Daily Flow-Routing Simulations for the Truckee River, California and Nevada

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	4,047	square meter
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
inch per year (in/yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556(°F-32).

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.

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Abstract

The U.S. Geological Survey (USGS), to support U.S. Department of the Interior implementation of the Truckee–Carson–Pyramid Lake Water Rights Settlement Act of 1990 (Public Law 101-618), developed a physically based flow-routing model of the Truckee River. The model routes daily mean streamflow along 114 miles of the mainstem Truckee River from just downstream from Lake Tahoe, California, to just upstream from Pyramid Lake, Nevada. No known previous study of the Truckee River has incorporated multi-agency streamflow data into one comprehensive data base and used these data to develop a physically based model that routes daily streamflow. This routing model is the first step toward developing a data-management and modeling system that would provide a modular framework for integrating many hydrologic and operational-analysis models.

The program used for the routing model is known as the Hydrological Simulation Program–FORTRAN. Constructing the model involved (1) collecting, assembling, and estimating daily mean flow data, as well as hydraulic data; (2) dividing the Truckee River and two tributaries into 47 reaches; and (3) determining hydraulic characteristics for each reach. The daily mean flow data for water years 1978-92 (October 1977-September 1992) for the Truckee River, tributaries, and irrigation systems used in the simulations were obtained from several agencies and were consolidated into a single data base. Most reach boundaries were defined at or near gaging stations and at hydrographic features—such as points of tributary inflow, points of diversion, or large riffles. Data to determine hydraulic characteristics of reaches were obtained from field surveys and maps.

Differences between streamflow measured at gaging stations and simulated by the model were evaluated for the entire simulation period, October 1977 through September 1992, and for the last few years of the simulation period, October 1987 through September 1992—the drought-evaluation period, which was particularly dry. One full model, encompassing the 114-mile length of the Truckee River, was used to evaluate simulation results. Three submodels were developed to represent three hydrographically distinct segments of the Truckee River; these three submodels were combined to create the full model. Simulation results were evaluated for these four models.

The four flow-routing models were evaluated by comparing simulated streamflow with observed streamflow at three USGS gaging stations: (1) Truckee River at Farad, Calif., (2) Truckee River below Tracy, Nev., and (3) Truckee River near Nixon, Nev. For October 1977 through September 1992, bias of simulated annual mean streamflow from the full model was less than 13 percent of the observed annual mean streamflow and bias of simulated annual mean streamflow from the submodels was less than 8 percent of the observed annual mean streamflow. Bias of simulated annual mean streamflow at individual gaging stations was within the reported accuracy of measurement at the station, except for the bias of the full model evaluated at the Nixon

gaging station. Also, from October 1977 through September 1992, mean absolute errors for monthly mean streamflow ranged from 4.7 to 36.0 percent for the full model and from 4.7 to 11.9 percent for the submodels, and bias ranged from 3.1 to -14.4 percent for the full model and from 3.1 to -9.0 percent for the submodels. For daily mean streamflow, mean absolute errors ranged from 6.2 to 46.0 percent for the full model and from 6.2 to 17.3 percent for the submodels; and bias ranged from 3.5 to -12.5 percent for the full model and from 3.5 to -8.6 percent for the submodels. For the drought-evaluation period, measures of difference between observed and simulated streamflow, as percentages, generally were larger, but as averages, generally were smaller when compared with differences from the entire simulation period.

Most of the differences between observed and simulated streamflow resulted from inadequate data describing inflows to and outflows from the Truckee River, rather than from inadequate data characterizing hydraulic properties of the reaches. Inflow and outflow data were considered inadequate for reaches where, and periods when, measurements were inaccurate or data were not available. The routing model cannot adequately simulate these inflows or outflows. Data are lacking for (1) undocumented spills and returns from ditches, (2) undocumented inflow from ephemeral tributaries downstream from the Farad gaging station, and (3) unaccounted ground-water/surface-water interactions. As the model routes flow downstream, these discrepancies may accumulate or compensate each other creating model uncertainties. These uncertainties are greater for the full model than for the submodels, which represent shorter segments of the river. These uncertainties increase for the full model downstream from Derby Diversion Dam, especially when a large amount of water is diverted to the Truckee Canal. Differences between observed and simulated streamflow at the Nixon gaging station, the farthest downstream station, are greatest for the full model because of these uncertainties.

INTRODUCTION

Conflicts have been long-standing and intense among various economic, political, ecological, and institutional interests over water in the Truckee River Basin. Truckee River water is used for power generation upstream from Reno, municipal and industrial supply for the Reno–Sparks vicinity (hereafter referred to as the Truckee Meadows), irrigation in both the Truckee River and Carson River Basins, maintaining Pyramid Lake levels, and for providing flows for spawning of the endangered cui-ui lakesucker and the threatened Lahontan cutthroat trout. The diversity in interests results in a wide range of alternatives for planning, allocating, and managing the water resources and operating the various reservoir and diversion systems.

In general, the demand for water in the system is greater than the supply. Water rights are fully or over-allocated with respect to average annual runoff volumes, and the surface-water systems cannot meet all demands during years of deficient precipitation. Droughts lasting several years, such as the recent drought of the late 1980's and early 1990's, can result in substantial water shortages for irrigation and municipal users and may stress fish and wildlife ecosystems.

Irrigated agriculture, municipal and industrial supply, and fish and wildlife habitat are three uses of Truckee River water. The annual volume of water diverted from the Truckee River for delivery for these uses is commonly a large percentage of annual volumes recorded at the U.S. Geological Survey (USGS) gaging station *Truckee River at Farad, Calif.* (hereafter referred to as the Farad gaging station), located upstream from the river diversions near the California–Nevada State line. During a drought, annual volumes of water diverted downstream exceed those observed at the Farad gaging station. For example, during 1991, an annual volume of 187,400 acre-ft was recorded at the gaging station, *Truckee River at Farad.* The same year, the Truckee River water delivered to downstream users totaled 44,740 acre-ft for municipal and industrial use (Richard D. Moser, Sierra Pacific Power Company, written commun., 1995); 207,158 acre-ft for agricultural use; and 16,311 acre-ft for Pyramid Lake to sustain fisheries (Blue Ribbon Drought Task Force, 1992). More water than that recorded at the Farad gaging station can be delivered to users downstream, because much of the agricultural, municipal, and industrial water is returned to the river either as irrigation return flow or as treated effluent to be reused downstream.

The Reno–Sparks Sewage Treatment Plant, for example, returned about 28,000 acre-ft of treated effluent to the Truckee River in 1991 (Blue Ribbon Drought Task Force, 1992) and the effluent was then used downstream for agricultural irrigation and fisheries.

Truckee River water is provided to irrigators in both the Truckee River and Carson River Basins (fig. 1). Within the Truckee River Basin, water is needed for irrigation in the Truckee Meadows and downstream along the Truckee River corridor to Pyramid Lake. Derby Diversion Dam (hereafter referred to as Derby Dam), about 25 mi downstream from Reno, diverts water into the Truckee Canal for delivery to the Newlands Project (the first completed Federal reclamation program in the United States). Construction of the dam and canal began in 1903, and the project was operational in 1915 with the completion of Lahontan Dam in the Carson River Basin. Some of the diverted water is used to irrigate about 3,500 acres of farmland along the Truckee Canal near Fernley, Nev. The rest is stored in Lahontan Reservoir for irrigation of about 60,000 acres within the Newlands Project in the Carson River Basin near Fallon, Nev. The Newlands Project area is entitled to receive water from both the Truckee River via the Truckee Canal and from the Carson River. From 1918 through 1992, the average net diversion from the Truckee River to the Truckee Canal to supply the Newlands Project was about 230,000 acre-ft/yr, or about 46 percent of the average annual runoff of the Truckee River upstream from Derby Dam (Matthai, 1974; U.S. Geological Survey, 1972-75, 1976-92). During 1987 through 1992, a period of severe drought, a yearly average of 191,000 acre-ft of Truckee River runoff was diverted to the Truckee Canal, or about 80 percent of the average annual runoff of the Truckee River for that period.

Truckee Meadows is the most populous area in the basin, and rapid population growth there has created a large municipal demand for the available supply of Truckee River water (fig. 1). The cities of Reno and Sparks, with a combined population of about 187,000 in 1990, had a growth rate of about 32 percent from 1980 through 1990 (Jones and others, 1991). The water demands of a growing number of municipal and industrial users generally have been met by the purchase and conversion of water rights previously used for irrigation and by water conservation. Despite increased population growth, annual deliveries of Truckee River water by Sierra Pacific Power Company to its Truckee Meadows municipal and industrial users has not increased since 1987. Sierra Pacific is the sole purveyor of river water to municipal and industrial users in the Truckee Meadows. Delivery of Truckee River water to these users was 41,440 acre-ft in 1980 and 54,209 acre-ft in 1987, an increase of about 31 percent. However, due to conservation measures, annual deliveries decreased to 47,450 in 1990. During periods of drought or extreme low streamflows during summer, municipal water-use restrictions have been necessary. In 1992, a year of extreme drought, delivery of Truckee River water to municipal and industrial users was only 42,960 acre-ft (Richard D. Moser, Sierra Pacific Power Company, written commun., 1995).

