow was distributed over nine reaches (490-570; fig. 2; pl. 1) on the basis of ground-water seep runs done by USGS personnel. Ground-water inflow and temperature inflow were assumed to be constant year round. Sensitivity of the model to ground-water temperature was tested by using three different temperatures 4.4, 10.0, and 15.6°C. The mean absolute errors for daily maximum, daily minimum, and hourly stream temperatures at the Marble Bluff gaging station were compared and the difference was less than 0.2°C among the results using the three temperature estimates. Therefore, the original estimate of 15.6°C was used as the ground-water inflow temperature estimate.

Meteorology

Three meteorological stations (Reno airport and Tracy Powerplant in the middle subunit, and S Bar S Ranch in the lower subunit) were used to collect data in the lower two-thirds of the Truckee River Basin. Two middle subunit and two lower subunit calibration models were run using different meteorological input data to determine the minimum level of data necessary to adequately simulate stream temperature.

The middle subunit model was used to determine if results based on meteorological data from Reno airport and Tracy Powerplant were superior to those based on the Reno airport alone. Except for the meteorological inputs, all other model inputs and parameters were held constant. Both models produced mean differences between observed and simulated stream temperatures at the Clark gaging station within 1.0°C for daily maximum, daily minimum, and hourly stream temperatures. The differences of daily maximum, daily minimum, and hourly mean absolute errors between the two models were not greater than 0.1°C. Thus, stream temperatures in the middle subunit were modeled accurately using only meteorological data from Reno airport.

The benefits, if any, of meteorological input data from multiple stations were tested differently for the lower subunit. Two models were calibrated; one model using S Bar S Ranch meteorological data and the other model using meteorological data from Reno airport. Two models were run because of the distance from Reno to the lower subunit (20 to 60 river miles) and the differences in physiographic characteristics between the middle and lower subunits. The Truckee River flows through a deeply incised canyon for much of the lower subunit. Therefore, a different set of model parameters might be necessary to successfully model stream temperatures in the lower subunit using these meteorological inputs. The Tracy Powerplant meteorological data were not used because of the nearly identical results using only Reno airport data for middle subunit calibration.

The results were very similar for the two models using meteorological data from S Bar S and Reno airport. The mean absolute errors for daily maximum, daily minimum, and hourly stream temperatures at the Marble Bluff gaging station were compared and the difference was less than 0.2°C between the two models. The results remained approximately the same at Marble Bluff when the full model was run using the two lower subunit models. Therefore, only meteorological data from Reno airport were used to simulate stream temperature for the middle and lower subunits.

Sensitivity of the Dissolved-Solids Model to Selected Input Data

Sensitivity of the dissolved-solids model to selected estimates of input data was determined because all of the input data had to be estimated. Model runs were made to find the best combination of estimated data. Estimated data are specific conductance for ungaged inflows in the upper subunit and for periods of missing conductance record. Estimated data also are dissolved-solids concentrations from specific-conductance values, and dissolved solids for ground-water inflows to the lower subunit.

Four estimates of specific-conductance time series were made for upper and middle subunits ungaged inflows. Three of the four estimates were made using Martis Creek data. The first estimate was made using the linear relation between specific conductance and streamflow (table 3, eq. 3). The second estimate was made using the monthly mean value (each month the monthly mean value was used for each day of that month). The third estimate was made using the annual mean (the mean value was used for each day of that year). The fourth estimate was made using the linear relation between specific conductance and streamflow developed from data for Bronco, Dog, and Hunter Creeks data (table 3, eq. 5). Dissolved-solids concentrations were estimated from each of these four specific-conductance estimates using the linear relation between specific conductance and dissolved solids determined for the upper and middle subunit ungaged inflows (table 3, eq. 4).

The results of four model runs showed that different estimates of dissolved solids changed simulation results at Farad gaging station. These results were expected because the estimates are the major inputs upstream from Farad gaging station. Changes were less pronounced at the Clark gaging station and almost disappeared at the Nixon gaging station. The final model used the linear relation between specific conductance and streamflow developed from Martis Creek data (table 3, eq. 3) to estimate the specific-conductance time series for ungaged inflows. This linear relation provided the best dissolved-solids simulations at the Farad gaging station.

The linear relation between specific conductance and dissolved solids initially used to estimate dissolved solids for TMWRF effluent (table 3, eq. 8) was not very strong ($r^2 = 0.50$). Therefore, another estimate was made using the stronger linear relation ($r^2 = 0.85$) developed for upper and middle subunits ungaged inflows (table 3, eq. 4). Simulation results using these two estimates showed that the estimate using equation 4 had a slightly better dissolved-solids simulation at the Clark gaging station. However, the difference in simulations disappeared at the Nixon gaging station because of the increase in dissolved solids between the Clark and Nixon gaging stations. The lower subunit had little sensitivity to estimates of TMWRF effluent dissolved solids. Consequently, this estimate (eq. 4) was used in the final model.

Model runs were made using the three estimates of dissolved solids in the ground-water inflow to the lower river to determine which estimate would provide the best dissolved-solids simulation. A fourth estimate was included which was a combination of TMWRF data and estimates from Bratberg and others (1982). The results indicated that changes in the estimates of dissolved-solids concentrations in ground-water inflow greatly affected model simulations at low flows. Differences were minor at high flows because of dilution. TMWRF data in combination with estimates and modified estimates from Bratberg and others (1982) provided the best dissolved-solids simulations at the Nixon gaging station. The estimated dissolved-solids concentrations used for model input data are listed in table 4.

RESULTS OF DAILY STREAMFLOW, HOURLY STREAM TEMPERATURE, AND DAILY DISSOLVED-SOLIDS SIMULATIONS

Observed data and simulation results were compared for daily streamflow, hourly stream temperature, and daily dissolved solids at one gaging station from each of the three subunits. The intent was to use the most downstream gaging station of each subunit where all three stream characteristics were measured. However, for the middle and lower subunits, this approach was not possible. Farad gaging station (reach 240; pl. 1) was used for the upper subunit. In the middle subunit, no stations in the lower part of the subunit (below the Truckee Meadows) had data on all three characteristics. Also, missing data precluded the use of certain stations in this subunit. The result was the use of three gaging stations in the middle subunit (fig. 2; pl. 1): Vista (reach 390) for stream temperature, Tracy (reach 430) for streamflow, and Clark (reach 440) for dissolved solids. Two gaging stations were used in the lower subunit: Nixon (reach 540) for streamflow and dissolved solids, and Marble Bluff (reach 570) for stream temperature.

Observed and simulated data were compared graphically and statistically. The graphical comparisons show visually what the statistics show quantitatively. Graphs show all of the data so that trends and anomalies are visible, whereas the statistics show an aggregation of the data which can hide these characteristics. Conversely, when the visual representation of all the data can be misleading (for example, when values have a large scatter, a few points are very different from the rest, or differences are subtle), a statistical aggregation can quantitatively show these differences. Two types of graphs, scatterplots and time-series plots, were used to compare observed and simulated data. The statistical measures, mean absolute error, bias, and standard error of estimate were used to compare simulated with observed data.

Time-series plots show variations in the observed values and the differences between observed and simulated values over time (hourly, daily, monthly, or seasonal). Scatterplots show observed (x) and simulated (y) data pairs plotted as points in relation to a line having a slope of 1 and y-intercept of 0. If all simulated values were the same as the corresponding observed values (no simulation errors), all of the points would fall exactly on the line. The distance points are from the line indicates the difference between observed and simulated values (the error), a greater distance indicates a larger simulation error. Deviation from this line also is a visual indication of bias. Points that are above this line indicate a positive bias (simulated value overestimated) and points below this line indicate a negative bias (simulated value underestimated). A plot with points distributed equally above and below the line over the entire range of values indicates no overall bias. The scatter or spread in the points is an indication of the variability in the differences between observed and simulated values. A plot with the points bunched closely over the entire range of values indicates small variability in the differences between observed and simulated.

Mean absolute error is the arithmetic average of absolute values (no regard to sign) of the differences between observed and simulated data. Bias is the arithmetic average of the differences between observed and simulated data including positive and negative values. Unless very large differences exist, a large positive bias indicates the model generally is overestimating the characteristic being simulated, and a large negative bias indicates the model generally is underestimating the characteristic being simulated. The greater the bias, the more likely the model is consistently overestimating or underestimating the characteristic of interest. The standard error of estimate is the standard deviation (a measure of variability) of the differences between observed and simulated data after the bias is removed. When the differences are normally distributed, two-thirds of the simulated data are within plus or minus one standard error of estimate of the observed data. For streamflow and dissolved solids, mean absolute error and bias also are reported as a percentage of observed data because streamflow data ranged between about 0 and 5,500 ft^3/s and dissolved-solids data ranged between about 50 and 800 mg/L. These wide ranges in values make differences easier to see (i.e. between flow classes) in relative terms than as actual data values. Stream-temperature data involved much smaller values ranging between 0 and 30°C, so that percentages are not necessary.

Statistical comparisons for the flow-routing and dissolved-solids models were made using three flow classes: flows from 0 to 99 ft^3/s inclusive (low flow), flows from 100 to 499 ft^3/s inclusive (middle flow), and flows greater than or equal to 500 ft^3/s (high flow). Also, an "all-flows" class was included. Statistical comparisons for the stream-temperature model were made using a low flow class of 10 to 99 ft^3/s and an all flows class of flows greater than or equal to 10 ft^3/s. Flows less than 10 ft^3/s were not used for the stream-temperature model because of the problems encountered at very low flows. This is explained further in the "Stream Temperature, Validation Period" section. Flow-routing model comparisons were divided into flow classes by observed flow. For the stream-temperature and dissolved-solids models, comparisons were divided into flow classes by simulated flow because simulated flows drive the stream-temperature and dissolved-solids models.

Streamflow

Results of daily streamflow simulations from the stream-temperature and dissolved-solids models were combined into one time period (June 1, 1993, through September 30, 1995) and compared with observed data at the following three gaging stations: Farad, Tracy, and Nixon (figs. 4-7, table 6). These stations also are reported by Berris (1996).

The time-series plots (figs. 4-6) show the high streamflows in late spring and early summer which are typical of streams dominated by snow hydrology, but the flows are influenced by the operations of reservoirs. Note the sharp drop in streamflow in late June and July. These plots show that simulated streamflows generally follow observed streamflows. Overall the closest fit between observed and simulated streamflow is at the Tracy gaging station (fig. 5).

The scatterplots show small errors between observed and simulated streamflow at Farad (fig. 7*A*) and Tracy (fig. 7*B*) gaging stations, and increased errors during low flows at Nixon (fig. 7*C*) gaging station. A small positive bias is shown for the entire range of values at Farad, little or no overall bias at Tracy, and a variable bias at Nixon.

Statistical results for streamflow are similar to those reported by Berris (1996, table 7) for the period October 1, 1977, through September 30, 1992 (table 6). In general, percent of mean absolute errors decreases with increasing flow at each of the three stations. For the Farad and Tracy gaging stations, the decreases in percent mean absolute errors from the 0-99 ft^3/s flow class to the 100-499 ft^3/s flow class were about 15 percent at both stations (table 6). Mean absolute errors for the all-flows class were about 12 percent for both stations. At the Nixon gaging station, where the all-flows mean absolute error (37 percent) and standard error of estimate (65 percent) were highest, the percent error decreases significantly when flows are greater than 500 ft^3/s. As with mean absolute errors, the bias tended to decrease with increasing flow. The largest biases (more than 20 percent) are in the low flow class for the Farad and Nixon gaging stations. The percent bias generally was lower at the Tracy station than at the other two stations.

The mean bias and the percent bias could have the opposite sign. For example, at Nixon gaging station the overall mean bias is negative but the overall percent bias is positive (table 6). These opposite biases occurred at Nixon because the magnitude of the negative errors in the middle and high flow classes overwhelmed the smaller magnitude positive errors in the low flow class. However, the large positive percent bias in the low flow class overwhelmed the small negative percent bias in the middle and high flow classes.

Stream Temperature

The three subunit models that provided the best simulations were combined into a single model for the mainstem Truckee River from Tahoe City to Marble Bluff. The single model is the calibrated Truckee River hourly stream-temperature model. Results of the hourly stream-temperature simulations were compared with observed data at the Farad, Vista, and Marble Bluff gaging stations, representing the upper, middle, and lower subunits, respectively. A short discussion of results at the Wadsworth gaging station for the validation period was included to illustrate an instability found in the new streambed conductance algorithm.

Calibration Period

The stream-temperature model was calibrated at Farad, Vista, and Marble Bluff gaging stations for the period June 1, 1993, through May 31, 1994. Comparisons of observed and simulated stream-temperature data are shown in figures 8-13 and listed in tables 7-9.

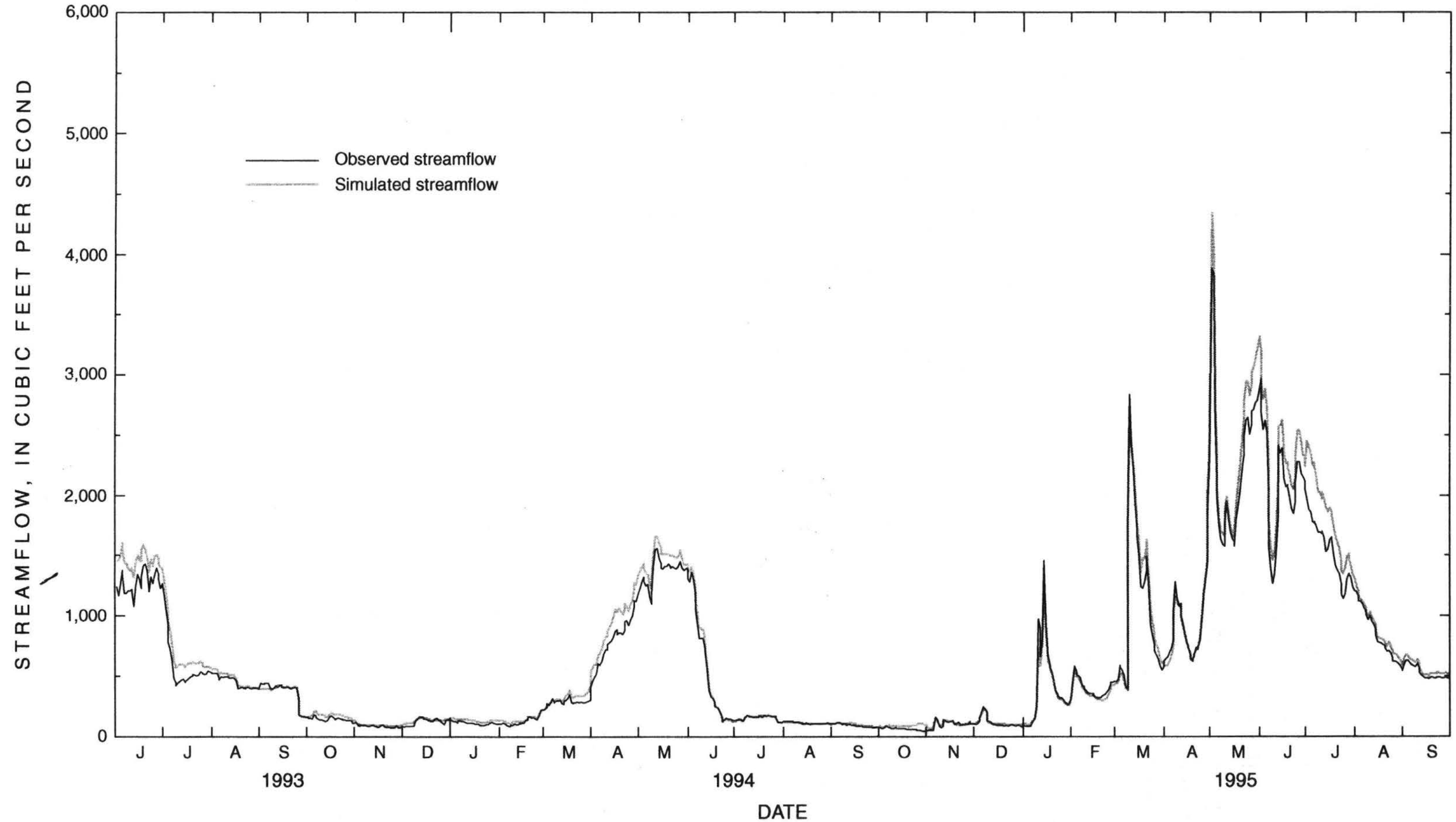

Figure 4. Observed and simulated daily streamflow from June 1, 1993, through September 30, 1995, for Truckee River at Farad, Calif.