Maintenance of fish and wildlife habitats in the lower Truckee River, Pyramid Lake, and the Carson River (in and downstream from Lahontan Reservoir) is dependent on Truckee River water (fig. 1). Pyramid Lake levels have declined more than 70 ft since diversion of water from the Truckee River to the Newlands Project began. The reduced lake and river levels have hindered the ability of the cui-ui lakesucker and Lahontan cutthroat trout to migrate upstream to spawn in the Truckee River. As a result, the Pyramid Lake Paiute Tribe has attempted to secure more water rights to sustain the lake's fishery. Pyramid Lake levels also are important to wildlife. Anaho Island National Wildlife Refuge is home to a colony of American white pelicans. A land bridge from the shore to Anaho Island would be formed at very low lake levels, allowing predators access to the nesting area (Jones and others, 1991, p. 85). Three wildlife areas in the lower Carson River Basin—Stillwater National Wildlife Refuge, Stillwater Wildlife Management Area, and Fallon National Wildlife Refuge—receive diverted Truckee River water from the Newlands Project. These wildlife areas are a critical stopover along the Pacific Flyway for migratory birds.

Title II of Public Law (P.L.) 101-618, the Truckee–Carson–Pyramid Lake Water Rights Settlement Act of 1990, provides a foundation for developing operating criteria to balance interstate and interbasin allocation and demands for water rights among the many interests competing for water from the Truckee River. Efficient execution of many of the planning, management, or environmental assessment requirements of P.L. 101-618 will require detailed water-resources and hydraulic data, coupled with sound analytical tools. Analytical modeling tools calibrated and evaluated with such data could

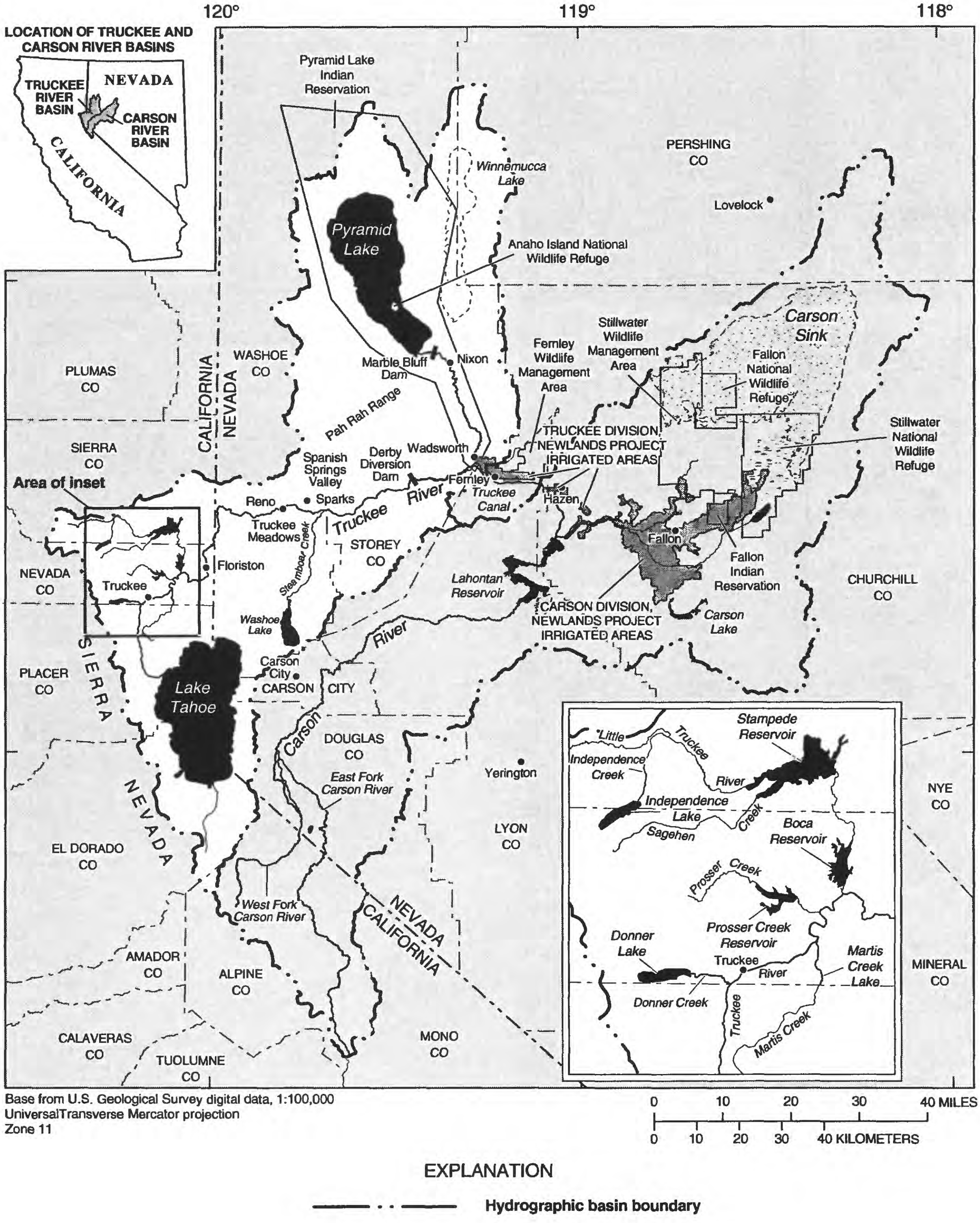


Figure 1. Location of study area, Truckee River Basin, California and Nevada.

help assess effects of alternative management and operational scenarios related to Truckee River operations, water-rights transfers, and changes in irrigation practices.

Physically based hydrologic models calibrated and evaluated with actual data are needed to assess alternatives for water allocation and management. Furthermore, 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 management issues of both the Truckee River and Carson River Basins. A hydrologic model that provides daily output is needed for improved understanding, management, and operations of the Truckee River and Carson River systems. In addition, there is a need for an overall hydrologic-systems model to provide the river-hydraulics and daily-flow data to other quantitative tools, such as water-quality models.

To improve understanding, management, and operations of both the Truckee River and Carson River systems in support of the U.S. Department of the Interior implementation of P.L. 101-618, the USGS began developing a data-management computer-modeling system that provides a mechanism for integrating various hydrologic-analysis models as modules within a single system. Such a system would be flexible enough to interface easily with other process models that have a similar standard format for data exchange; therefore, modules can be built into the framework in a logical stepwise fashion. The initial modules can then be used to estimate characteristics needed for simulations in subsequent modules.

The strategy for constructing the modular modeling system to describe hydrologic processes of the Truckee River 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. The individual flow-routing models will be integrated into a single interbasin module that will be a useful tool to predict changes in streamflow for various water-management scenarios. Other modules can be developed that will use the result of the flow-routing module to simulate water temperatures, reservoir operations/flow allocations, precipitation-runoff relations, and selected water-quality constituents.

The program chosen for the mainstem flow-routing model of the Truckee River is the Hydrological Simulation Program–FORTRAN (Bicknell and others, 1993), hereafter referred to as HSPF. The flow-routing model described in this report is based on the hydraulic characteristics of the Truckee River and can run continuously with a daily time step. The streamflow data used for the routing simulations were obtained from several agencies and were incorporated into a comprehensive data base. For the model, HSPF represents the pertinent hydraulic characteristics of the river, such as channel geometry, slope, and roughness. Simulated streamflows at many locations along the mainstem of the river are available for output. Additionally, the HSPF code is well documented and technically supported, and is available within the public domain.

Purpose and Scope

The purpose of this report is (1) to describe the data, including a description of the methods used to estimate ungaged flows, and reach segmentation used in the construction of a daily flow-routing model that incorporates hydraulic characteristics of the Truckee River mainstem, (2) to test the hydrologic and hydraulic characterization of the Truckee River by comparing observed and simulated streamflow, and (3) to discuss the differences between observed and simulated streamflows and the limitations of the model.

The scope of the report includes analysis of the Truckee River mainstem from the gaging station just downstream from Lake Tahoe to Marble Bluff Dam (about 3.5 mi upstream from Pyramid Lake) and parts of two tributaries, Donner Creek and Martis Creek (fig. 1). Streamflow data used to provide input to and evaluation of the model were collected from October 1977 through September 1992. Streamflow data at a daily time step (called daily mean streamflow) were used to create input time series to the model and represented inflows to and diversions from the Truckee River mainstem. Daily data collected on the Truckee River mainstem were compared with simulated flow values to assess how accurately the flow-routing model simulated streamflow along the mainstem.