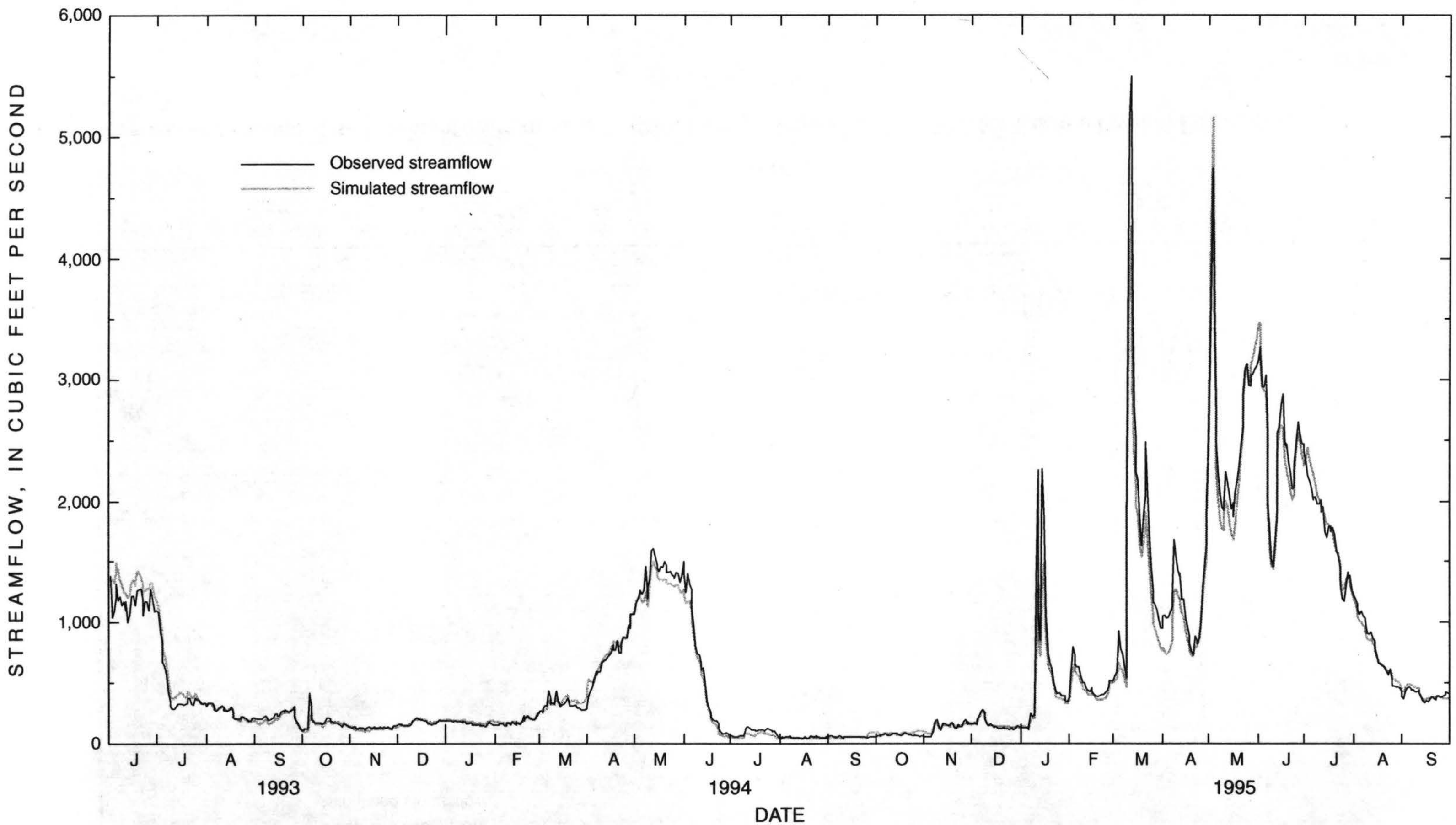

Figure 5. Observed and simulated daily streamflow from June 1, 1993, through September 30, 1995, for Truckee River below Tracy, Nev.

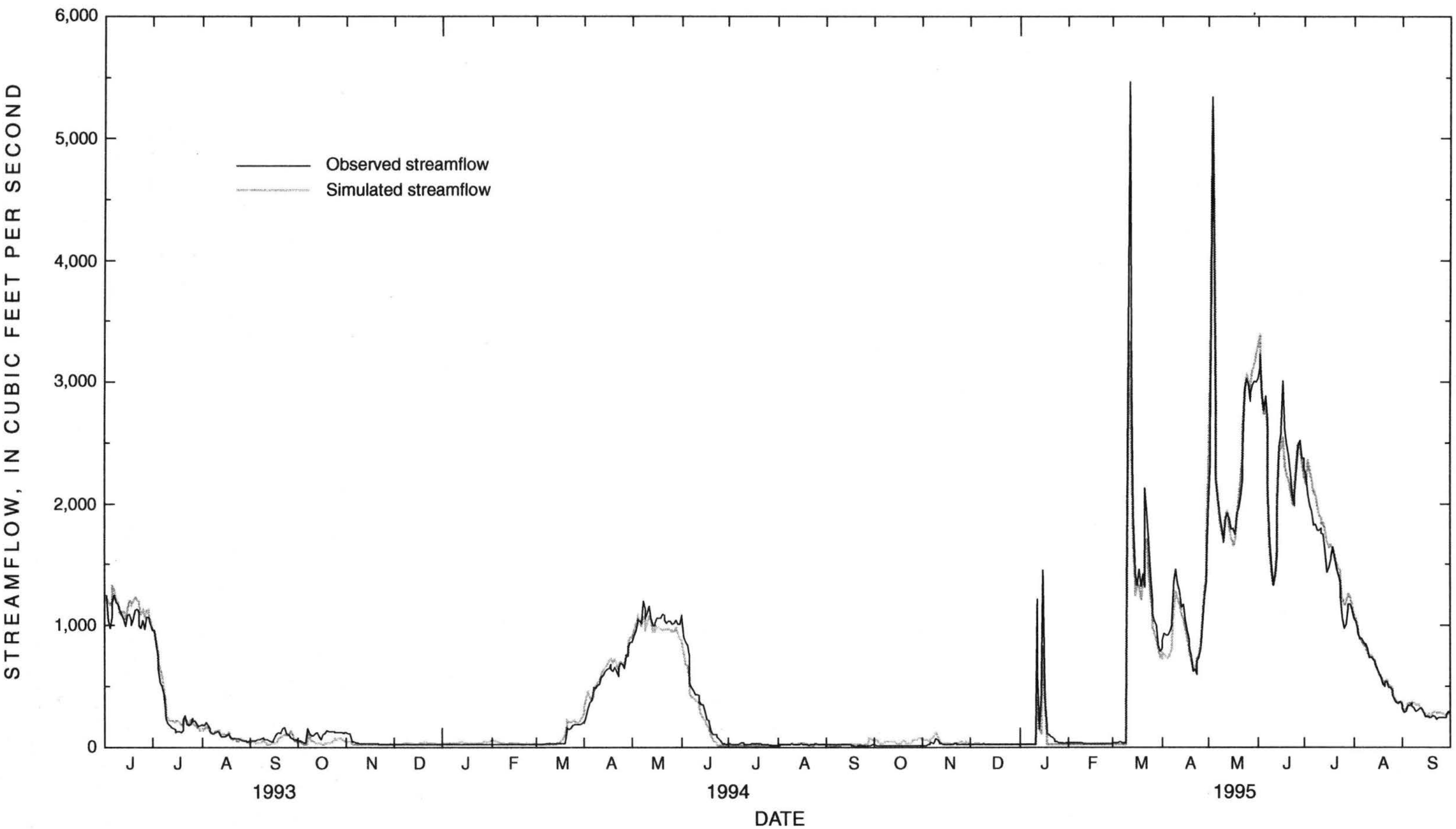

Figure 6. Observed and simulated daily streamflow from June 1, 1993, through September 30, 1995, for Truckee River near Nixon, Nev.

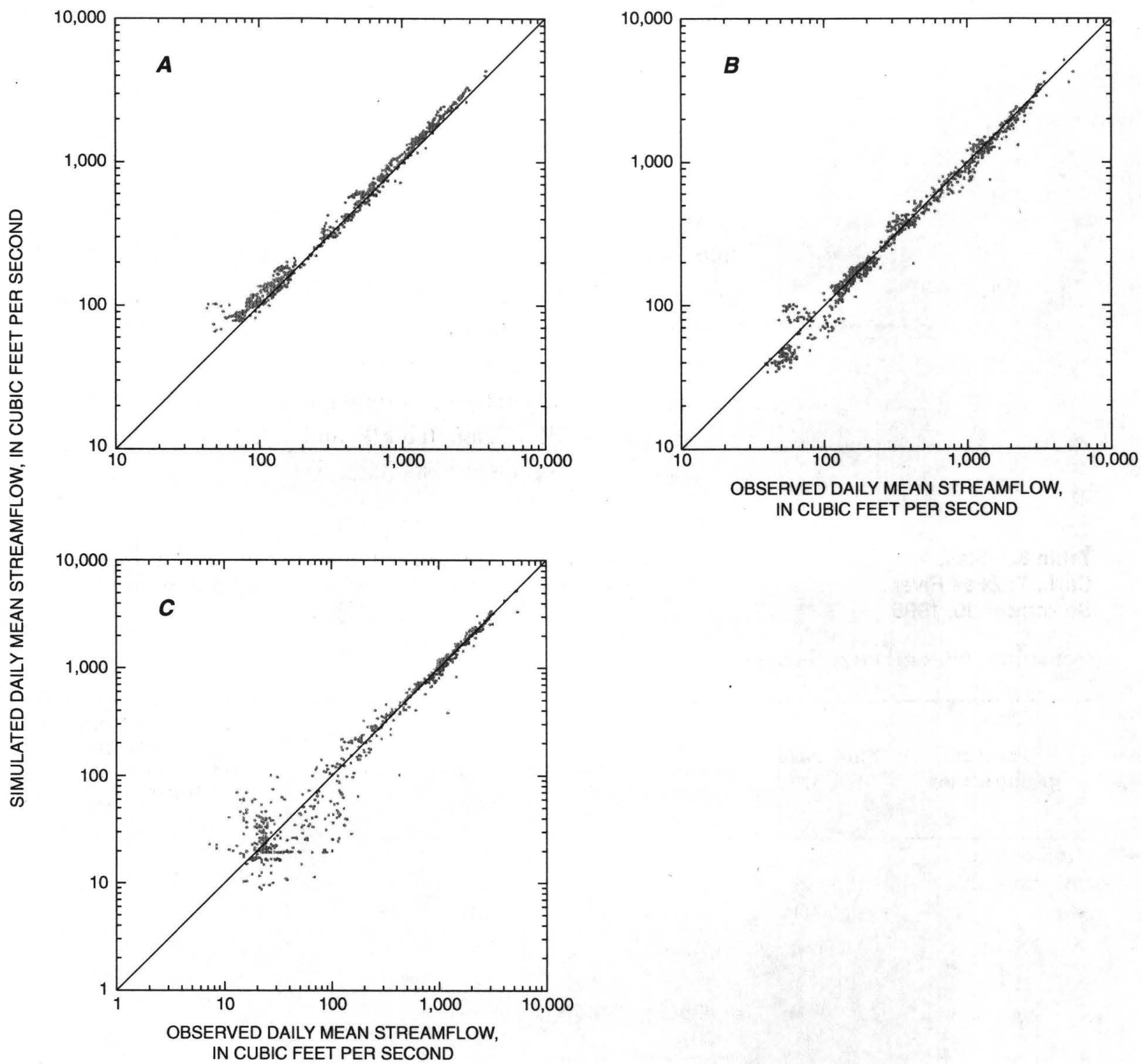

Figure 7. Relation between observed and simulated streamflow from June 1, 1993, through September 30, 1995, for (*A*) Truckee River at Farad, Calif., (*B*) Truckee River below Tracy, Nev., and (*C*) Truckee River near Nixon, Nev.

Early in the model calibration, a phase difference between observed and simulated stream temperatures became apparent, as evidenced by the graphical time-series traces (figs. 8-10). The negative bias at Farad and Marble Bluff gaging stations in the hourly stream-temperature data is probably due to the phase shift between observed and simulated temperatures. Bias generally is positive on the rising limb of the daily thermograph and negative on the falling limb of the daily thermograph, because simulated hourly stream temperatures tend to rise or fall ahead, in time, of observed hourly stream temperatures. The phase shift shown in figures 8 and 10 is more pronounced on the falling limb of the daily thermograph, which tends to make the net hourly bias negative each day. The hourly bias generally is small because the rising side of the daily thermograph cancels out the falling side to some degree. The phase difference, was not consistent and at times disappeared. During the calibration process, many of the model parameters were adjusted to improve or eliminate this phase difference without success. No calibration parameter was found to improve the timing of simulated stream temperatures only the magnitude of simulated stream temperatures could be consistently altered.

Scatterplots of daily maximum, daily minimum, and hourly stream temperatures were similar at Farad, Vista, and Marble Bluff gaging stations (figs. 11-13). Bias and variability in the errors at each station appeared to be fairly uniform and small throughout the range of values. Looking at individual stations the plots indicate a negative bias for daily and hourly values at Farad and for daily minimum and hourly values at Marble Bluff. Little or no bias is seen for daily and hourly values at Vista and daily maximum values at Farad and Marble Bluff.

The statistical comparisons of daily maximum, daily minimum, and hourly stream temperatures, when all flows were considered, confirm the visual observations from the scatterplots. Mean absolute errors for the all-flows class were less than or equal to 1.0°C (tables 7-9). Bias was negative ranging from -0.6 to 0.0°C for the all-flows class at Farad, Vista, and Marble Bluff gaging stations and the variability as measured by the standard error in the mean absolute errors at each station generally was 1.0°C. At individual gaging stations, the mean absolute error decreased as flow increased and the smallest errors were at Vista. A negative bias (-0.6 to -0.2°C) is seen in the daily maximum, daily minimum, and hourly values at Farad (table 7) and in the daily minimum and hourly values at Marble Bluff Dam (table 9), and little or no bias (-0.3 to 0.0°C) is seen at Vista (table 8).

Table 6. Statistical comparison of observed and simulated daily streamflow for Truckee River at Farad, Calif., Truckee River below Tracy, Nev., and Truckee River near Nixon, Nev., June 1, 1993, through September 30, 1995

[Abbreviation: ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Name of gaging station	Flow class (ft^3/s)	Number of values compared	Mean absolute error [1]		Mean bias [2]		Standard error of estimate [3]	
			Mean (ft^3/s)	Percent	Mean (ft^3/s)	Percent	Mean (ft^3/s)	Percent
Truckee River at Farad, Calif.	0-99	136	16.9	24.5	16.5	24.0		
	100-499	385	21.0	9.0	12.9	5.9		
	≥500	331	131	10.3	119	8.9		
	All flows	852	63.1	12.0	54.7	10.0	91.4	14.7
Truckee River below Tracy, Nev.	0-99	117	14.8	24.6	0.5	0.9		
	100-499	428	22.3	9.9	.3	-1.0		
	≥500	307	132	8.9	-66.7	-4.1		
	All flows	852	60.8	11.6	-23.8	-1.8	125	16.4
Truckee River near Nixon, Nev.	0-99	435	14.5	58.7	2.3	27.4		
	100-499	153	44.8	25.9	-8.2	-7.6		
	≥500	264	108	7.8	-15.0	-.5		
	All flows	852	49.0	37.0	-4.9	12.5	114	65.0

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$

$$Percent = 100 \times \Sigma(|S-O|/O)/n$$

[2] Bias: $Mean = \Sigma(S-O)/n$

$$Percent = 100 \times \Sigma(((S-O)/O)/n)$$

[3] $Standard\ error\ of\ estimate = \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

$$Percent = \sqrt{\langle n/(n-1)\rangle \times (100 \times (\Sigma(((S-O)/O)^2)/n) - (Percentbias)^2)}$$

(Where S = simulated daily mean streamflow, in cubic feet per second; O = observed daily mean streamflow, in cubic feet per second; n = number of pairs of daily values for which O > 0 in the simulation period; and || = absolute value.)