Previous Investigations

Many investigators have designed and constructed models to simulate the physical and operational characteristics of the Truckee River. The Desert Research Institute at University of Nevada, Reno, developed a model that simulated Truckee River flows using historical and reconstructed monthly streamflow data (Butcher and others, 1969). The Truckee River was divided into: regulated upstream reaches; a reach through the Truckee Meadows; a reach from Vista, Nev., to Nixon, Nev. (including the Truckee Canal); and a reach representing Pyramid Lake. The model incorporated a monthly mass balance which transmitted flows and accounted for gains and losses through each reach. Fordham and Butcher (1970) and Fordham (1972) combined that flow model with an optimization routine to maximize the beneficial use of surface water. This model was expanded to include both the Truckee River and Carson River Basins. The flow model developed by Butcher and others (1969) also was incorporated into a model that simulated concentrations of inorganic constituents in the Truckee River (Sharp and others, 1970; Westphal and others, 1974). Monthly mass-flux balances of the inorganic constituents were simulated presuming that concentrations of inorganic constituents were conserved and complete mixing occurred instantaneously in each of six river reaches from Tahoe City, Calif., to Nixon, Nev. Water-quality data collected from December 1967 through March 1971 were used to formulate and calibrate the model. Model results were verified with data collected between March 1971 and March 1972. Chiatovich and Fordham (1979) combined the water-quality model developed by Westphal and others (1974) with a model of monthly reservoir operations to simulate an optimum operating policy. This combined model represents the water stored in all reservoirs in the upper Truckee River Basin downstream from Lake Tahoe as one combined reservoir and it was developed to maximize the beneficial use of surface water by considering both downstream water demands as well as concentrations of constituents affecting water quality.

Gupta and Afaq (1974), also from the Desert Research Institute, constructed a flow model of the Truckee River from Tahoe City, Calif., to Nixon, Nev., with explicit and implicit finite-difference solutions to the unsteady-flow equations. In contrast to the monthly time intervals used in the models previously discussed, this model required hourly data. Streamflow could be simulated for short durations, such as individual runoff peaks and floods.

In 1978, the USGS began to gather information to assess river quality in the Truckee River and Carson River Basins (Nowlin and others, 1980). The researchers collected and compiled physical, chemical, and biological data to identify effects of resource management on water quality in the two basins and to support development of water-quality models to assess these resource-management problems (Brown and others, 1986; La Camera and others, 1985). Nowlin (1987) constructed a one-dimensional model of nutrient and dissolved-oxygen transport for 56 mi of the Truckee River from just downstream from Reno, Nev., to Pyramid Lake, and for the Truckee Canal. The model dynamically simulated concentrations of nutrients and dissolved oxygen, but used steady-state assumptions of streamflow and constituent loadings into the river. The model was calibrated and validated against independent field data for two conditions: spring snowmelt observed in June and low flows observed in August 1979 and 1980. The model was applied by simulating river quality in response to various Truckee River flows and various constituent loadings into the river from different management alternatives associated with the expansion of the Reno–Sparks Sewage Treatment Plant (now called Truckee Meadows Water Reclamation Facility). Jim Brock (Rapid Creek Research, oral commun., 1994), using parts of the model developed by Nowlin (1987), 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 between Reno and Pyramid Lake.

The Bureau of Reclamation (BOR) constructed a monthly mass-balance model to analyze both operation of reservoirs and allocation of water within the Truckee River and Carson River Basins (Cobb and others, 1990). The BOR model was later modified by consultants for Sierra Pacific Power Company to include water-management alternatives discussed in the Preliminary Settlement Agreement (Pyramid Lake Paiute Tribe of Indians and Sierra Pacific Power Company, 1989). This agreement, between the Pyramid Lake Paiute Tribe and Sierra Pacific Power Company, provides for water storage for the Truckee Meadows during drought and for augmentation and modification of flows in the lower Truckee River at times to improve spawning conditions for endangered and threatened fish species. The modified BOR model, referred to as the Negotiations Model, is not intended to simulate historical streamflow, but to make relative comparisons of the effects of alternative management practices on flows and allocations (Cobb and others, 1990). The Negotiations Model is currently used to examine the effects of operation and allocation policies proposed in P.L. 101-618.

Cobb and others (1990) reviewed the BOR model and the Negotiations Model, both of which lacked formal documentation. Both models are monthly mass-balance accounting-type models, as opposed to physically based flow-routing models. Both models use synthesized data of monthly average streamflow at significant points in the Truckee River and Carson River systems. The data bases are composites of historical records and, when no historical records exist, estimated records. Both models (1) use streamflow and runoff data as input, (2) impose a complex set of legal constraints, operating criteria, and assumptions for effects of development on surface- and ground-water relations, and (3) incorporate an accounting procedure to simulate monthly average streamflow at several locations in the system. The BOR model and Negotiations Model were designed to provide simulations for comparisons of operational effects on streamflow and allocations, not to reproduce observed streamflow; a classic calibration comparing simulated and observed streamflow is impossible with these models and data bases.

Acknowledgments

The author gratefully acknowledges the support of personnel from the Office of the Federal Water Master, Sierra Pacific Power Company, Truckee Meadows Water Reclamation Facility, and Washoe County Department of Public Works, all of Reno, Nev., and U.S. Army Corps of Engineers, Sacramento, Calif., for providing data and consultation necessary to produce this report.

DESCRIPTION OF STUDY AREA

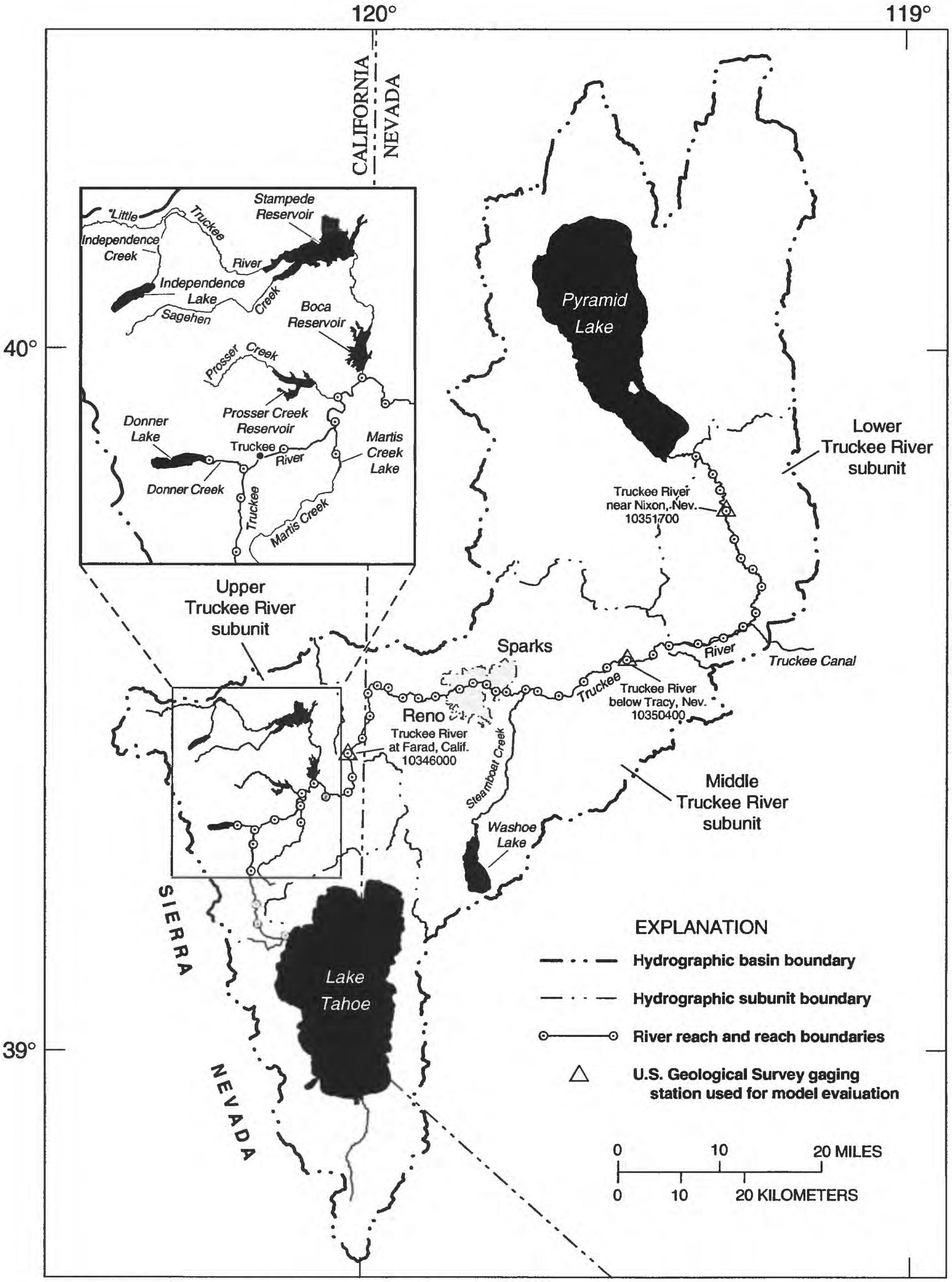
The Truckee River has its headwaters in the Sierra Nevada in California and flows eastward into a topographically closed desert lake in Nevada. Its headwaters, where altitudes exceed 10,000 ft above sea level, flow into Lake Tahoe—a mountain lake with a surface area of about 192 mi^2 and an average depth of 990 ft. The terminus of the Truckee River is at Pyramid Lake—located in the Basin and Range Province of western Nevada. Pyramid Lake is a vast sink, about 3,800 ft in altitude, where water cannot leave through a surface-water outlet. Drainage area for the entire Truckee River Basin is about 3,120 mi^2, but only about 1,430 mi^2 contribute to the 114-mi length of the Truckee River between the outlet of Lake Tahoe and Marble Bluff Dam, located about 3.5 mi upstream from its mouth at Pyramid Lake.