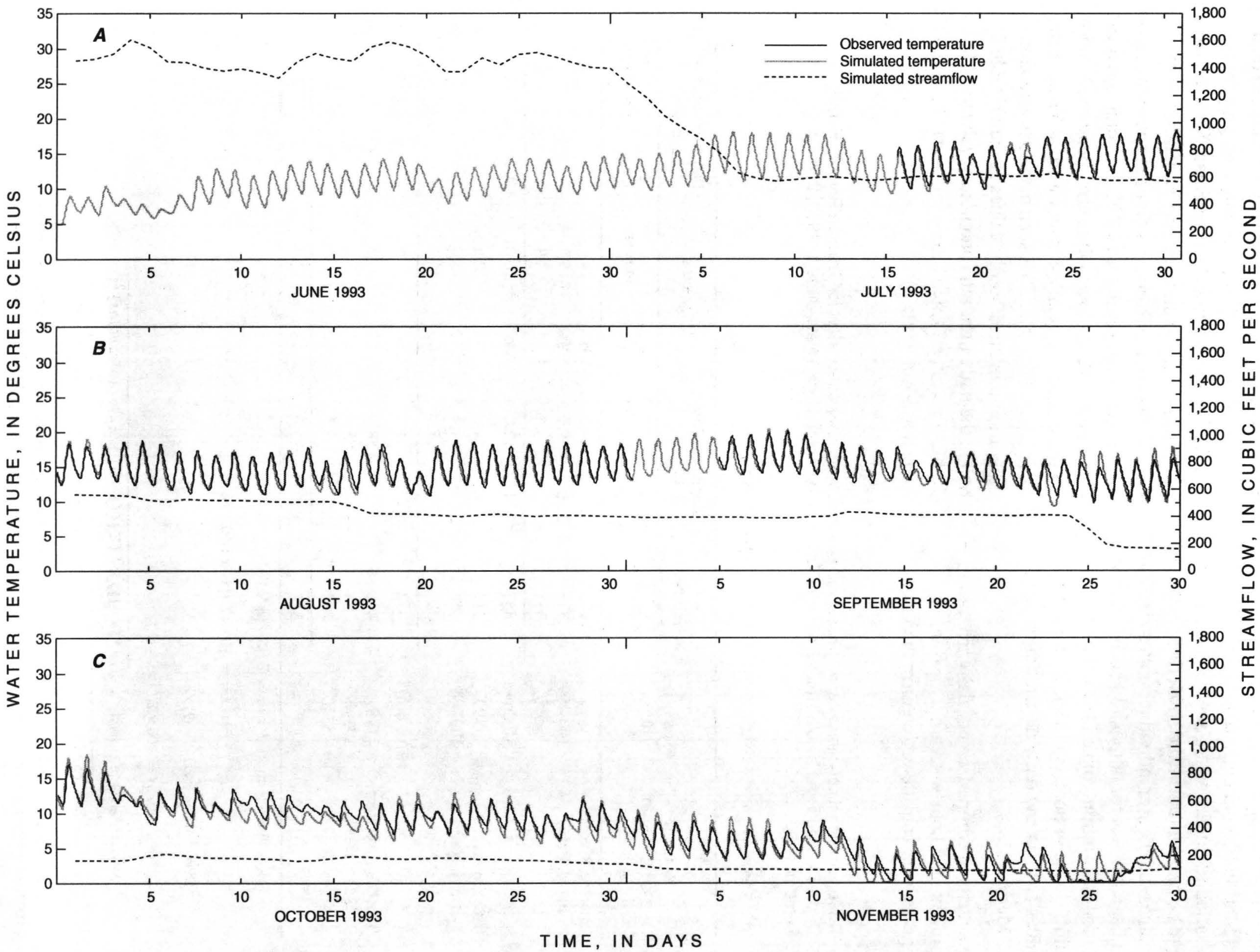

Figure 8. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Farad, Calif.

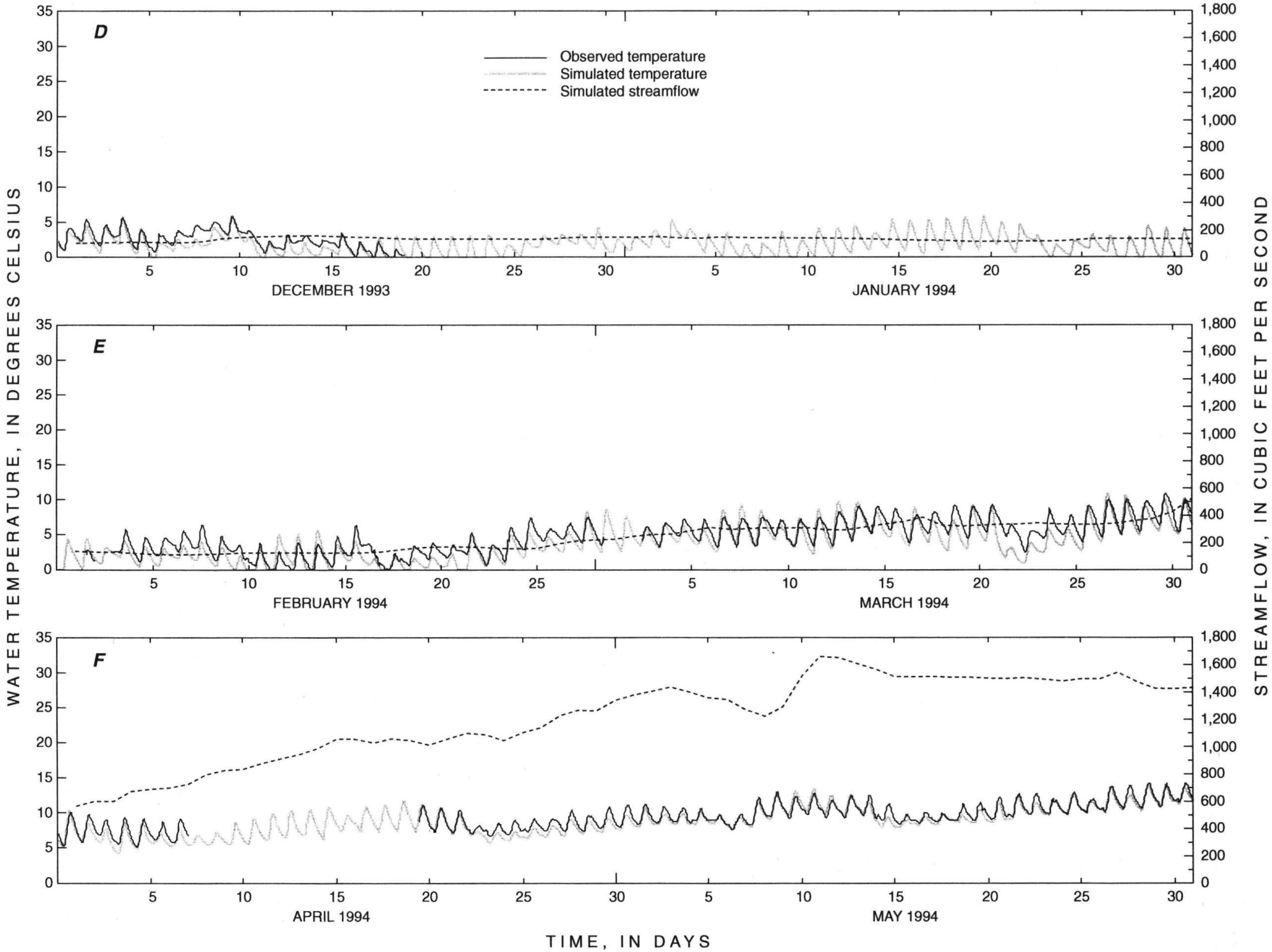

Figure 8. Continued.

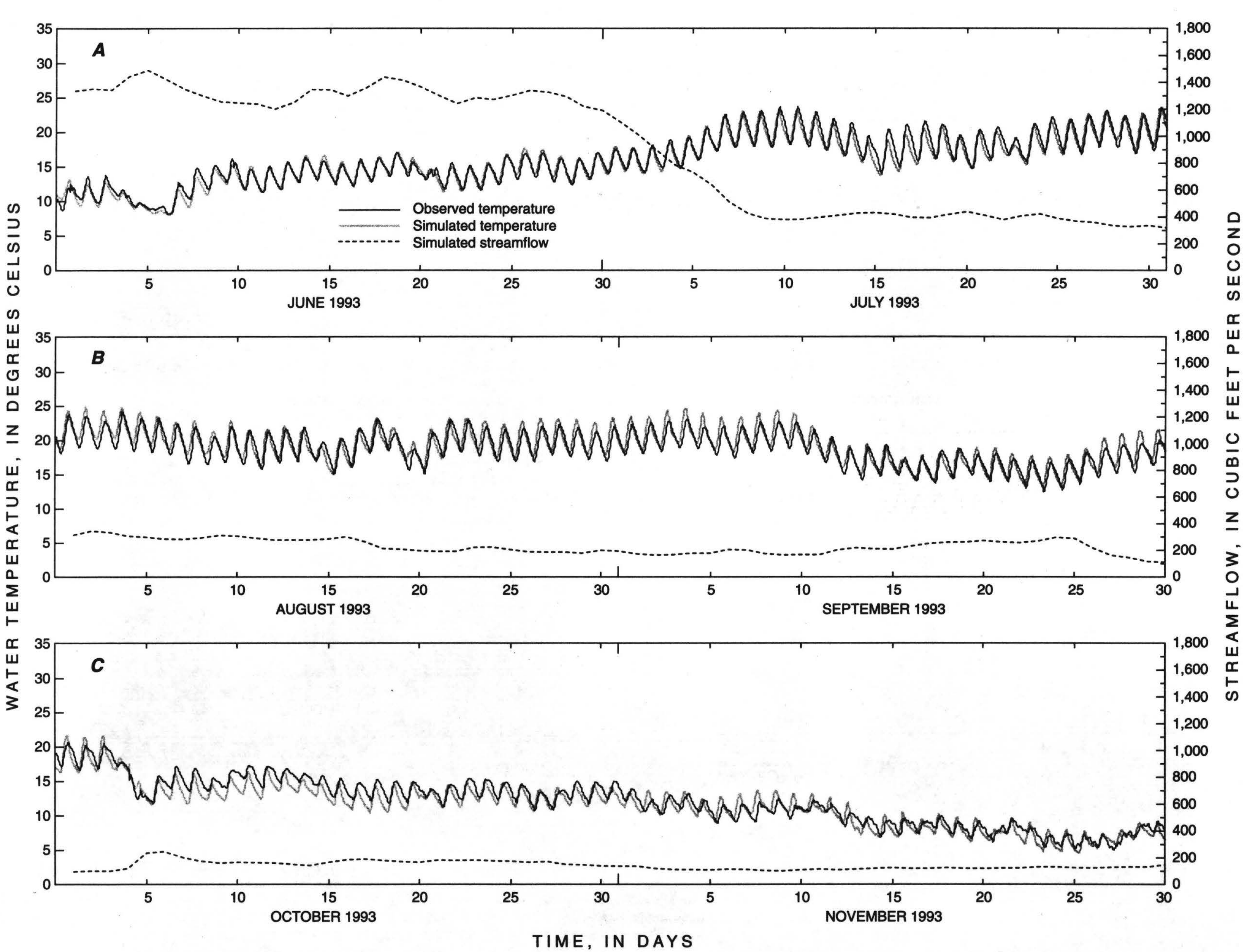

Figure 9. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Vista, Nev.

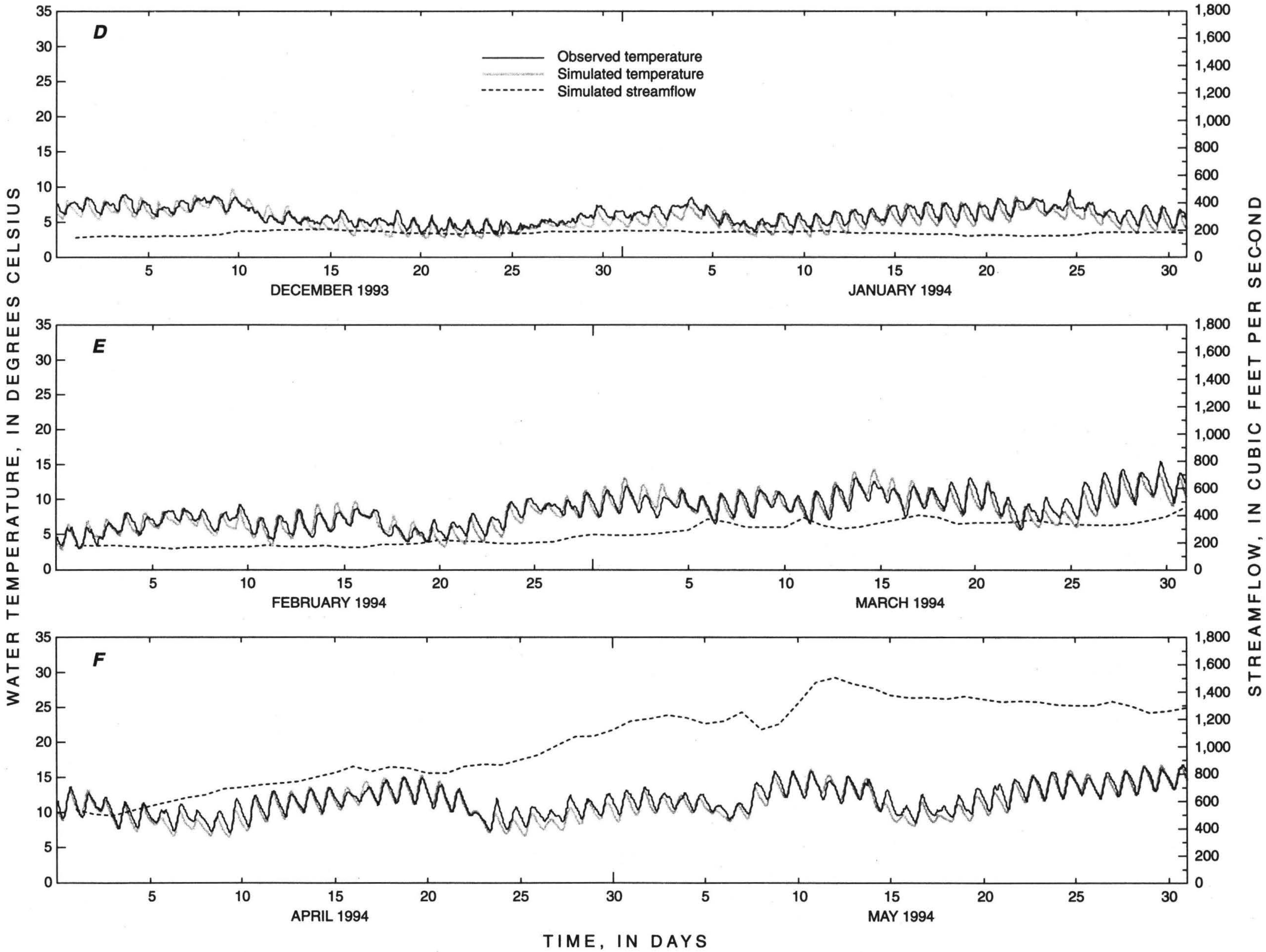

Figure 9. Continued.

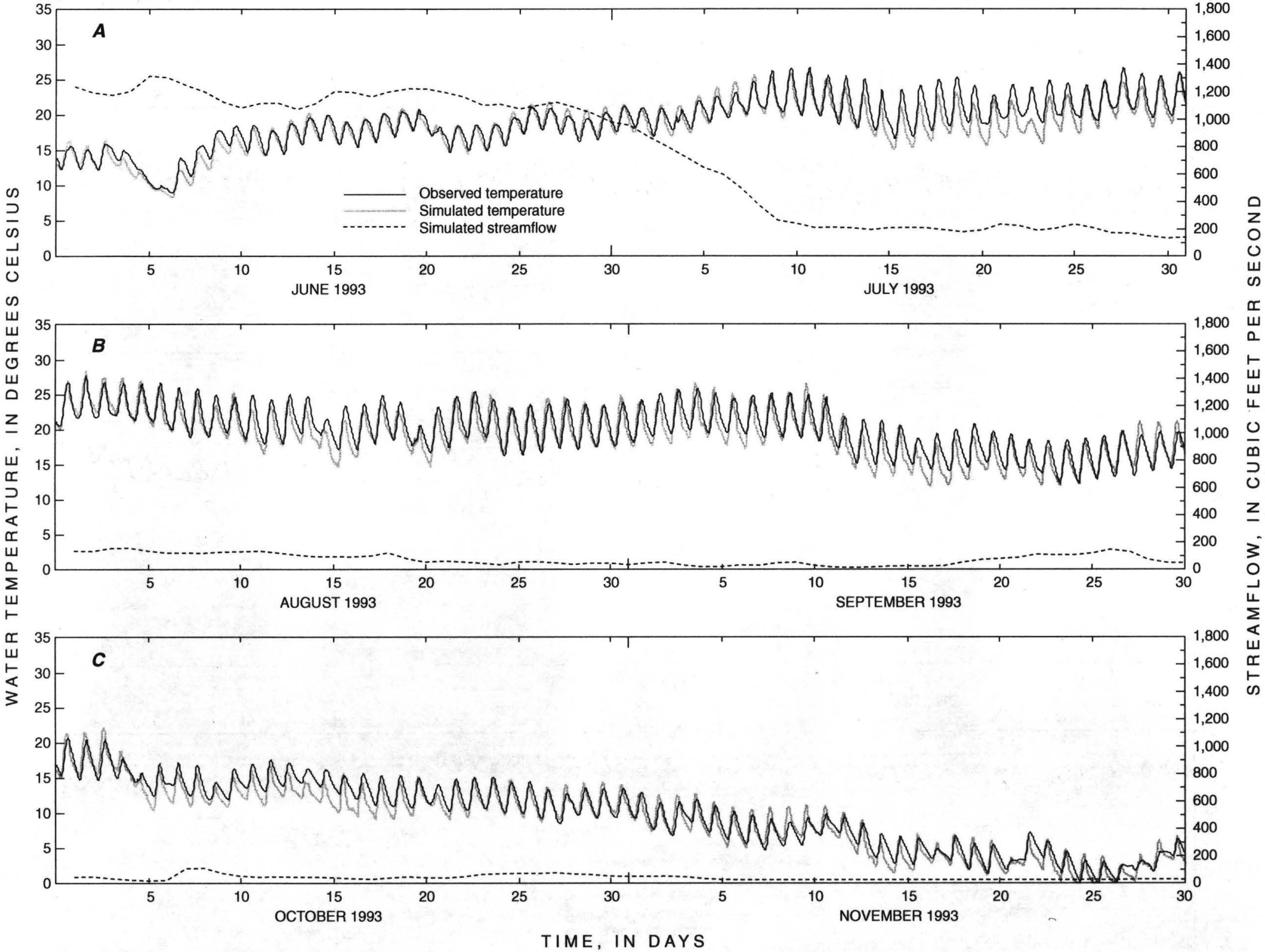

Figure 10. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Marble Bluff Dam, Nev.

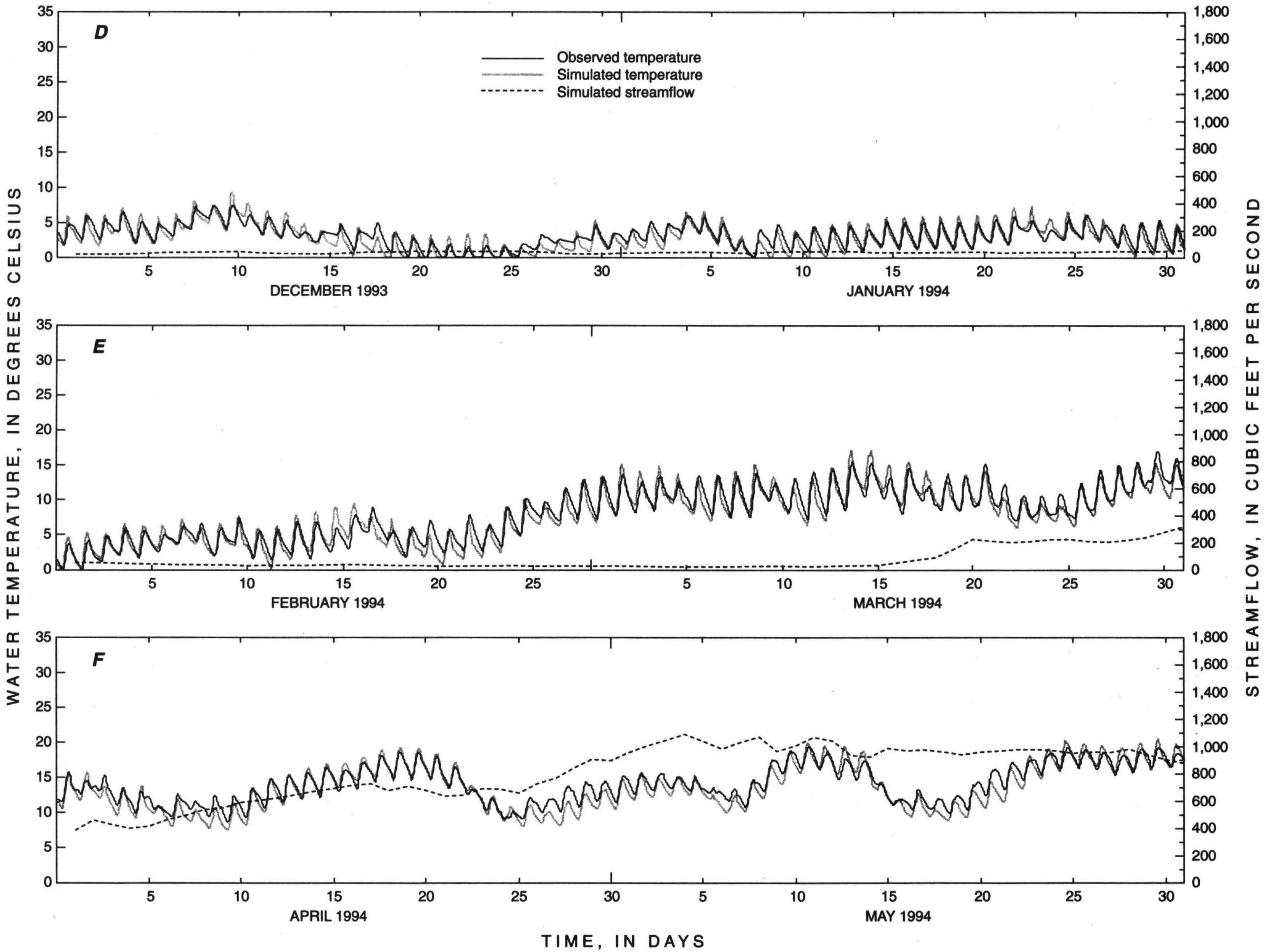

Figure 10. Continued.

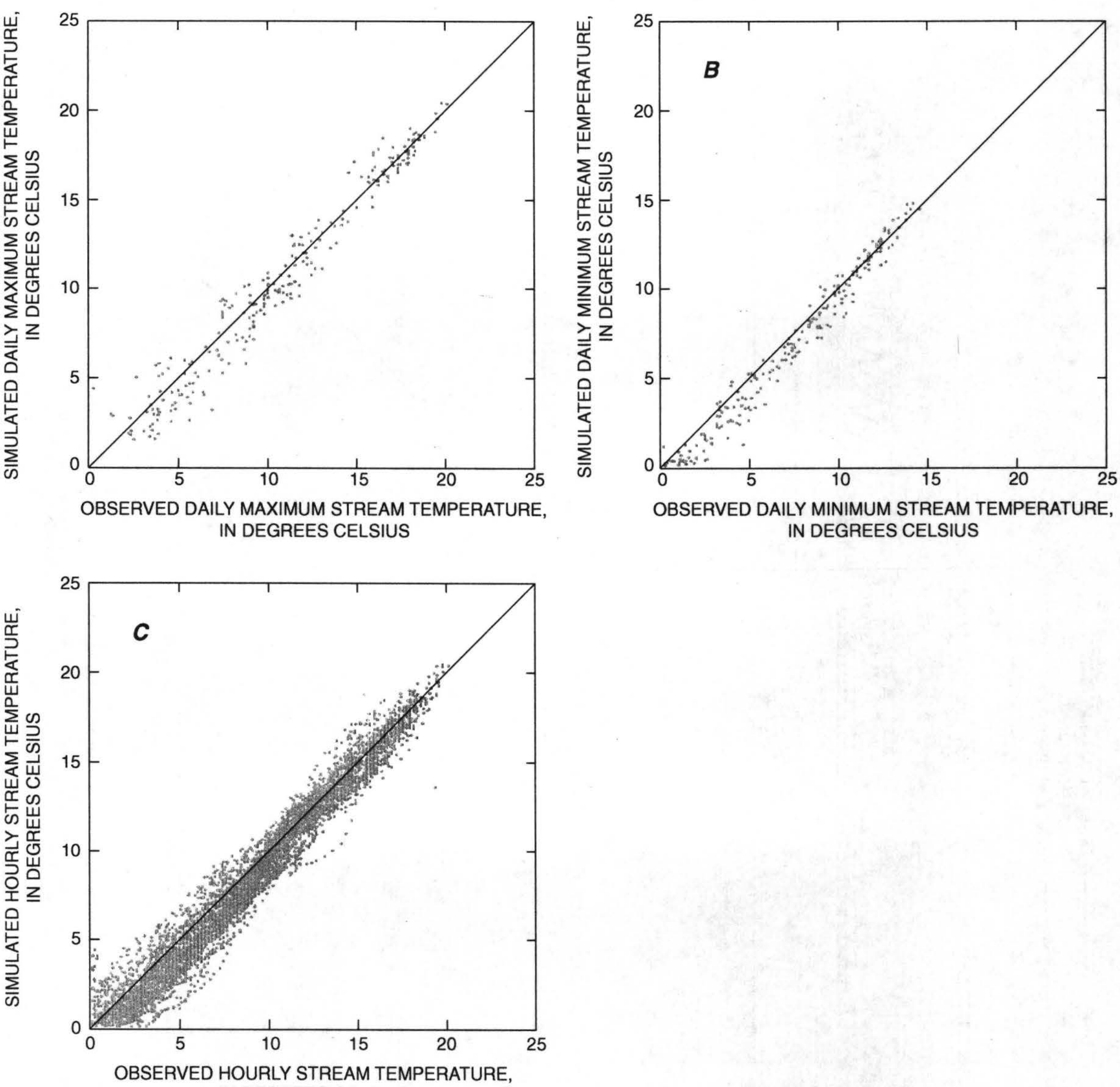

Figure 11. Relation between observed and simulated stream temperature for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Farad, Calif., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

The models were calibrated under a specific set of conditions (meteorological, tributary and ground-water inputs, instream, and riparian vegetation) and the evaluation of model results shown only pertains to those conditions. Changing conditions may require updated model input data sets and, for the stream-temperature model, recalibration. An example of changing conditions are restoration of the lower Truckee River riparian zone, the planting of trees, and increased population in the Truckee Meadows with accompanying changes in water use. Mature trees would increase shading during the summer and could alter ground-water flow to the river, both of which might require model recalibration. Improvements in model input data might also necessitate model recalibration. At the least, certain environmental changes in the Truckee River system or model input data will require reevaluation of the model to determine if recalibration is necessary.

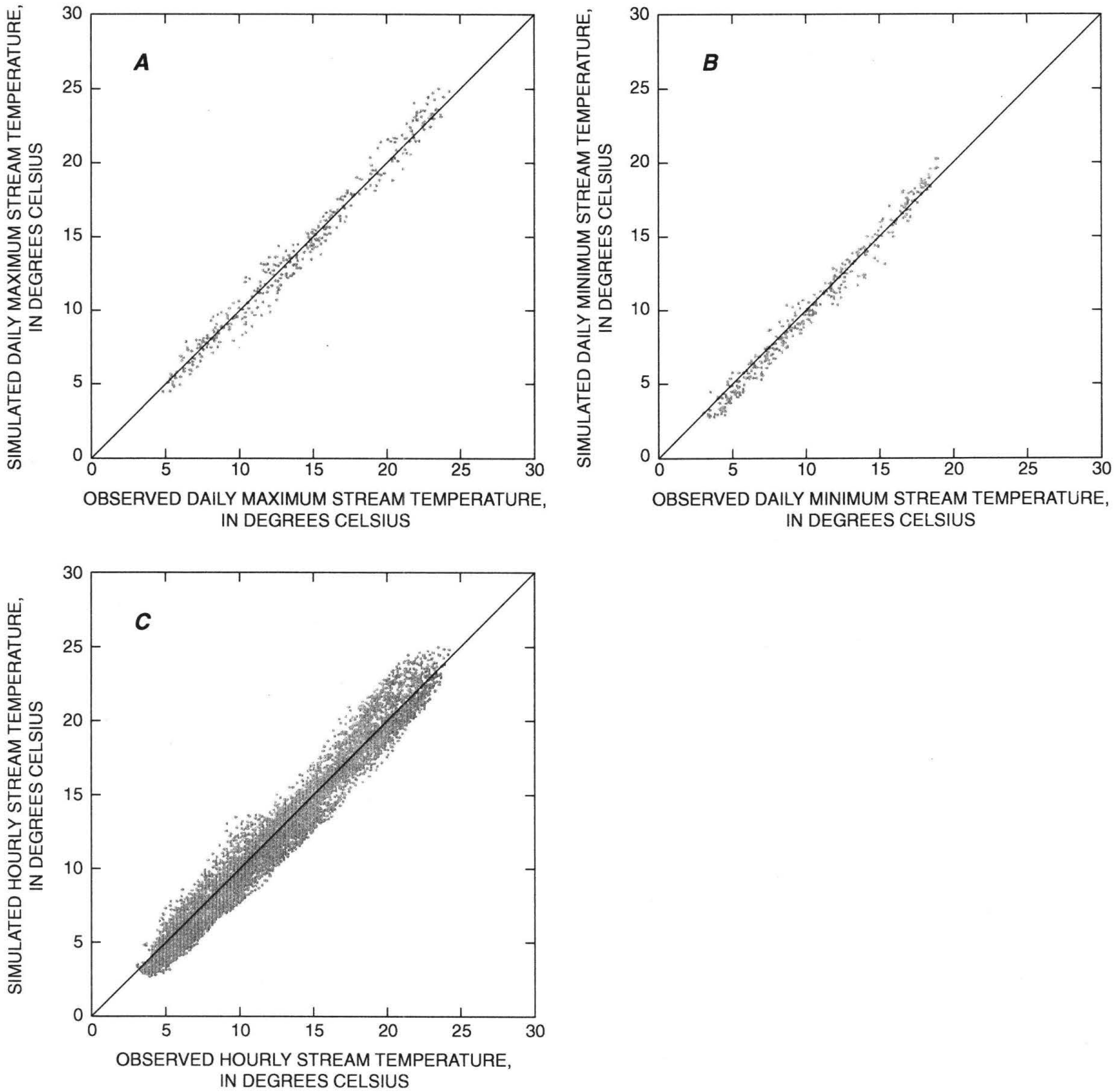

Figure 12. Relation between observed and simulated stream temperature for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Vista, Nev., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

Validation Period

The calibrated stream-temperature model was validated at Farad, Vista, and Marble Bluff gaging stations for the period June 1 through September 30, 1994. This validation period was used because data were available and it included summer streamflow lower than the 1993 calibration period. The maximum streamflow at the Nixon gaging station for July-September 1994 was less than the minimum streamflow for the same site and period in 1993 (38 and 45 ft^3/s, respectively). Low summer streamflow creates the potential for higher stream temperatures and larger daily fluctuations between maximum and minimum stream temperatures. Generally, lower flows have lower volume, shallower depths, and slower velocity; thus, external forces have a greater affect on the water. The validation period, therefore, should be a robust test of the model to simulate low-flow stream temperatures. Comparisons of observed and simulated stream-temperature data are shown in figures 14-19 and listed in tables 10-12.