The Truckee River Basin—from the outlet of Lake Tahoe to Pyramid Lake—was divided into three hydrologic subunits for this study. These subunits, the upper Truckee River, the middle Truckee River, and the lower Truckee River, were delineated on the basis of similarity in streamflow characteristics, physiography, human activities, and water quality (fig. 2). The boundaries of these subunits generally conform to published hydrographic boundaries for consistency with previous work (Brown and others, 1986).

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 USGS Farad gaging station, located near the California–Nevada State line (fig. 2 and pl. 1, site 10). 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. The Sierra Nevada, with peaks ranging from 8,000 to 10,000 ft in altitude in this subunit, is a major barrier to masses of moist air from the Pacific Ocean. Between 30 and 60 in/yr of precipitation falls in the higher and wetter parts of this subunit—mostly as snow during the winter and late spring months from November through April. This mountain barrier to moist Pacific air masses causes a distinct rainshadow 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 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.



Base from U.S. Geological Survey digital data, 1:100,000, 1979-80
Universal Transverse Mercator projection, Zone 11

Figure 2. Hydrologic features, river reaches, and hydrologic subunits of the Truckee River Basin used for model.

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 annual snowpack characteristics of the Sierra Nevada located 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 derived from subtropical air masses falling on large winter snowpacks. When the relatively warm rains fall on large snowpacks, rain in addition to large amounts of water from melting snowpacks act together to generate periods of high runoff or even floods. In contrast, during late summer and fall after the snowpack has melted, there is little water entering the Truckee River and, as a consequence, extremely low flows commonly result.

Seven reservoirs were constructed in the upper Truckee River subunit to augment water supply to downstream users during the low flows in summer and to control floods during high flows. In addition to a small dam that regulates the upper 6.1 ft of Lake Tahoe, Donner Lake, Martis Creek Lake, Prosser Creek Reservoir, Independence Lake, Stampede Reservoir, and Boca Reservoir—were built on four tributary streams. Prosser Creek Reservoir and Boca Reservoir are operated together with Lake Tahoe (figs. 1 and 2) to provide flows to a site near Floriston, Calif. (just upstream of the Nevada State line), as required by the Truckee River Agreement of 1935. These flows, named Floriston Rates, are measured at the Farad gaging station. This gaging station is a key site for allocating Truckee River water between California and Nevada and within Nevada.

Urban and agricultural development is not extensive in the upper Truckee River subunit and therefore requires little of the available surface water. Small communities centered around the town of Truckee, Calif., use about 5,000-6,000 acre-ft/yr, primarily from ground water (Jones and others, 1991). Some small water systems serve the ski resorts located between the towns of Truckee and Lake Tahoe. Use of water for snowmaking has been about 1,000 acre-ft/yr but will probably increase (Jones and others, 1991). Since 1980, effluent from the area around Truckee and the ski resorts, 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 located between the town of Truckee and the mouth of Martis Creek, and discharged into a leach field. From the leach field, the effluent percolates to ground water and may indirectly contribute to flows in both the Truckee River and Martis Creek after an estimated detention period of 3 to 6 months (Brown and others, 1986). Developed agricultural land is negligible in this subunit because of the short growing season in the mountainous terrain. Water diverted from the Little Truckee River upstream of Stampede Reservoir (pl. 1) to irrigate in the Feather River Basin averages about 6,000 acre-ft/yr. Fisheries and wildlife do not consume a lot of water, but threshold streamflow, called instream flows, are necessary to provide viable habitat for fisheries and wildlife in this and all of the Truckee River subunits. For power generation, water is temporarily diverted from the Truckee River near Floriston, Calif., close to the California–Nevada State line. Diverted water is carried in a wooden flume to a riverside powerplant. At the powerplant, water is returned to the river after passing through penstocks and rotating turbines, or through bypass spillways. The U.S. Forest Service manages a substantial quantity of land in this subunit and uses negligible Truckee River water. These lands, including parts of Tahoe and Toiyabe National Forests, provide recreation in the form of skiing, camping, and hiking. Although logging was historically a major industry in this region, its role as a major employer has recently declined.

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 Dam (fig. 2 and pl. 1). The section of the Truckee River contained in this subunit is about 46 mi long. Many tributary streams and reservoirs upstream provide and regulate flow that reaches this subunit and from this flow, large volumes of water are diverted for power generation, irrigation, and municipal and industrial water supply. This subunit has about 26 diversions, but this number is variable because diversion ditches and water intakes may not be in operation every day or even every year.

Although the Truckee River enters the drier Basin and Range Province of Nevada in the middle Truckee River subunit, the extreme southwestern part of this subunit consists of high mountain uplands. The 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 downstream (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 USGS gaging station *Truckee River at Vista, Nev.* (hereafter referred to as Vista gaging station; pl. 1, site 38). Downstream of this gaging station, the area that drains to the Truckee River consists 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 cities of Reno, Nev., and Sparks, Nev., along with their adjacent valleys, make up the Truckee Meadows—the most populous area of the entire Truckee River Basin. Urban and suburban developments in this rapidly growing area have replaced large areas that had been devoted to agriculture. As a consequence, much of the water previously diverted for agricultural uses is now diverted for municipal and industrial needs. In some cases, ditch systems that used to supply 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 outside of the Truckee Meadows urban areas, as well as along the Truckee River corridor to the east.

Wooden flumes carry diverted water for power generation to three powerplants between the Farad gaging station and the town of Verdi, Nev. Like the diversion for power generation in the upper Truckee River subunit, the water returns to the river after passing through a powerplant. Water also is diverted to a thermal powerplant for cooling purposes at Tracy, Nev. (pl. 1), between the Vista gaging station and Derby Dam. Water not consumed by evaporation at the powerplant was, until recently, discharged to holding ponds to percolate into the river alluvium. Currently, the small amount of water diverted for cooling purposes is consumed by evaporation within the powerplant.

Agricultural diversions in the middle Truckee River subunit, such as Pioneer Ditch and McCarran Ditch, transport water from the river to agricultural areas. The diverted water then flows through intricate lateral ditches and fields. Excess water not infiltrated to deep ground water or consumed by evapotranspiration may return to the river either (1) through drains or ditch returns at discreet locations or (2) by field returns over wide areas where fields are adjacent to the river. Drains typically intercept water applied to fields that either runs off the surface or infiltrates to shallow ground water. If diverted water is never applied to fields, such as stockwater or excess diverted water, the water may return directly to the river through that same ditch or indirectly through tributaries of the river. Agricultural water also may return to the river along fields immediately adjacent to the river. This water may run off the field at several locations or it may infiltrate to shallow ground water that subsequently may discharge along the river. The primary agricultural returns in the Truckee Meadows enter the Truckee River through North Truckee Drain and Steamboat Creek (the two principal tributaries draining the agricultural/urban basins to the north and south, respectively, of the Truckee River in the Truckee Meadows). 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 with headwaters in the high mountains southwest of the Truckee Meadows—such as Galena, Whites, and Thomas Creeks (pl. 1). Downstream of the Truckee Meadows, local diversions carry water for irrigation of benchlands adjacent to the river. Agricultural water used on these benchlands returns to the river at scattered locations. At Derby Dam, the downstream boundary of the middle Truckee River subunit, large volumes of water are diverted to the Truckee Canal for delivery to irrigators along the canal and in the Carson River Basin near Fallon, Nev., as part of the Newlands Project (fig. 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.

Water for municipal and industrial use is taken from the river at the Steamboat Ditch, Highland Ditch, Idlewild, and Glendale diversions (pl. 1) for delivery to treatment facilities. Steamboat and Highland Ditches previously delivered almost all diverted water to agricultural users but now deliver much of it to water-treatment facilities. After municipal and industrial water is distributed and used, the untreated effluent is transported through a sewage collection system to the

Reno–Sparks Sewage Treatment Plant. The treated effluent is then discharged into Steamboat Creek near its confluence with the Truckee River near Vista, Nev.

The large number of water users in the middle Truckee River subunit can, at times, compete for the limited resource. Because municipal and industrial water supplies are mostly provided from direct diversions from the Truckee River, problems may result during low flows when agricultural, municipal and industrial, and fisheries demands are all high. At these times, mostly during summer, the total municipal demand may not be met by direct-diversion water rights and water restrictions or rationing may be necessary. Thus, there is a continual search for supplemental water supplies, such as importing ground water from another basin or acquiring additional upstream storage to lag high streamflow further into the summer. Additionally, competition for water rights among the various water users instigated continued settlement negotiations to determine how to best meet the needs of all parties during these periods of low flow.

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). This section of the Truckee River is about 34 mi long. Downstream from Derby Dam, the Truckee River flows eastward to Wadsworth, Nev., and then northward to Marble Bluff Dam. Downstream from Marble Bluff Dam, the Truckee River enters Pyramid Lake across a broad delta. The interface of the delta and the lake shoreline is migratory, depending on lake levels and the volume of flow from the Truckee River. This interface 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 flow only intermittently. Therefore, when large amounts of water are diverted from the middle Truckee River subunit to the Truckee Canal, flows in the lower Truckee River can be reduced appreciably. Inflows to the lower section of the river are from either of two major spillways from the Truckee Canal and from ground-water discharge, some of which originates as seepage from the Truckee Canal.

Water is diverted from the river at 10 locations to irrigate land along the river corridor in this subunit. However, unlike the middle Truckee River subunit, no power generation, or municipal and industrial interests require water diversions. Irrigation water may return to the river either as surface water inflows through ditches, return drains, or along fields adjacent to the river, or as ground-water discharge.

As the Truckee River turns northward near Wadsworth, Nev., it enters the Pyramid Lake Indian Reservation. The reservation, created in 1859 by the Secretary of the Interior, follows the Truckee River corridor to Pyramid Lake and includes the entire lake, except for Anaho Island, and adjacent area. Within the reservation, water is diverted from the Truckee River to cultivate the strip of land along the river corridor and adjacent benchlands.

Lower Truckee River water also is used for maintaining flows for fish spawning of an endangered 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, formation of a broad shallow river delta at Pyramid Lake, and periodic shallow water levels in the Truckee River. As a result of these recent changes in lake and river levels, migration of both species of fish up the Truckee River to spawn is limited in dry years.

Marble Bluff Dam was built in 1975 to help reestablish Pyramid Lake and Truckee River fisheries. A fishway leading from the dam to the lake allows some of the fish to migrate to fish-handling facilities at the dam where fertilized eggs stripped from the fish are transferred to hatcheries. 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 DAILY FLOW-ROUTING MODEL

Four flow-routing models using Hydrological Simulation Program–FORTRAN (HSPF) were constructed to simulate streamflow along the mainstem Truckee River. The first three models—called the upper, middle, and lower submodels—simulate streamflow for three distinct segments of the Truckee River. These segments have boundaries that closely correspond to the boundaries of the hydrologic subunits discussed in the section, "Description of Study Area." The fourth model, called the full model, simulates streamflow along the entire mainstem Truckee River from the outlet of Lake Tahoe to Marble Bluff Dam. The full model combines the three submodels. The full model will become the first module in the interbasin modeling system for both the Truckee and Carson Rivers. The following sections describe (1) how the HSPF program simulates streamflow, (2) the data used by the flow-routing models to simulate streamflow, (3) division of the Truckee River and two tributaries into channel segments called reaches for the models, (4) determination of hydraulic characteristics for the reaches for the models, (5) designation of reaches for the full model and three submodels, and (6) selection of simulation periods for the models.

Description of Hydrological Simulation Program–FORTRAN

HSPF is a set of computer codes that can simulate hydrologic and associated water-quality processes on pervious and impervious land surfaces, within the soil profile, and in drainage networks and well-mixed lakes and reservoirs (Bicknell and others, 1993). HSPF separates operations for each simulation into "blocks." Only one block involved in routing streamflow—the RCHRES (reach-reservoir) block—and three utility blocks involved in transferring time series—the NETWORK block, the EXTERNAL SOURCES block, and the EXTERNAL TARGETS block—are used for the Truckee River flow-routing models.

HSPF was selected for the Truckee River flow-routing models primarily because: (1) it can simulate streamflow continuously over long periods of time including periods of storm runoff and low flows, (2) it can simulate streamflow at a variety of time intervals including hourly and daily time steps, (3) it can simulate the hydraulics of complex natural and manmade drainage networks; (4) it can account for both channel inflows and diversions; and (5) it can produce simulation results at a large number of locations along the river.

HSPF can simulate streamflow over long periods of time by numerically representing channel inflow, channel outflow, and channel hydraulics. Channel inflow and outflow may be simulated in HSPF or provided to HSPF by external time series. Channel inflow is routed as streamflow through the drainage network by a modified kinematic-wave algorithm that is a component of HSPF. The drainage network may include any natural or manmade flow-conveyance system, but hydraulic properties of individual reaches must be held constant. HSPF cannot accommodate such hydraulic conditions as backwater or pressurized flow. Water lost from the drainage network is represented either as channel outflow or evaporation.

The previous discussion provided a general overview of the features and limitations of the method HSPF uses to route streamflow. The following discussion on HSPF provides a description of (1) the HSPF drainage network segments called reaches, (2) the HSPF parameters used to characterize reaches, (3) how reach outlets allow delivery of water to specific destinations, such as a downstream reach or a diversion ditch, and (4) how HSPF routes streamflow from reach to reach in a drainage network.

HSPF requires that the linked network of river channels, lakes, reservoirs, wetlands, or drainage pipes be divided into segments called reaches. A reach must have relatively uniform hydraulic properties. For this study, reach segmentation was generalized to simulate only the essential properties that determine streamflow in the Truckee River drainage network. It was not necessary to simulate streamflow through every pool, riffle, or diversion dam.

Numerical values of HSPF model parameters in the RCHRES block represent hydraulic properties of all designated reaches in a drainage network and for time-step weighting of reach outflows. The hydraulic properties, which include channel shape, channel roughness, channel slope, and channel length, determine the relation of streamflow to the volume of water stored in a reach. Function tables of the RCHRES block, referred to as F-tables, contain the relation between the two parameters, streamflow at the downstream end of a reach and volume of water stored in a reach. Additionally, a time-weighting parameter, *KS*, in the RCHRES block is used to compute the weighted mean of streamflow at the start and end of a given time step. Water volume in storage and corresponding streamflow, and the time-weighting parameter, *KS*, are the parameters that define how water is routed through a channel from reach to reach. For this study, field surveys, field reconnaissance, and USGS topographic maps provided the information about hydraulic properties that determined parameter values used for channel routing. A value of 0.5 was assigned to the parameter, *KS*. This value was selected from previous modeling studies (Dinicola, 1990; Berris, 1995) and gave the most accurate simulation results in studies elsewhere (Bicknell and others, 1993).

A reach may have up to five outlets within HSPF. HSPF can produce simulation results at all locations wherever reach outlets exist. Typically, a reach outlet represents the downstream boundary of a reach and enables delivery of water from that reach to the next downstream reach in the same channel. Reach outlets also allow diversion of water from a reach to ditches or canals, or seepage of water from river or lake bed to ground water. When water is diverted from a reach to a ditch or canal, that ditch or canal may or may not be a part of the modeled drainage network. If the ditch or canal is a part of the modeled drainage network, flow can be routed through reaches defined for that ditch or canal system. If the ditch or canal is not a part of the modeled drainage network, the water diverted from a given reach is not routed through the ditch or canal system and is lost from the simulation.

HSPF can route streamflow along channels of a drainage network, from reach to reach, to the designated downstream boundary of a drainage basin. A water budget is determined for each reach by accounting for water entering a reach, water stored in a reach, and water leaving a reach during a given time interval. The total volume of water entering a reach over a given time interval is the sum of the volumes from all inflows during that interval. Inflows to a reach consist of all connected upstream reaches, tributaries, and runoff and ground water from contributing subbasin areas that drain to the reach. In turn, the total water stored in a reach in a given interval is the sum of all volumes draining into the reach from all connected reaches and drainage areas plus the initial volume stored in the reach, minus the volume discharged from the reach during the time interval. In HSPF, outlet discharge from a reach is a function of volume of water stored in the reach, a function of time, or a combination of both functions of volume and time. When outlet discharge is a function of volume, the total volume of water in the reach determines the outlet discharge as specified by model parameters. The volume function is most useful when a stage–discharge relation can characterize outlet discharge. When outlet discharge is a function of time, an external time series governs the outlet discharge. The time function is useful when a control structure governs outlet discharge to agricultural or municipal and industrial demands. When a reach has more than one outlet, then the priority of outflow demands for the outlets can be specified.