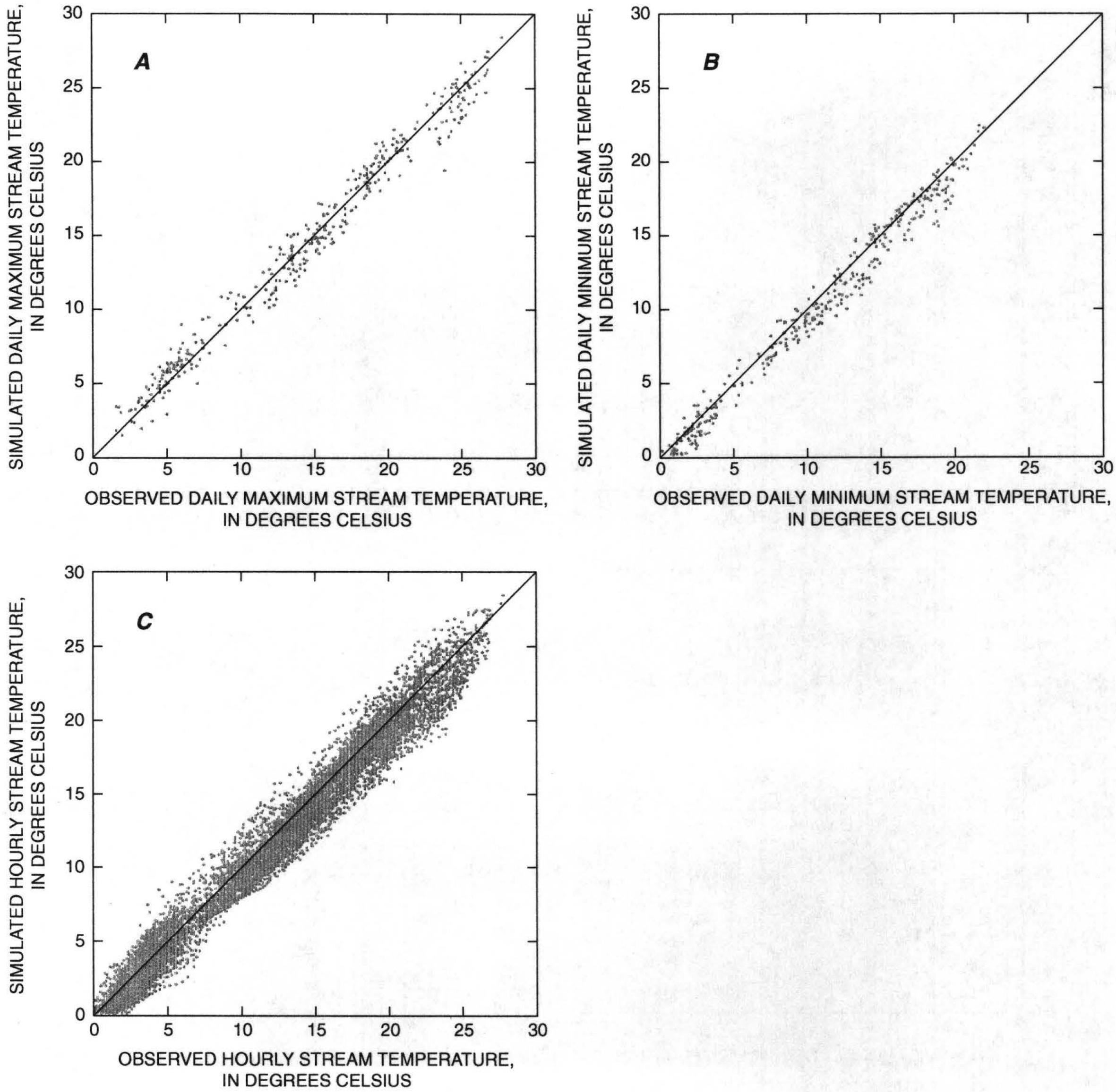

Figure 13. Relation between observed and simulated stream temperature for the stream-temperature model calibration period June 1, 1993, through May 31, 1994, for Truckee River at Marble Bluff Dam, Nev., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

For the validation period, simulated stream temperatures of up to 67°C were found for reach 490 (pl. 1). The cause of these unrealistic stream temperatures was an instability in the streambed heat-conductance algorithm. When simulated stream depths were between 2 and 3 in. simulated heat was continually being added to the streambed which caused stream temperature to continually increase. Attempts were made to compensate for this instability by making adjustments to the existing stream-temperature model to increase simulated stream depths. It was possible to reduce the effects of the instability by reducing the time the depth was between 2 and 3 in., but the instability could not be eliminated. Therefore, the model was kept as originally calibrated, but a streamflow threshold was determined. Examination of discharge and channel geometry in several reaches yielded the conservative estimate of this streamflow as 10 ft^3/s. This threshold discharge was used so that results potentially affected by the instability could be eliminated when presenting comparative statistics.

Table 7. Statistical comparison of observed and simulated stream temperatures for Truckee River at Farad, Calif., calibration period from June 1, 1993, through May 31, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum	10-99	25	2	1.3	0.3	
	100-499	146	54	.9	-.2	
	≥500	79	59	.7	-.5	
	All flows ≥10	250	115	0.9	-0.2	1.1
Daily minimum	10-99	25	2	0.8	-0.7	
	100-499	146	54	.8	-.6	
	≥500	79	59	.4	-.2	
	All flows ≥10	250	115	0.7	-0.5	0.7
Hourly...........	10-99	657	4	1.0	-0.3	
	100-499	3,539	1,250	1.0	-.6	
	≥500	1,921	1,389	.6	-.4	
	All flows ≥10	6,117	2,643	0.8	-0.5	0.9

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$

[2] Bias: $Mean = \Sigma(S-O)/n$

[3] *Standard error of estimate* $= \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where *S* = simulated hourly stream temperature, in °C; *O* = observed hourly stream temperature, in °C; *n* = number of pairs of hourly values for which O > 0 in the simulation period; and || = absolute value.)

Table 8. Statistical comparison of observed and simulated stream temperatures for Truckee River at Vista, Nev., calibration period from June 1, 1993, through May 31, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum..	10-99	4	0	1.1	1.1	
	100-499	264	0	.6	.1	
	≥500	97	0	.6	-.3	
	All flows ≥10	365	0	0.6	0.0	0.8
Daily minimum ..	10-99	4	0	0.5	-0.3	
	100-499	264	0	.6	-.2	
	≥500	97	0	.5	-.2	
	All flows ≥10	365	0	0.6	-0.2	0.7
Hourly	10-99	95	0	1.2	0.2	
	100-499	6,357	0	.9	-.3	
	≥500	2,308	0	.6	-.3	
	All flows ≥10	8,760	0	0.8	-0.3	1.0

[1] Mean absolute error: $Error = \Sigma(|S-O|/n)$

[2] Bias: $Bias = \Sigma(S-O)/n$

[3] *Standard error of estimate* $= \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where *S* = simulated hourly stream temperature, in °C; *O* = observed hourly stream temperature, in °C; *n* = number of pairs of hourly values for which O > 0 in the simulation period; and || = absolute value.)

Table 9. Statistical comparison of observed and simulated stream temperatures for Truckee River at Marble Bluff Dam, Nev., calibration period from June 1, 1993, through May 31, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum	10-99	208	0	0.8	0.3	
	100-499	67	0	1.1	-.9	
	≥500	90	0	.7	.0	
	All flows ≥10	365	0	0.8	0.0	1.0
Daily minimum.	10-99	208	0	0.8	-0.6	
	100-499	67	0	1.0	-.9	
	≥500	90	0	.7	-.5	
	All flows ≥10	365	0	0.8	-0.6	0.9
Hourly........	10-99	4,997	0	1.1	-0.4	
	100-499	1,581	0	1.1	-.8	
	≥500	2,182	0	.8	-.4	
	All flows ≥10	8,760	0	1.0	-0.5	1.1

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$

[2] Bias: $Mean = \Sigma(S-O)/n$

[3] $Standard\ error\ of\ estimate = \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where S = simulated hourly stream temperature, in °C; O = observed hourly stream temperature, in °C; n = number of pairs of hourly values for which $O > 0$ in the simulation period; and || = absolute value.)

Results of the validation period June 1 through September 30, 1994, for the Farad, Vista, and Marble Bluff gaging stations are shown graphically in figures 14-19. The time-series plots (figs. 14-16) for the validation period show the phase shift. These figures also show an overall increase in stream temperatures and an increase in the maximum-minimum temperature range over the calibration period (figs. 8-10), which accompanied the lower flows present in 1994. The range between maximum and minimum temperatures was more constant for the Vista gaging station than for the Farad and Marble Bluff gaging stations. The consistency is probably due to the influence of the TMWRF, which contributed a large portion of the summer low flows that passed the Vista gaging station.

The scatterplots (figs. 17-19) for the validation period, when compared with the scatterplots (figs. 11-13) for the calibration period, are similar but with distinct differences. In all instances, the stream temperatures generally are higher and the scatter about the line of equal value is greater for the validation period. Biases present in the calibration period were magnified in the validation period and were evident at sites where no bias was present in the calibration period.

Results at Marble Bluff gaging station have the greatest change. For the calibration period, daily maximum values have no bias and a uniform distribution (fig. 13*A*). However, for the validation period, a distinct positive bias appears to increase with increasing temperature (fig. 19*A*). For the calibration period, daily minimum values have a negative bias and a uniform distribution (fig. 13*B*). The overall negative bias for the validation period appears to have remained, but the bias changes to near zero at higher temperatures (fig. 19*B*). For the calibration period, hourly results have a uniform negative bias (fig. 13*C*). However, for the validation period, hourly results have a negative bias at lower temperatures and a positive bias at higher temperatures (fig. 19*C*).

Results of statistical comparisons of observed and simulated stream temperatures for the validation period (tables 10-12) are compared with results for the calibration period (tables 7-9). Results at Farad, Vista, and Marble Bluff gaging stations for the all-flows class

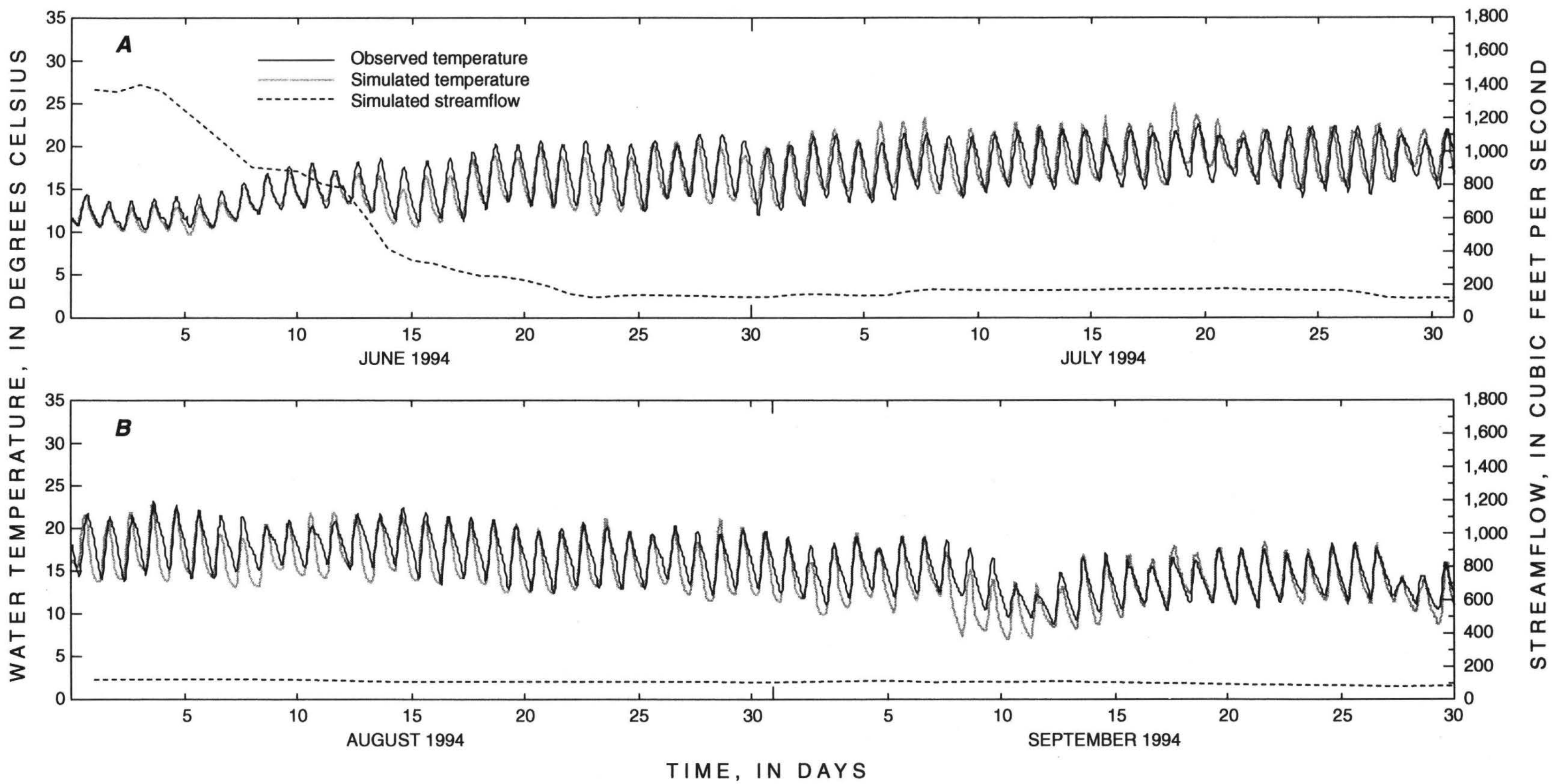

Figure 14. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Farad, Calif.

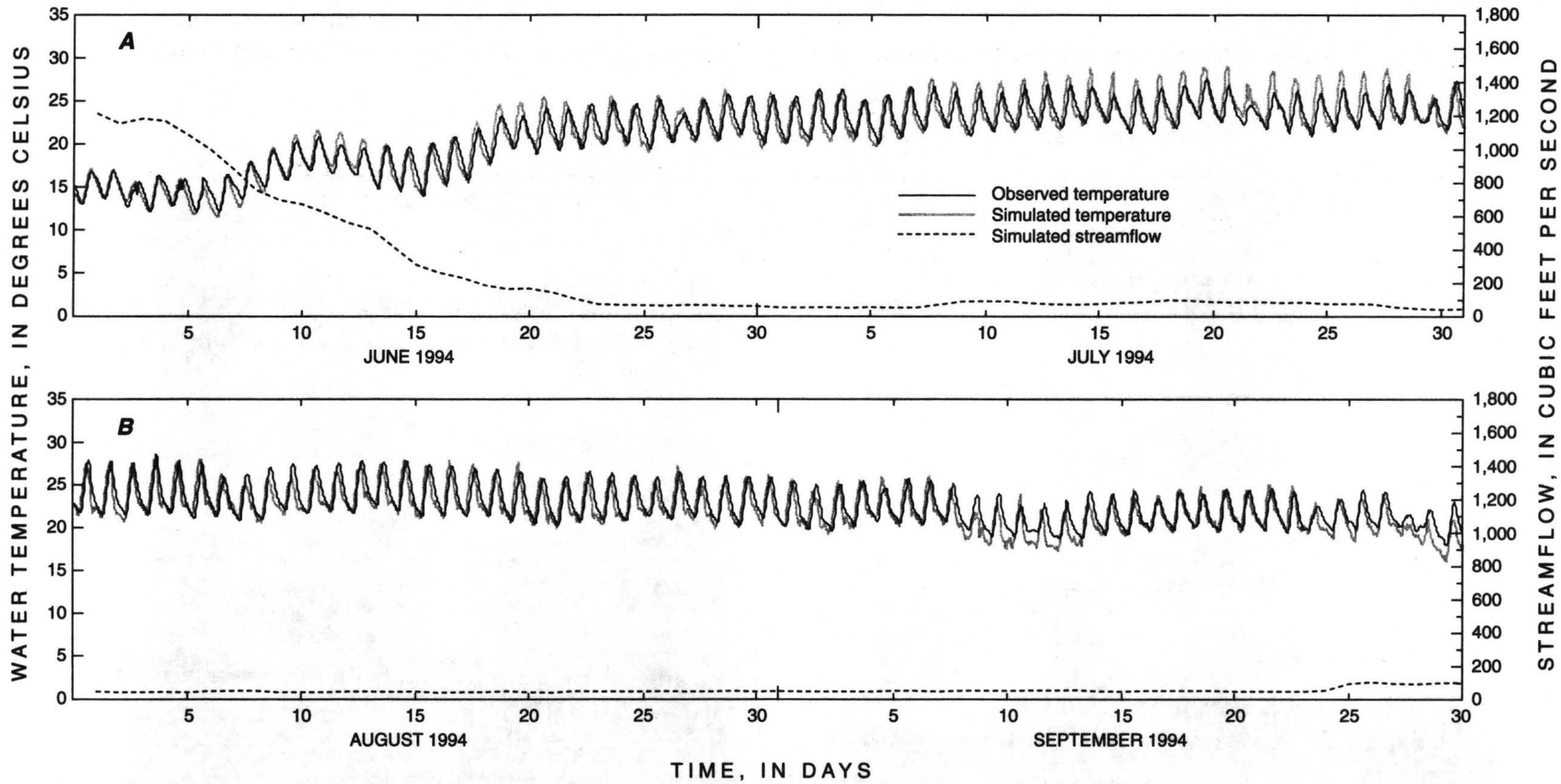

Figure 15. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Vista, Nev.