Data Used for Simulation of Streamflow

Construction of the three submodels and one full model described in this report requires streamflow data, climate data, and hydraulic data to route streamflow along the Truckee River. Daily mean streamflow data and climate data for water years 1978-92 were obtained from several agencies and were consolidated into a single data base. (Water year is defined as the 12-month period beginning October 1 and ending September 30 designated by the calendar year in which the water year ends.) HSPF streamflow simulations retrieve input streamflow and climate data from time series data storage files and writes simulated streamflow data to different files within the data base. Water years 1978-92 represent a variety of streamflow conditions. At the Farad gaging station, for example, the mean streamflow for water year 1983 was 2,443 ft^3/s—about 320 percent of average (mean annual streamflow at this site was 756 ft^3/s for water years 1909-92) and the mean streamflow for water year 1992 was 197 ft^3/s—about 26 percent of average. Streamflow data computed from gage-height records collected at gaging stations were used when possible. However, streamflow values had to be estimated when observed data were not available to quantify gains or losses to mainstem Truckee River streamflow. Hydraulic data used to determine routing parameters were determined from measurements of cross sections along the Truckee River during field surveys and reconnaissance, and from measurements of some channel properties directly from USGS topographic maps. A more detailed description of the observed and estimated data for the flow-routing models is presented in the following sections.

Observed Flow Data

Streamflow data computed from gage-height records collected at gaging stations are referred to as "observed" data throughout this report. Gaging stations that provided streamflow data for the Truckee River flow-routing models are listed in table 1. Streamflow data collected at gaging stations were used for three purposes: (1) streamflow estimation, (2) model simulation, and (3) model evaluation.

Observed streamflow data were used to estimate ungaged streamflow and to estimate streamflow at gaging stations when streamflow records were either inadequate or inaccurate. A description of the reasons for and methods of streamflow estimation is presented in the following section, "Estimated Flow Data."

Simulation of Truckee River streamflow required input of time series of flows that describe inflows to and diversions from the river. The input time series usually consisted of flow records from gaging stations. Quality of the records depended on the type and location of the gaging stations. Three types of gaging stations were used: continuous-recording gaging stations, flowmeters, and staff gages. The continuous recording gaging stations measure water levels at specified time intervals, usually every 15 min to 1 hr. Flow records produced from the water-level data are available as daily time series. Flowmeters directly measure flow, usually in a pipe. Flow data from flowmeters are usually available as daily time series. In contrast, water levels must be manually read at staff gages. Water-levels at staff gages are read only periodically, and therefore, daily streamflow data are usually not available. Daily streamflow data at staff-gage sites must be estimated for the flow-routing model. Thus, flow data from staff gages are not as accurate as the flow data from continuous-recording gaging stations or flowmeters.

Location of the gaging stations also affects the quality of the flow records. Gaging stations on diversions, such as irrigation ditches or the Truckee Canal, are commonly located upstream of operational spills or irrigation returns back to the Truckee River, and flows in these spills and returns are not typically measured. In such cases, the records may not adequately describe the net diversions and returns from the river. Gaging stations located on the Truckee Canal are typically affected by severe backwater. As a result, stable stage–discharge relations are difficult to maintain, and daily streamflow data from these stations are of questionable accuracy. For example, the accuracy of records collected at the USGS gaging station, *Truckee Canal near Wadsworth, Nev.* (pl. 1, site 47), has been rated only "fair" and "poor" for water years 1978-92. (A fair rating means that 95 percent of the observed daily streamflow are accurate to within 15 percent of the true values. Streamflow records that do not meet the fair rating are rated poor.)

Several different types of inflows to and diversions from the Truckee River are gaged by several agencies. Gaged inflows are usually major tributaries but occasionally include agricultural and municipal returns. Additionally, streamflow data from gaging stations located on the Truckee River at upstream boundaries of each of the four Truckee River flow-routing models were used to define upstream inflows to the models.

Most gaging stations on tributaries are continuous-recording stations and operated by the USGS, but the U.S. Army Corps of Engineers, U.S. Forest Service, Sierra Pacific Power Company, and the U.S. District Court Water Master (Federal Water Master) also operate, or have operated, gaging stations on some tributaries. Streamflow data from most of these stations on tributaries is put directly into the Truckee River reaches represented in the flow-routing models, because most of the stations are close to the confluence with the river. However, Donner Creek and Martis Creek both receive water from major reservoirs, contribute large volumes of water to the Truckee River, and have gaging stations more than 1.6 mi upstream from confluence with the Truckee River. Consequently, streamflow from these tributaries was routed from the gaging stations downstream to the Truckee River.

Agricultural users commonly return diverted irrigation water to the Truckee River, but only a few of these returns are gaged. The Federal Water Master (FWM) has maintained and operated gaging stations on some of these returns beginning in about 1985. Usually, these gaging stations consist of a staff gage. Water levels are periodically read at a staff gage, such as once a week, from April through October (ditches are typically operated during these 7 months that constitute the irrigation season). Return flows are computed from staff gage readings and are subtracted from the diverted flows, usually gaged near the head of a ditch, to provide the "net diverted flow" for a given ditch.

Table 1. Streamflow data-collection sites used for constructing the Truckee River flow-routing models

[Abbreviations: C, data used for evaluation of simulations; E, data used for streamflow estimation; FWM, Federal Water Master; M&I, municipal and industrial; S, data used as input for model simulation; SPPC, Sierra Pacific Power Company; USCOE, U.S. Army Corps of Engineers; USFS, U.S. Forest Service; USGS, U.S. Geological Survey; Washoe, Washoe County]

Site no. (pl. 1)	Agency-assigned station number [1]	Station name	Operating agency	Period of record used for streamflow simulation (water years [2])	Purpose of data
		Upper subunit			
1	USGS 10336660	*Blackwood Creek near Tahoe City, Calif.*	USGS	1978-92	E
2	USGS 10336676	*Ward Creek at State Highway 89, near Tahoe Pines, Calif.*	USGS	1978-92	E
3	USGS 10337500	*Truckee River at Tahoe City, Calif.*	USGS	1978-92	S
4	USGS 10338000	*Truckee River near Truckee, Calif.*	USGS	1978-82	C
5	USGS 10338500	*Donner Creek at Donner Lake near Truckee, Calif.*	USGS	1978-92	S
6	USCOE USGS 10339400	*Martis Creek near Truckee, Calif.*	USGS USCOE	1978-92	S
7	USGS 10340500	*Prosser Creek below Prosser Creek Dam near Truckee, Calif.*	USGS	1978-92	S
8	USGS 10343500	*Sagehen Creek near Truckee, Calif.*	USGS	1978-92	E
9	USGS 10344500	*Little Truckee River below Boca Dam near Truckee, Calif.*	USGS	1978-92	S
10	USGS 10346000	*Truckee River at Farad, Calif.*	USGS	1978-92	C,S
		Middle subunit			
11	USFS SPPC USGS 10347300	*Dog Creek near Verdi, Nev.*	USFS SPPC	1978-92	S
12	FWM USGS 10347331	*Katz Ditch near Verdi, Nev.*	FWM	1978-86	S
13	FWM T2 USGS 10347390	*Coldron Ditch at Verdi, Nev.*	FWM	1978-92	S
14	SPPC FWM T4 USGS 10347420	*Highland Ditch at Reno, Nev.*	SPPC	1978-92	S
15	SPPC USGS 10347600	*Hunter Creek near Reno, Nev.*	USGS SPPC	1978-92	S,E
16	SPPC	*Steamboat Canal Diversion to Hunter Creek Water Treatment Plant*	SPPC	1978-92	S
17	SPPC	*Hunter Creek Water Treatment Plant Delivery to M&I System*	SPPC	1978-92	S
18	SPPC	*Idlewild Water Treatment Plant delivery to M&I System*	SPPC	1978-92	S
19	SPPC	*Highland Water Treatment Plant delivery to M&I System*	SPPC	1978-92	S

Table 1. Streamflow data-collection sites used for constructing the Truckee River flow-routing models—Continued