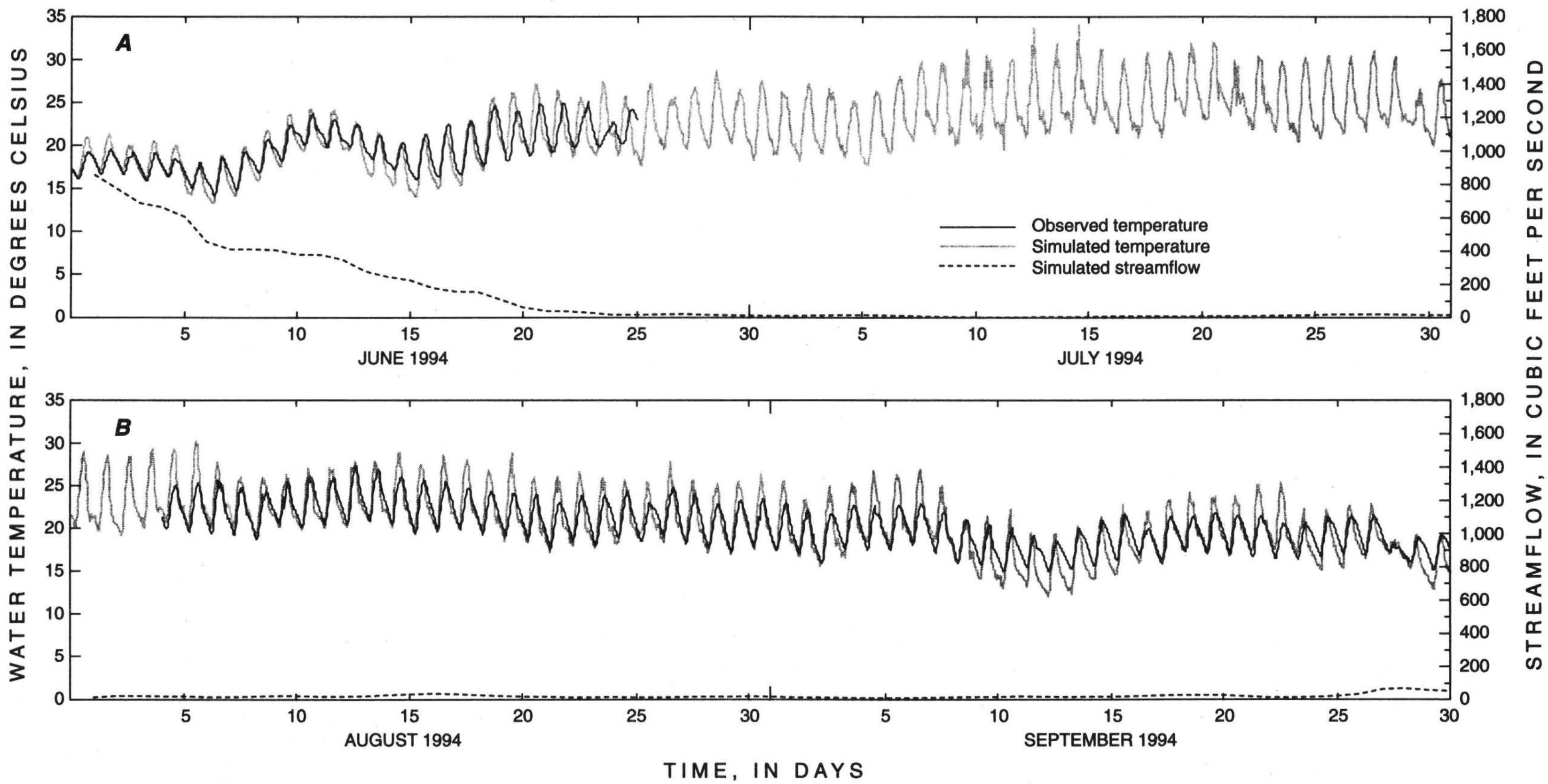

Figure 16. Observed and simulated hourly stream temperature and simulated daily streamflow for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Marble Bluff Dam, Nev.

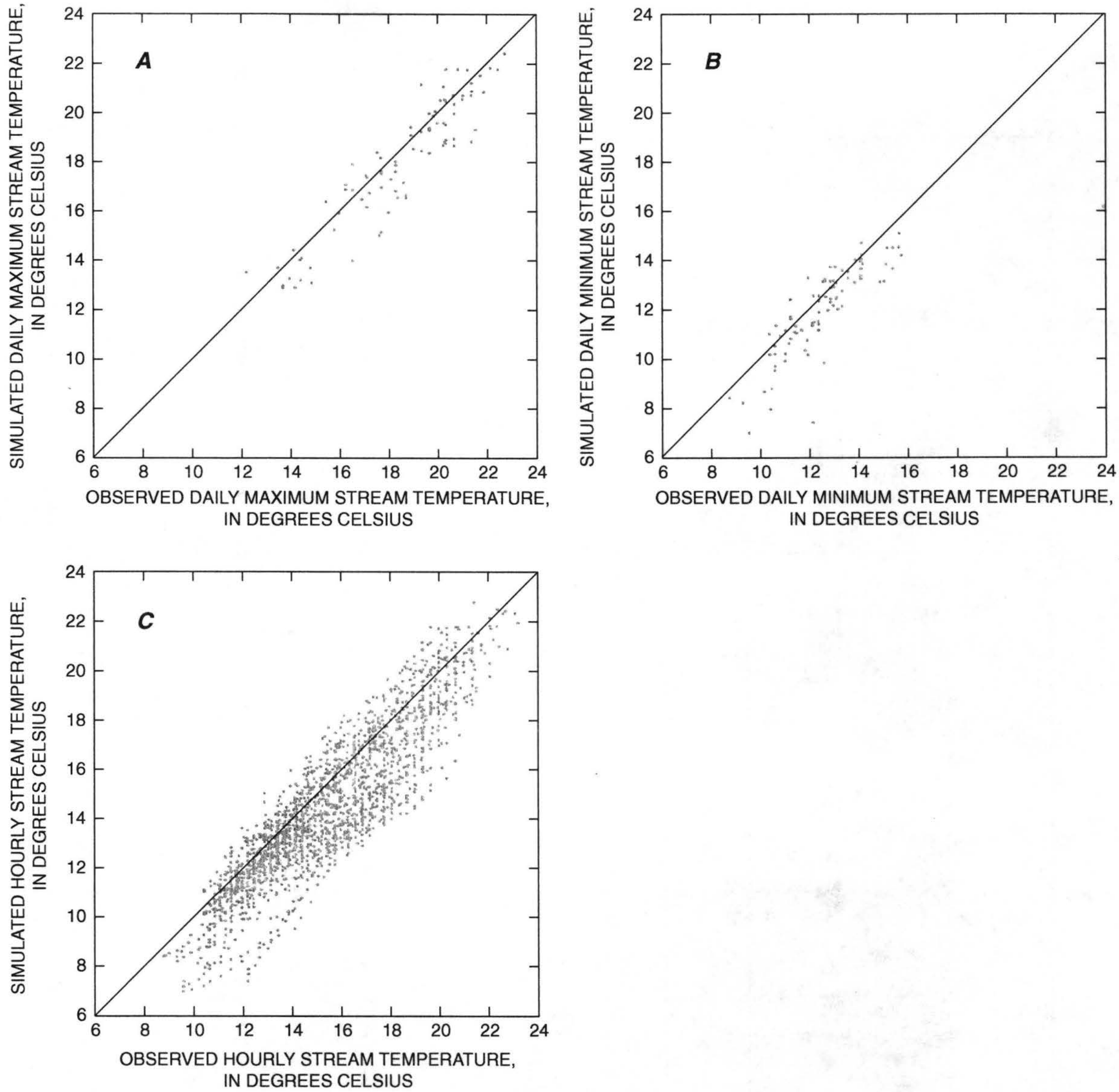

Figure 17. Relation between observed and simulated stream temperature for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Farad, Calif., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

generally are similar for the validation and calibration periods. The trend of decreasing errors with increasing flow is still apparent in the validation period, but is not as pronounced as for the calibration period. The best simulations were found when simulated streamflows were greater than or equal to 500 ft^3/s. When simulated streamflows were greater than or equal to 500 ft^3/s, daily and hourly mean absolute errors ranged from 0.4 to 0.8°C for the calibration and validation periods at all three gaging stations. An error outside this range was the daily maximum error of 1.5°C at Marble Bluff for the validation period. However, only five values were compared at this site when the streamflow was greater than or equal to 500 ft^3/s.

The mean absolute error between observed and simulated daily maximum stream temperatures for the all-flows class during the validation period (table 12) at Marble Bluff was 1.0°C higher than for the calibration period (table 9). Also, the all-flows class has a high positive bias of 1.7°C during the validation period and

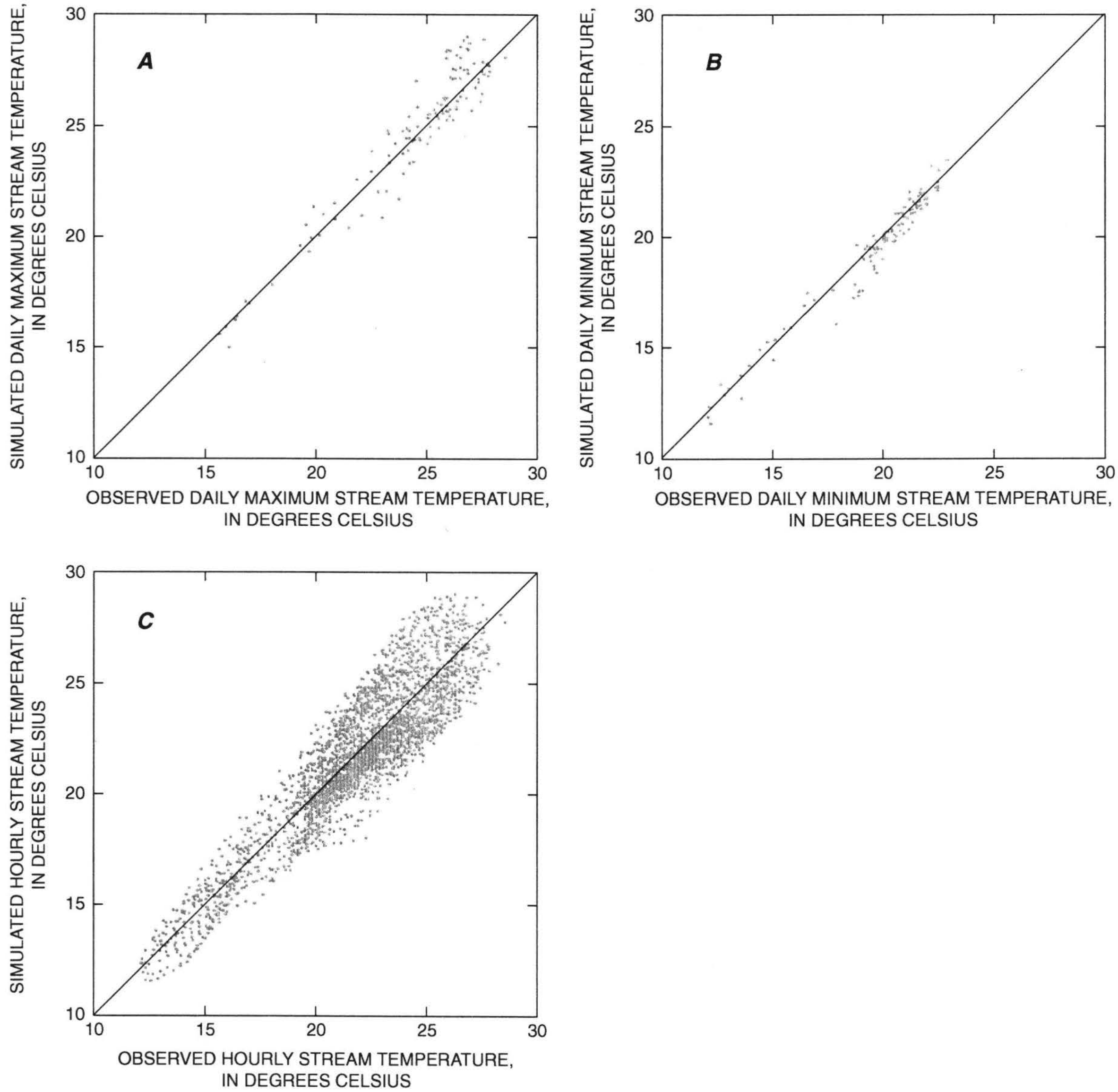

Figure 18. Relation between observed and simulated stream temperature for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Vista, Nev., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

no bias during the calibration period. The mean absolute errors for hourly stream temperatures increased for the validation period over the calibration period at all three stations, and all were still less than 1.5°C. The biggest change in hourly stream-temperature errors was at Farad gaging station, where the bias doubled to -1.0°C for the validation period (table 10) from -0.5°C for the calibration period (table 7). This increase in error could be due to the validation period only including spring and summer months and the fact that the flows were much lower during the validation period than the calibration period. Simulation errors in the stream-temperature model may be lower for the fall and winter months, which could reduce errors over an entire year. Also, at the lower flows present during the validation period, any model-input errors would have a greater affect on simulated stream temperatures.

Simulation results were best in the middle subunit at the Vista gaging station. The smaller errors and biases are at Vista, probably because less estimation of input data was necessary; therefore, less error was introduced to the model for this subunit than for the other two subunits.

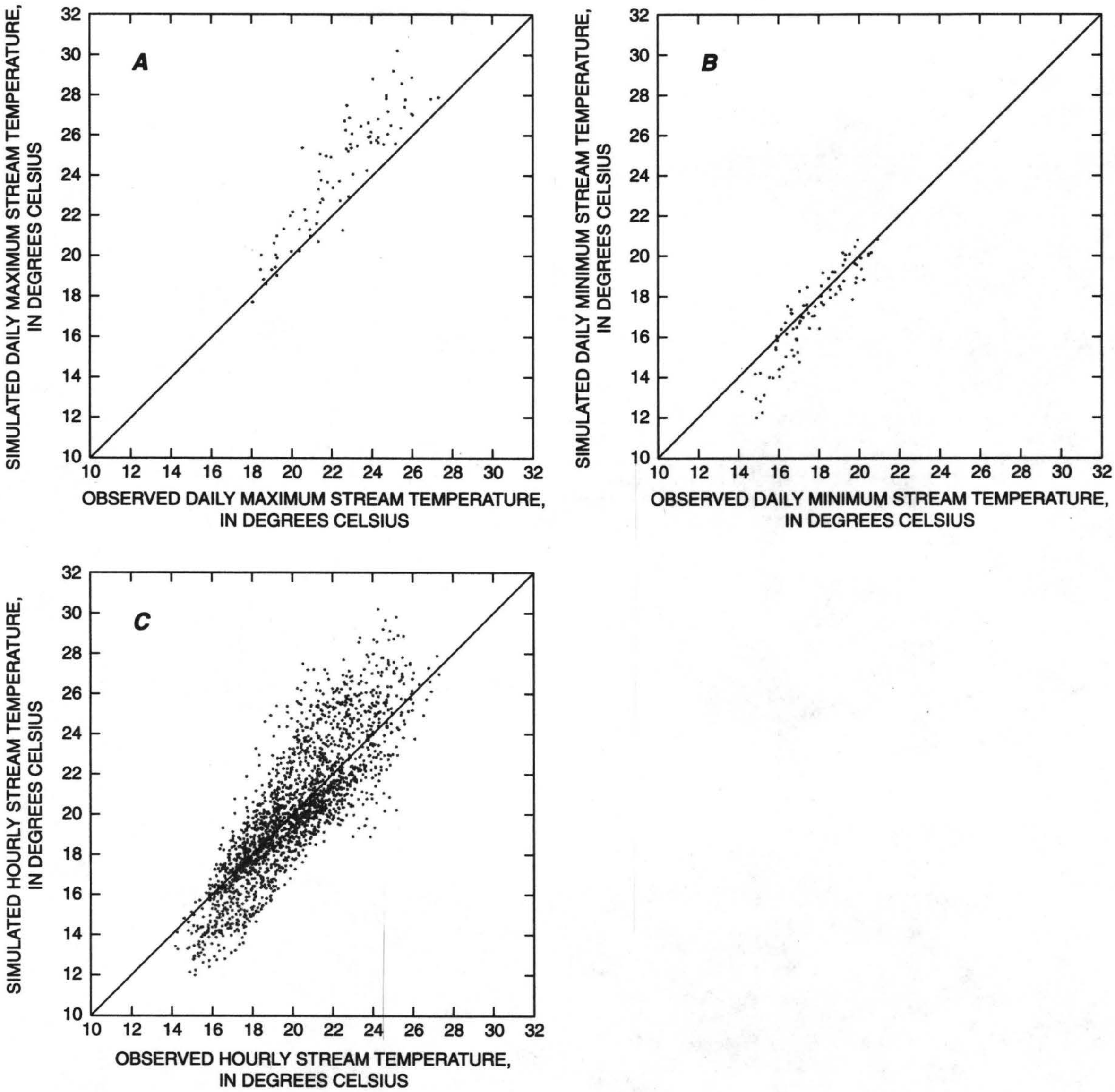

Figure 19. Relation between observed and simulated stream temperature for the stream-temperature model validation period June 1 through September 30, 1994, for Truckee River at Marble Bluff Dam, Nev., for (*A*) daily maximum, (*B*) daily minimum, and (*C*) hourly.