Site no. (pl. 1)	Agency-assigned station number [1]	Station name	Operating agency	Period of record used for streamflow simulation (water years [2])	Purpose of data
20	SPPC	*Highland Plant Spill to Washington Street Drain*	SPPC	1985-92	S
21	USGS 10348000	*Truckee River at Reno, Nev.*	USGS	1978-92	C
22	SPPC USGS 10348034	*Glendale Water Treatment Plant Delivery to M&I System*	SPPC	1978-92	S
23	FWM USGS 10348150	*Sessions Ditch near Reno, Nev.*	FWM	1978-88	S
24	USGS 10348200	*Truckee River near Sparks, Nev.*	USGS	1978-92	C
25	FWM T7 USGS 10348210	*Orr Ditch near Reno, Nev.*	FWM	1978-92	S
26	FWM T9, T9a, T9b USGS 10348270	*North Truckee Ditch at Reno, Nev.*	FWM	1978-92	S
27	FWM T59 USGS 10348300	*North Truckee Drain at Kleppe Lane near Sparks, Nev.*	FWM	1978-92	S
28	FWM T12 USGS 10348310	*Glendale Ditch near Sparks, Nev.*	FWM	1978-92	S
29	USGS 10348900	*Galena Creek near Steamboat, Nev.*	USGS	1978-92	E
30	FWM T1 USGS 10349350	*Steamboat Ditch near Floriston, Calif.*	FWM	1978-92	S
31	FWM T5 USGS 10349740	*Last Chance Ditch at Hunter Creek, near Reno, Nev.*	FWM	1978-92	S
32	FWM T6 USGS 10349810	*Lake Ditch at Mayberry Drive near Reno, Nev.*	FWM	1978-92	S
33	FWM T8 USGS 10349938	*Cochran Ditch at Reno, Nev.*	FWM	1978-92	S
34	FWM T11 USGS 10349971	*Pioneer Ditch at Reno, Nev.*	FWM	1978-92	S
35	FWM USGS 10349974	*Eastman Ditch at Reno, Nev.*	FWM	1978-85	S
36	FWM T54 USGS 10349980	*Steamboat Creek at Cleanwater Way, near Reno, Nev.*	FWM	1978-92	S
37	Washoe USGS 10349995	*Reno–Sparks Sewage Treatment Plant Outfall at Reno, Nev.*	Washoe	1978-92	S
38	USGS 10350000	*Truckee River at Vista, Nev.*	USGS	1978-92	C,E
39	FWM T16 USGS 10350048	*Noce Ditch near Vista, Nev.*	FWM	1978-92	S
40	FWM USGS 10350130	*Groton Ditch at Lockwood, Nev.* [3]	FWM	1978-84	S

Table 1. Streamflow data-collection sites used for constructing the Truckee River flow-routing models—Continued

Site no. (pl. 1)	Agency-assigned station number [1]	Station name	Operating agency	Period of record used for streamflow simulation (water years [2])	Purpose of data
41	FWM USGS 10350140	*Sheep Ranch Ditch near Lockwood, Nev.*	FWM	1978	S
42	FWM T17 USGS 10350150	*Murphy Ditch near Vista, Nev.*	FWM	1978-92	S
43	FWM T19 USGS 10350320	*McCarran Ditch near Patrick, Nev.*	FWM	1978-92	S
44	USGS 10350400	*Truckee River below Tracy, Nev.*	USGS	1978-92	C,E
45	FWM USGS 10350475	*Hill Ditch opposite Tracy Power Plant at Tracy, Nev.*	FWM	1978-86	S
46	FWM T14 USGS 10351010	*Truckee Canal below Derby Dam, near Wadsworth, Nev.*	FWM	1978-92	S,C
47	USGS 10351300	*Truckee Canal near Wadsworth, Nev.*	USGS	1978-92	S,C
		Lower subunit			
48	USGS 10351600	*Truckee River below Derby Dam, near Wadsworth, Nev.*	USGS	1978-92	S,C,E
49	FWM T20 USGS 10351615	*Washburn Ditch at Orchard, Nev.*	FWM	1978-92	S
50	FWM T23 USGS 10351630	*Pierson Ditch at Interstate-80 Bridge, at Wadsworth, Nev.*	FWM	1978-92	S
51	FWM T22 USGS 10351635	*Herman Ditch near Wadsworth, Nev.*	FWM	1978-92	S
52	FWM T21	*Gregory Ditch near Wadsworth, Nev.*	FWM	1978-92	S
53	USGS 10351650	*Truckee River at Wadsworth, Nev.*	USGS	1978-86	C
54	FWM T25 USGS 10351660	*Fellnagle Ditch near Wadsworth, Nev.*	FWM	1978-92	S
55	FWM T24 USGS 10351668	*Proctor Ditch at Wadsworth, Nev.*	FWM	1978-92	S
56	FWM T26 USGS 10351682	*Gardella Ditch near Wadsworth, Nev.*	FWM	1978-92	S
57	FWM	*Olinghouse #1 Pump near Wadsworth, Nev.*	FWM	1978-92	S
58	FWM	*Olinghouse #3 Pump near Wadsworth, Nev.*	FWM	1978-92	S
59	USGS 10351700	*Truckee River near Nixon, Nev.*	USGS	1978-92	C
60	FWM T27 USGS 10351755	*Indian Ditch near Nixon, Nev.*	FWM	1978-92	S

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

[2] Water year is defined as 12-month period beginning October 1 and ending September 30, and is designated by calendar year in which water year ends.

[3] *Groton Ditch at Lockwood, Nev., and Murphy Ditch near Vista, Nev., were combined in 1985 and are currently known as Murphy Ditch near Vista, Nev.*

The major municipal and industrial return flow to the Truckee River is treated effluent discharged from the Reno–Sparks Sewage Treatment Plant to Steamboat Creek, just upstream from its mouth on the Truckee River. Effluent flow data from a flowmeter at the reclamation facility had a monthly time step before water year 1985 and a daily time step during and after water year 1985. Before 1985, daily effluent flows during a given month were considered equivalent to the monthly mean effluent flows provided by the water-reclamation facility.

Model simulations require time series of streamflow data that describe water diverted from the Truckee River. Gaged diversions are irrigation ditches, the Truckee Canal, and diversions to water-treatment plants. Most gaging stations on irrigation ditches are operated and maintained by the FWM and consist of both continuous-recording gaging stations and staff gages. Diverted flows, obtained from gaging-station records, were commonly treated as direct outflows from the Truckee River, but, as previously discussed, when return flows are measured, the net diverted flows were computed to describe the outflows from the river.

Continuous-recording gaging stations on the Truckee Canal are operated by the FWM and the USGS. Data from these stations are of questionable accuracy because of frequent backwater conditions. Therefore, the flow record had to be estimated. A description of the flow-estimation procedure is presented in a later section, "Flow Data Affected by Backwater."

Sierra Pacific Power Company measures water diverted to water-treatment plants and the volume of water treated at these plants for municipal and industrial use. They use continuous-recording gaging stations, flowmeters, and staff gages.

Finally, streamflow data observed at gaging stations were used to evaluate the accuracy of the streamflow simulations from the flow-routing models. During model evaluation, simulated streamflow were compared to observed streamflow at these gaging stations. The gaging stations that provided the streamflow data used for evaluation are operated by the USGS and located on the mainstem Truckee River.

Estimated Flow Data

Data on ground-water inflow and surface-water flow were estimated when continuous or accurate data were not available to quantify inflows to and outflows from the Truckee River. Data were not always available because (1) gaging stations did not always provide continuous time series of tributary, diversion, or return flows, (2) gaging stations did not always provide accurate tributary and diversion flow data due to backwater conditions, or (3) gaging stations were not available at all locations to measure all inflow to the river. Flow losses due to evapotranspiration from phreatophytes also were estimated.

Discontinuous Flow Data

Daily flow records had to be estimated for some gaging stations to construct the continuous time series required by the flow-routing models because there were missing periods of daily records. Daily records were missing because of gaging-station malfunctions or gaging-station type.

Gaging-station malfunctions are usually because of equipment failure or vandalism. When this happens, periods of missing flow records can be estimated from the hydrographs of nearby gaging stations, either by comparing the shapes of hydrographs between stations (called hydrographic comparison) or by water-balance computations. Often, both techniques are used to increase the accuracy of the estimation. If hydrographs from nearby gaging stations do not show similar flow trends and do not represent enough of the necessary components for complete water-balance computations, then missing periods of data cannot be estimated, resulting in a reduction of data accuracy and, ultimately, model accuracy.

The type of gaging station determines the time intervals that data are collected. Staff gages, commonly on irrigation ditches and returns, do not continuously record water levels. Periodic observations of water levels are made only during regular field inspections, usually once or twice a week during irrigation season, and do not provide daily data. Flow records were estimated for periods between staff-gage measurements either by linear interpolation from measurement to measurement or by using the previous measured value until the next measurement is made (which produces a "stair-stepping" effect and is therefore called "stepping"). Flow records at staff-gage sites or ditches were not estimated from nearby hydrographs, because ditches are independently operated for irrigation, and flow in one ditch does not correlate with flow in nearby ditches. Accuracy of daily flow records from staff-gage sites on ditches is lower than accuracy from continuous-recording gaging stations, because daily data are not often available and, therefore, interpolating or stepping daily flow data between measurements is necessary for the development of continuous time series of flow.