Results of the Daily Dissolved-Solids Simulations

Results of the daily dissolved-solids simulations were compared with observed data at the Farad, Clark, and Nixon gaging stations. Data are shown in figures 20-23 and listed in table 13.

The time-series plots show the inverse relation of dissolved solids with streamflow. The highest values of dissolved solids are in the fall and winter during low-flow months. Dissolved solids generally are overestimated (positive bias) at Farad (fig. 20) and underestimated (negative bias) at Clark and Nixon (figs. 21-22). The scatterplots show the overall bias at Farad (fig. 23*A*) was slightly positive, and the overall biases at Clark (fig. 23*B*) and Nixon (fig. 23*C*) were negative. In addition, these plots show a general trend toward increased bias and variability with increased concentration (decreased flow).

Mean absolute errors for daily dissolved-solids simulations when all flows were considered at Farad, Clark, and Nixon gaging stations were less than 11 percent (table 13). The smallest simulation error of 6.6

Table 10. Statistical comparison of observed and simulated stream temperatures for Truckee River at Farad, Calif., validation period from June 1 through September 30, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum .	10-99	14	0	0.5	0.3	
	100-499	63	32	.9	-.6	
	≥500	13	0	.8	-.8	
	All flows ≥10	90	32	0.8	-0.5	1.0
Daily minimum .	10-99	14	0	0.7	-0.2	
	100-499	63	32	.9	-.8	
	≥500	13	0	.4	-.1	
	All flows ≥10	90	32	0.8	-0.6	0.9
Hourly.	10-99	364	0	0.7	-0.3	
	100-499	1,433	817	1.6	-1.3	
	≥500	314	0	.5	-.4	
	All flows ≥10	2,111	817	1.3	-1.0	1.3

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$

[2] Bias: $Mean = \Sigma(S-O)/n$

[3] $Standard\ error\ of\ estimate = \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where S = simulated hourly stream temperature, in °C; O = observed hourly stream temperature, in °C; n = number of pairs of hourly values for which O > 0 in the simulation period; and || = absolute value.)

Table 11. Statistical comparison of observed and stimulated stream temperatures for Truckee River at Vista, Nev., validation period from June 1 through September 30, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum	10-99	99	0	0.8	0.3	
	100-499	10	0	.7	.5	
	≥500	13	0	.5	.3	
	All flows ≥10	122	0	0.7	0.3	0.9
Daily minimum	10-99	99	0	0.4	-0.3	
	100-499	10	0	.4	.1	
	≥500	13	0	.4	.0	
	All flows ≥10	122	0	0.4	-0.2	0.5
Hourly	10-99	2,364	0	1.2	-0.2	
	100-499	262	0	1.2	.0	
	≥500	302	0	.7	.0	
	All flows ≥10	2,928	0	1.1	-0.1	1.4

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$

[2] Bias: $Mean = \Sigma(S-O)/n$

[3] $Standard\ error\ of\ estimate = \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where S = simulated hourly stream temperature, in °C; O = observed hourly stream temperature, in °C; n = number of pairs of hourly values for which O > 0 in the simulation period; and || = absolute value.)

Table 12. Statistical comparison of observed and simulated stream temperatures for Truckee River at Marble Bluff Dam, Nev., validation period from June 1 through September 30, 1994

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second. Symbol: ≥, greater than or equal to]

Type of stream temperature	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1] (°C)	Mean bias [2] (°C)	Standard error of estimate [3] (°C)
Daily maximum	10-99	60	24	2.0	2.0	
	100-499	14	0	.6	.3	
	≥500	5	0	1.5	1.5	
	All flows ≥10	79	24	1.8	1.7	1.3
Daily minimum.	10-99	60	24	0.8	-0.4	
	100-499	14	0	1.1	-1.1	
	≥500	5	0	.3	.2	
	All flows ≥10	79	24	0.8	-0.5	0.9
Hourly........	10-99	1,432	564	1.5	0.1	
	100-499	324	0	1.0	-.5	
	≥500	123	0	.8	.6	
	All flows ≥10	1,879	564	1.4	0.1	1.8

[1] Mean absolute error: $Mean = \Sigma(|S - O|/n)$

[2] Bias: $Mean = \Sigma(S - O)/n$

[3] *Standard error of estimate* $= \sqrt{\langle n/(n-1)\rangle \times [\{\Sigma(\langle\langle S-O\rangle^2\rangle/n)\} - \{Meanbias\}^2]}$

(Where S = simulated hourly stream temperature, in °C; O = observed hourly stream temperature, in °C; n = number of pairs of hourly values for which O > 0 in the simulation period; and || = absolute value.)

percent was at Farad. Bias for the all-flows class at these stations was 3.1 percent at Farad, -2.8 percent at Clark, and -7.9 percent at Nixon. The standard error of estimate was less than 12 percent at all three stations. These mean absolute errors generally are similar to the flow-routing model errors at these stations for the time period of the dissolved-solids simulations (table 14). When the results were divided into flow classes, a trend showing a decrease in model error for dissolved solids with increasing streamflow was not as apparent as it was for streamflow or stream temperature.

The errors associated with the daily dissolved-solids simulations probably were due to errors in estimating input data and errors in the flow-routing model. For the dissolved-solids model, three methods were used to estimate dissolved-solids data for input to the model. First, all dissolved-solids data were estimated from specific-conductance data by regression equations. Second, in some instances, missing conductance data were themselves estimated before corresponding dissolved solids could be estimated. Third, estimates for some dissolved-solids data, such as concentrations in ground water for the lower subunit, were taken from previous work (Bratberg and others, 1982).

Errors in the flow-routing model could have caused some of the errors in the dissolved-solids model, because the dissolved-solids model is highly dependent on the flow-routing model. Because dissolved-solids data are given as concentrations, when the flow-routing model overestimates flow (more flow than expected), simulated dissolved solids will be less (diluted) than expected (underestimated). The opposite would happen if the flow-routing model underestimates flow. However, on average, the direction of the bias was the same for the flow-routing and dissolved-solids models (both models either overestimate or underestimate simultaneously at a given station on average). This same direction of biases indicates that the effects of errors in the flow-routing model on the dissolved-solids model were overwhelmed by errors in the dissolved-solids model. Better definition of model input data is needed in order to improve the simulation of dissolved solids.

Table 13. Statistical comparison of observed and simulated daily dissolved-solids concentrations for the Truckee River, October 1, 1994, through September 30, 1995

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter. Symbol: ≥, greater than or equal to]

Name of gaging station	Flow class (ft^3/s)	Number of values compared	Number of missing values	Mean absolute error [1]		Mean bias [2]		Standard error of estimate [3]	
				Mean (mg/L)	Percent	Mean (mg/L)	Percent	Mean (mg/L)	Percent
Truckee River at Farad, Calif.	0-99	22	19	7.1	5.4	-4.3	-2.9		
	100-499	102	0	6.5	6.7	.7	.8		
	≥500	222	0	3.6	6.7	2.2	4.8		
	All flows	346	19	4.7	6.6	1.4	3.1	6.2	8.0
Truckee River at Clark, Nev.	0-99	36	0	54.9	14.4	-54.6	-14.3		
	100-499	128	4	22.4	9.3	-19.5	-7.3		
	≥500	161	36	8.9	9.8	1.1	3.4		
	All flows	325	40	19.3	10.1	-13.2	-2.8	25.4	11.8
Truckee River near Nixon, Nev.	0-99	127	26	69.7	11.6	-52.6	-8.0		
	100-499	47	0	18.9	8.6	-18.9	-8.6		
	≥500	30	135	18.0	10.8	-14.1	-6.6		
	All flows	204	161	50.4	10.8	-39.2	-7.9	56.1	11.1

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$ $\quad Percent = 100 \times (\Sigma(|S-O|/O)/n)$

[2] Bias: $Mean = \Sigma(S-O)/n$ $\quad Percent = 100 \times (\Sigma(((S-O)/O))/n)$

[3] Standard error of estimate $= \sqrt{(n/(n-1)) \times ((\Sigma(((S-O)^2)/n)) - (Meanbias)^2)}$

$Percent = \sqrt{(n/(n-1)) \times (100 \times (\Sigma(((S-O)/O)^2)/n) - (Percentbias)^2)}$

(Where S = simulated daily mean total dissolved-solids concentrations, in milligrams per liter; O = observed mean dissolved-solids concentrations, in milligrams per liter; n = number of pairs of daily values for which O > 0 in the simulation period; and || = absolute value.)

Table 14. Statistical comparison of observed and simulated daily streamflow for Truckee River at Farad, Calif., Truckee River below Tracy, Nev., and Truckee River near Nixon, Nev., October 1, 1994, through September 30, 1995

[Abbreviations: °C, degrees Celsius; ft^3/s, cubic feet per second; mg/L, milligrams per liter]

Name of gaging station	Number of values compared	Mean absolute error [1]		Mean bias [2]		Standard error of estimate [3]	
		Mean (ft^3/s)	Percent	Mean (ft^3/s)	Percent	Mean (ft^3/s)	Percent
Truckee River at Farad, Calif......	365	54.5	9.0	47.6	8.4	78.9	13.0
Truckee River below Tracy, Nev...	365	104	9.5	-80.0	-2.6	178	12.3
Truckee River near Nixon, Nev....	365	75.0	16.2	-66.1	-4.1	123	25.2

[1] Mean absolute error: $Mean = \Sigma(|S-O|/n)$ $\quad Percent = 100 \times \Sigma(|S-O|/O)/n$

[2] Bias: $Mean = \Sigma(S-O)/n$ $\quad Percent = 100 \times \Sigma(((S-O)/O)/n)$

[3] Standard error of estimate $= \sqrt{(n/(n-1)) \times [\{\Sigma(((S-O)^2)/n)\} - \{Meanbias\}^2]}$

$Percent = \sqrt{(n/(n-1)) \times (100 \times (\Sigma(((S-O)/O)^2)/n) - (Percentbias)^2)}$

(Where S = simulated daily mean streamflow, in cubic feet per second; O = observed daily mean streamflow, in cubic feet per second; n = number of pairs of daily values for which O > 0 in the simulation period; and || = absolute value.)

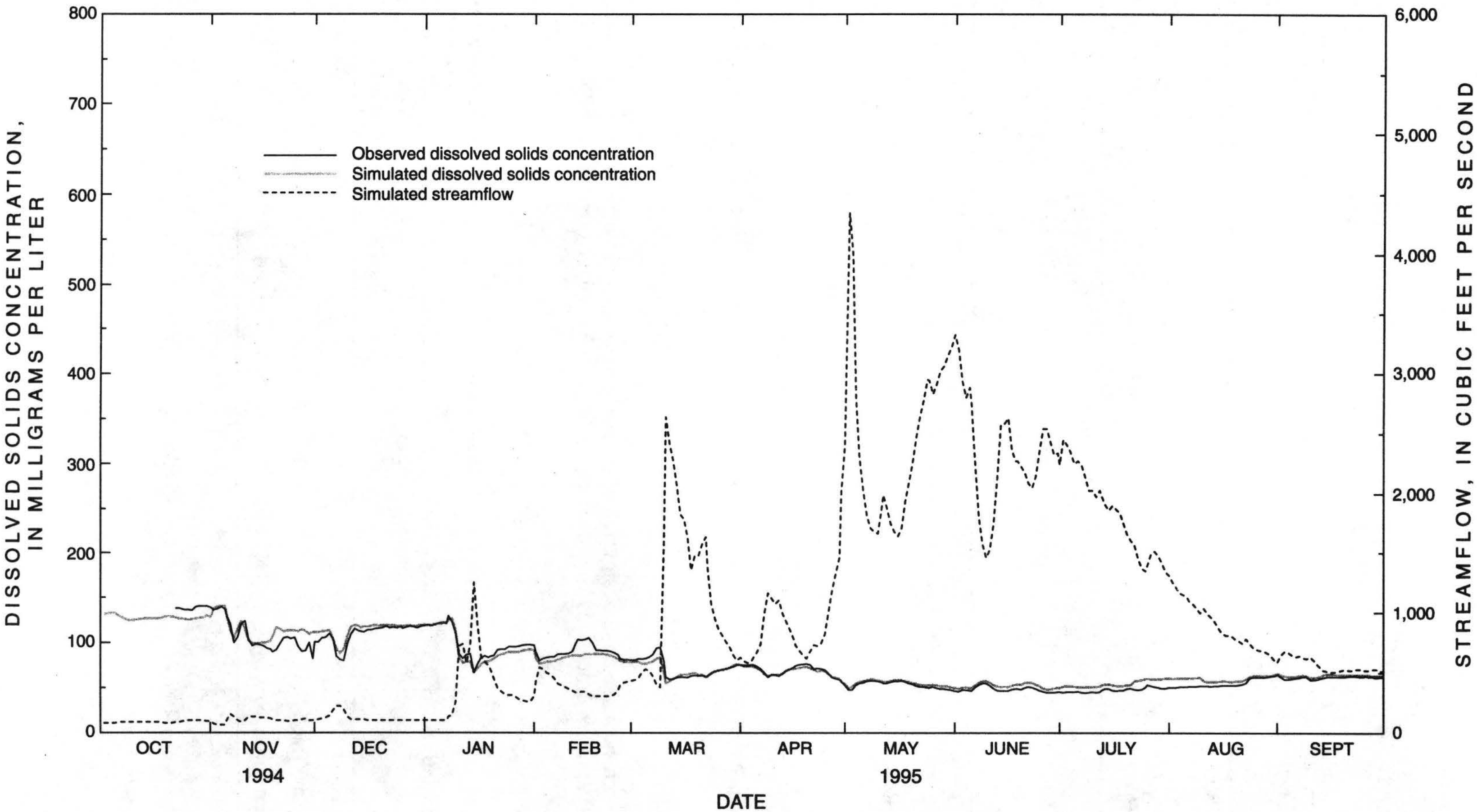

Figure 20. Observed and simulated daily dissolved-solids concentrations and streamflow for the dissolved-solids model from October 1, 1994, through September 30, 1995, for Truckee River at Farad, Calif.

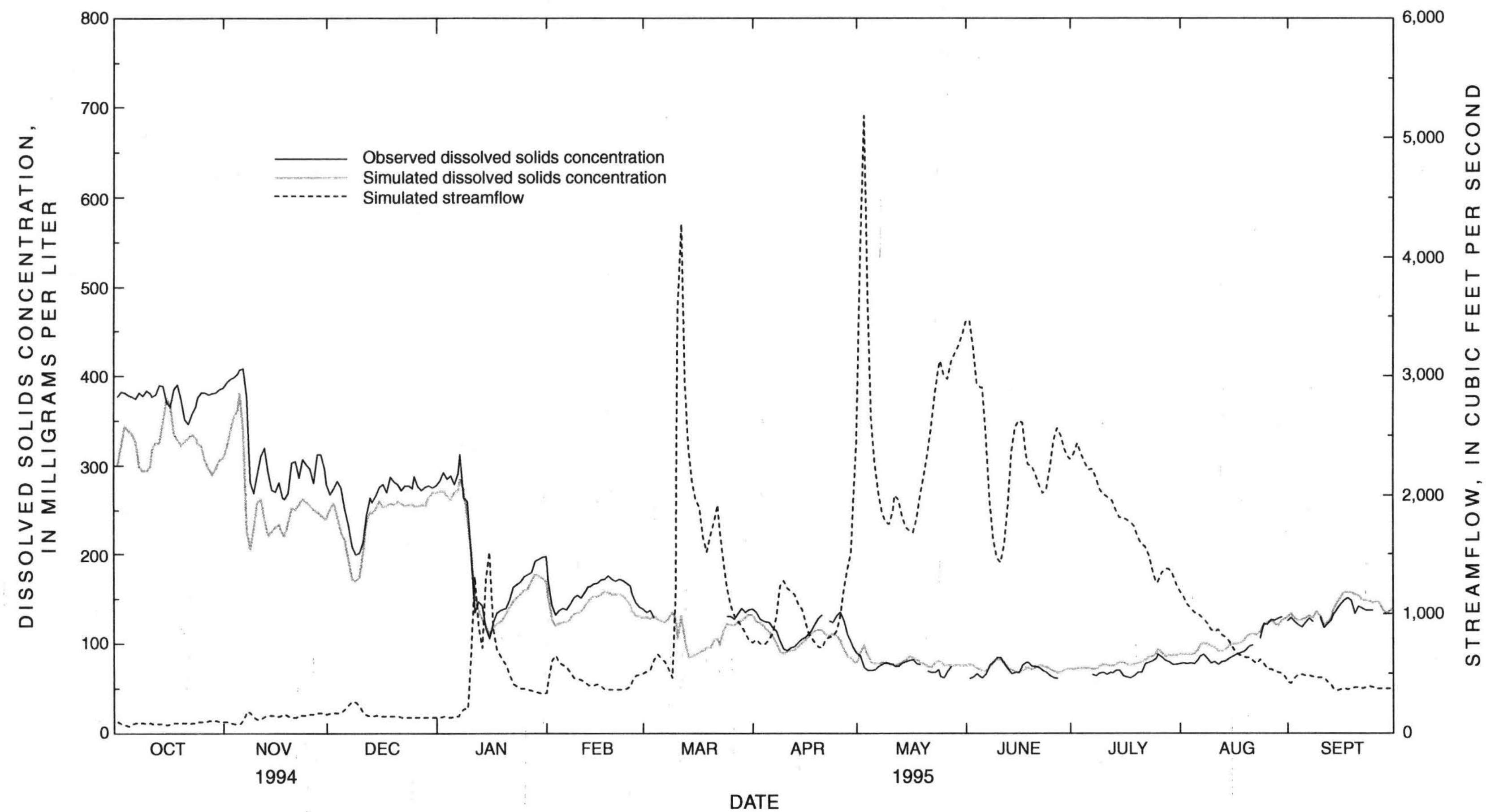

Figure 21. Observed and simulated daily dissolved-solids concentrations and streamflow for the dissolved-solids model from October 1, 1994, through September 30, 1995, for Truckee River at Clark, Nev.

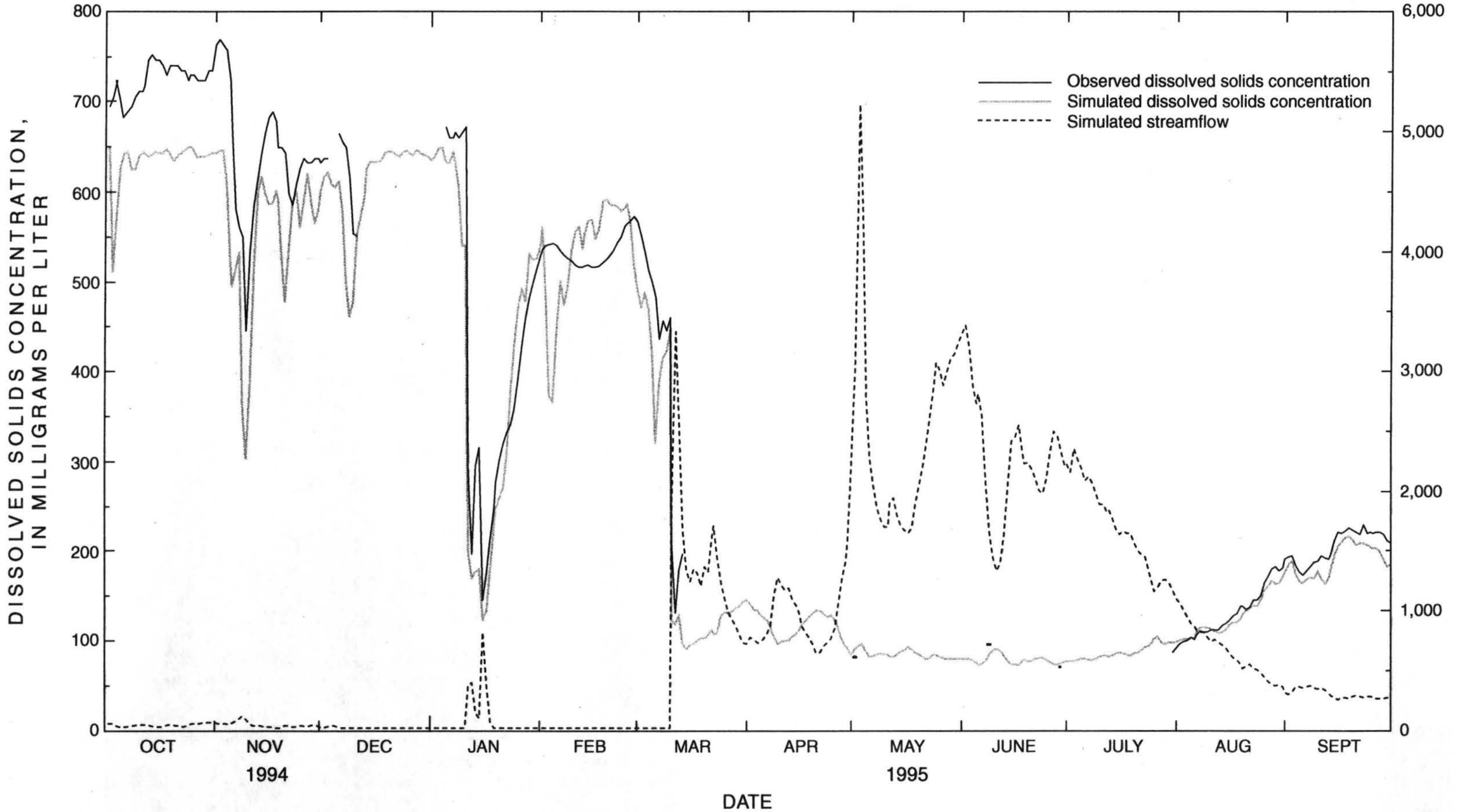

Figure 22. Observed and simulated daily dissolved-solids concentrations and streamflow for the dissolved-solids model from October 1, 1994, through September 30, 1995, for Truckee River near Nixon, Nev.

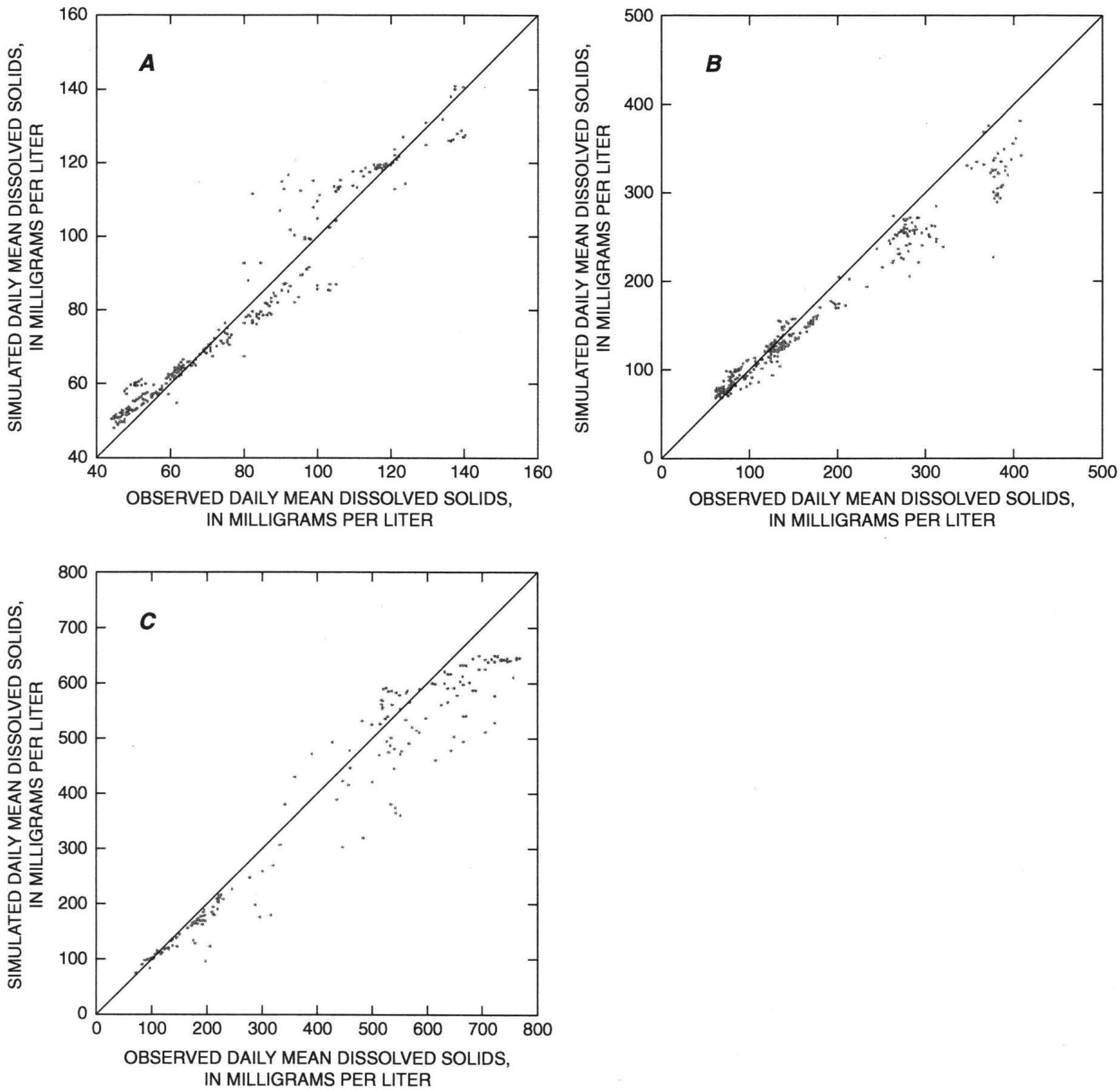

Figure 23. Relation between observed and simulated dissolved-solids concentrations for the dissolved-solids model from October 1, 1994, through September 30, 1995, for (*A*) Truckee River at Farad, Calif., (*B*) Truckee River at Clark, Nev., and (*C*) Truckee River near Nixon, Nev.

SUMMARY

The limited water supply of the Truckee River has many varied and conflicting uses. Truckee River water is used for municipal supply in California and Nevada, to generate power upstream from Reno, for irrigation inside and outside the Truckee River Basin, to maintain Pyramid Lake levels, and to provide flows of sufficient quantity and quality for the endangered cui-ui lake-sucker and the threatened Lahontan cutthroat trout. Use and reuse of this limited water supply potentially increases water temperature and dissolved solids in the river. The Truckee River stream-temperature and dissolved-solids models were developed for use as tools in managing this limited resource.

Daily streamflow, hourly stream temperature, and daily dissolved solids were simulated for the Truckee River in California and Nevada using HSPF. Streamflow was simulated for the period June 1, 1993, through September 30, 1995, stream temperature was simulated for the period June 1, 1993, through September 30, 1994, and dissolved solids was simulated for the period October 1, 1994, through September 30, 1995. Model simulations were compared with data observed at gaging stations along the length of Truckee River mainstem to check the effectiveness of the simulations in describing the streamflow, stream temperature, and dissolved-solids concentrations of the Truckee River.

Streamflow simulation results were best upstream from Derby Dam (upper and middle subunits) where mean absolute percent errors were about 12 percent, and were worse downstream from Derby Dam (lower subunit) where the mean absolute percent error was about 37 percent.

Stream-temperature simulations, in general, averaged within 1.0°C of observed stream temperatures during the calibration period (June 1, 1993-May 31, 1994) and within 1.5°C of observed stream temperatures during the validation period (June 1, 1994-September 30, 1994) for mean absolute errors for the all-flows class. Validation period results were similar to calibration period results for the all-flows class, except for daily maximum simulations at the Marble Bluff gaging station and hourly simulations at Farad, Vista, and Marble Bluff gaging stations. Two differences between the calibration and validation periods may account for these increased errors: (1) the calibration period covered an entire year, but the validation period only covered the spring and summer, and (2) the validation period low flows were much lower than calibration period low flows. Simulations were best during both periods for streamflows greater than or equal to 500 ft^3/s, when daily and hourly mean absolute errors were 0.4 to 0.8°C at all three gaging stations (except daily maximum error of 1.5 at Marble Bluff for the validation period, which only had five values to compare).

Two problems were evident with the hourly stream-temperature model. The first was the phase shift or lag between observed and simulated stream temperatures. The second was the instability in the new streambed-conductance algorithm. No satisfactory solutions were found for these problems; however, the phase shift problem only affects hourly results (not daily maximums or minimums) and the streambed-conductance instability only affects the lowest flows (less than 10 ft^3/s). Neither problem affects daily stream-temperature simulation at flows greater than 500 ft^3/s.

The phase shift affected the timing of simulated stream temperatures and increased hourly mean errors (in general, hourly mean errors were greater than daily mean errors). Simulated temperatures are increasing too quickly during the day and decreasing too quickly at night and the effect is greater on the falling side of the daily thermograph. This caused a generally negative bias in hourly stream-temperature simulations. No adjustments were made to calibration parameters or model input estimates that would eliminate or even lessen the phase shift. To improve the phase shift between observed and simulated hourly stream temperatures may require changes in the HSPF algorithms, better definition of low flow channel geometry, or both.

Instability of the streambed-conductance algorithm had a large and unrealistic affect on simulated stream temperatures where simulated streamflow (somewhat less than 10 ft^3/s depending on reach geometry) caused simulated stream depth to remain about 2 in. for more than a few hours. Consequently, simulated stream temperatures should be considered unreliable when simulated flows are less than 10 ft^3/s.

Dissolved-solids simulation results at the Farad and Clark gaging stations show that the model can produce dissolved-solids concentrations within about 10 percent of observed concentrations when all flows are considered. Dissolved-solids concentrations tend to be overestimated in the upper subunit and underestimated in the middle subunit, but the bias is small (about 3 percent). Dissolved-solids concentrations were underestimated at Nixon also but to a greater degree (a bias of about -8.0 percent).

The Truckee River flow-routing, stream-temperature, and dissolved-solids models are useful tools in the planning and management of the Truckee River system. These models were calibrated under a specific set of environmental conditions (meteorological, tributary and ground-water input, instream, and riparian vegetation). This means the results for a different set of conditions should be examined closely and used with caution. Changing conditions may require updated input data sets and, for the stream-temperature model, may require recalibration to this new set of conditions. An example is the planned restoration of the lower Truckee River achieved, in part, by planting of cottonwood trees in the riparian zone. Mature trees would increase shading during the summer and could alter ground-water flow to the river, both of which might require model recalibration. Improvements in model input data might also necessitate model recalibration. At the least, certain environmental changes in the Truckee River system or model input data will require reevaluation of the model to determine if recalibration is necessary.

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Appendix. Name, size, and description of files used in daily flow-routing, hourly stream-temperature, and daily dissolved-solids simulations for the Truckee River, California and Nevada [1]

File	Size (bytes)	Description
hspf12.0	5,859,268	binary file containing source code for HSPF model version 12.0.
annie2.2	3,425,836	binary file containing source code for data-management system ANNIE.
fin.trkqw.wdm	57,712,640	binary file created using ANNIE which contains input and output data sets.
flowroute.final.uci	87,604	UCI file for flow-routing model used with both the stream-temperature and dissolved-solids models.
tempcal.final.uci	109,872	UCI file for stream-temperature model calibration period.
tempval.final.uci	110,756	UCI file for stream-temperature model validation period.
tdsmod.final.uci	81,645	UCI file for dissolved-solids model.

[1] For more information, please contact the USGS, Water Resources Division in Nevada at (702) 887-7649 or email request to <usgsinfo_nv@usgs.gov>.