Flow Data Affected by Backwater

Inaccurate records from gaging stations subject to severe backwater conditions were commonly replaced with estimated flow data. Gaging stations on the Truckee Canal were often affected by backwater and gaging stations on Steamboat Creek and North Truckee Drain were occasionally affected by backwater. Severe backwater conditions are common along most of the Truckee Canal because of its low gradient coupled with (1) variable regulation of spillways and diversion ditches at check dams, and (2) variable and seasonal aquatic vegetation along the length of the canal. Therefore, flow data on the canal at the point of diversion from the Truckee River had to be estimated by water-balance computations. The computations used streamflow records obtained at the USGS gaging stations *Truckee River below Tracy, Nev.* (about 5.75 mi upstream from Derby Dam; pl. 1, site 44), and *Truckee River below Derby Dam, near Wadsworth, Nev.* (located about 0.4 mi downstream from Derby Dam; pl. 1, site 48).

Steamboat Creek and North Truckee Drain are subject to intermittent backwater conditions near their confluences with the Truckee River. During periods of high streamflow on the Truckee River, backwater conditions may affect the lower length of these tributaries. If high streamflow on these tributaries coincides with high streamflow on the Truckee River, severe backwater and overbank flooding conditions may result up to several miles upstream from the Truckee River. The gaging stations on these tributaries, *North Truckee Drain at Kleppe Lane, near Sparks, Nev.* (pl. 1, site 27), and *Steamboat Creek at Cleanwater Way, near Reno, Nev.* (pl. 1, site 36), are both less than 1 mi upstream from the Truckee River. Thus, backwater conditions during periods of high streamflow reduce the accuracy of the streamflow records from these gaging stations. Streamflow records from North Truckee Drain and Steamboat Creek during periods of backwater were estimated by both water-balance computations and hydrographic comparisons. The computations used streamflow records obtained at the gaging stations, *Truckee River near Sparks, Nev.* (pl. 1, site 24), and *Truckee River at Vista, Nev.* (pl. 1, site 38).

Ungaged Inflows

The previous discussion described estimation of streamflow records at gaging stations that did not provide continuous and accurate time series of daily streamflow data. The following discussion describes estimating inflows to the Truckee River when gaging stations are not available to measure these inflows. Ungaged inflows to the Truckee River are estimated for (1) ungaged tributary inflows, (2) ungaged spills and returns from irrigation ditches, and (3) ungaged ground-water inflows.

Ungaged Tributaries

Most of the ungaged, perennial tributaries are in the upper Truckee River subunit between the outlet of Lake Tahoe and the Farad gaging station. These tributaries, with headwaters in the high elevations of the Sierra Nevada, supply most of the ungaged tributary inflows to the Truckee River. In contrast, downstream from the Farad gaging station, most of the ungaged tributaries are ephemeral and, as a result, do not normally supply large volumes of water to the Truckee River. Daily time series of ungaged inflows to the upper Truckee River were estimated by monthly regression equations to provide data to the flow-routing models for streamflow simulations. The regression equations were useful for distributing ungaged inflow data to modeled river reaches of the upper Truckee River. The ungaged inflows are from tributary subbasins and from intervening drainage areas between tributary subbasins.

Simple linear regression analyses related daily mean streamflow from index gaging-station records to daily ungaged inflows to two segments of the upper Truckee River. An upstream segment and downstream segment were defined for the computation of ungaged inflows, and each segment had boundaries defined at gaging stations. The upstream segment, between USGS gaging stations *Truckee River at Tahoe City, Calif.* (pl. 1, site 3), and *Truckee River near Truckee, Calif.* (pl. 1, site 4), has a length of about 12.5 mi. The downstream segment—between USGS gaging stations *Truckee River near Truckee, Calif.*, and *Truckee River at Farad, Calif.*, has a length of about 21.5 mi. Daily ungaged inflows to the Truckee River were computed for the regression analyses by subtracting all gaged inflows to a given segment from the gaged outflow of that segment. Daily ungaged inflows computed by this "water-balance" method also incorporate minor river gains and losses from other unmeasured sources, such as losses from phreatophyte evapotranspiration, losses from evaporation, and gains from precipitation.

Equations used to estimate ungaged tributary inflows were developed using methods similar to those described by Riggs (1968) and Blodgett and others (1984). Flows at several nearby gaging stations were hypothesized to have similar trends to ungaged inflows for the two segments of the upper Truckee River. Results from multiple regression analyses indicated that daily mean streamflow from one index gaging station adequately described ungaged inflows to a segment for a given month. For each month of the year, regression equations were developed that relate daily mean streamflow for ungaged tributaries (response variable) to the daily mean streamflow from a nearby, physiographically similar gaged basin (explanatory variable). For most months, coefficients of determination (r^2) for these regression equations ranged from 0.80 to 0.98, but for some months (usually months of low streamflow) the coefficients of determination could be lower.

The monthly regression equations were used to estimate ungaged inflows to the upper Truckee River for water years 1978-92, the same period used for streamflow simulations by the flow-routing models. However, the equations were developed using streamflow data from water years 1978-82. Thus, the regression equations were used to estimate ungaged inflows for a period that was 10 years longer than the 5-year period used to develop the equations. Streamflow data from the gaging station *Truckee River near Truckee, Calif.*, were available only through the water year 1982 because the gaging station was taken out of operation at the beginning of water year 1983. The regression equations were especially useful for distributing ungaged inflow data when the Truckee River near Truckee gaging station was out of operation for water years 1983-92. This gaging station was at a key location for the designation of the two segments used in the multiple regression analyses. Streamflow data from this station were used to determine that streamflow observed at gages on the west side of Lake Tahoe were more representative of ungaged inflows to the upper segment, whereas tributaries of the Truckee River downstream of the town of Truckee were more representative of ungaged inflows to the downstream segment. Streamflow records from USGS gaging stations *Blackwood Creek near Tahoe City, Calif.* (pl. 1, site 1), and *Ward Creek at State Highway 89, near Tahoe Pines, Calif.* (pl. 1, site 2), were used to estimate ungaged inflows to the upstream segment. Streamflow records from USGS gaging stations *Sagehen Creek near Truckee, Calif.* (pl. 1, site 8), and *Galena Creek near Steamboat, Nev.* (pl. 1, site 29), were used to estimate ungaged inflows to the downstream segment. The daily time series of ungaged inflows to each segment were then apportioned to each model reach according to intervening ungaged drainage areas.

Ungaged Spills and Returns

Like the many ungaged perennial tributaries to the upper Truckee River, spills and returns from irrigation ditches and canals to the middle and lower Truckee River are only rarely gaged and time series of flow data are usually not available. Beginning about 1985, the FWM has maintained and operated staff gages on some of the major returns and spills, but most still are not gaged. Ungaged inflows to the Truckee River from ditch spills and returns were estimated to quantify net diversions to ditches and canals from the Truckee River for the flow-routing models. Net ditch diversions were determined using spill or return flows that were wholly or partially estimated during the simulation period. Net diversions were computed by subtracting spill or return inflows from a given ditch system from the outflow diverted to that ditch system.

The amounts of diverted water returned to the Truckee River could only be crudely estimated, because ungaged spills and returns from a given ditch could not be related to nearby gaged spills and returns from other ditches. Operations of ditch headgates along the Truckee River determine the amount of water diverted to ditches and canals. Additionally, operation of gates along a given ditch determine the quantity of water allocated to irrigation and the quantity of water that spills back to the Truckee River. Operation of the gates is based on (1) water rights of irrigators along a given ditch, (2) various characteristics of the irrigated land, such as the area to be irrigated, crop type, and soil moisture, and (3) quantity of streamflow available to be diverted from the Truckee River. The amount of water returned to the Truckee River after irrigation depends on the amount of irrigation water applied to the land, soil characteristics, ground-water characteristics, and climate characteristics.

Information on (1) hydraulic characteristics of some irrigation systems, (2) water rights, and (3) historical and present patterns of water use, returns, and spills, obtained from the FWM and Sierra Pacific Power Company was helpful to estimate spills and returns to the Truckee River (Jeff Boyer, U.S. District Court Water Master, oral commun., 1993; R. Moser, Sierra Pacific Power Company, oral commun., 1993). Estimates were computed by one or more of the following methods:

- applying simple return coefficients to diverted flows,
- applying irrigation duties (water rights) to acreages of irrigated land while assuming ditch seepage and evapotranspiration losses,
- applying historical and present patterns of spills and returns from gaged periods to ungaged periods for a given ditch system, and
- applying hydraulic characteristics to determine the maximum flow capacity of ditch systems to gaged diverted flows.

The methods of estimating return flows are crude, but are more accurate than if return flows from diversions were ignored.

Regulatory spills from the Truckee Canal to the Truckee River downstream from Derby Dam were ungaged and could not be estimated. Therefore, these spills are not accounted for in the flow records used for the flow routing, and inflow to the Truckee River from these spills is underestimated, resulting in reduced model accuracy.

Ungaged Ground-Water Inflows

Ground-water inflows were estimated for the lower Truckee River. During irrigation season, inflows to the Truckee River from ground water are difficult to isolate by water-balance computations using streamflow data from gaging stations because the irrigation diversions and returns that must be considered are usually estimated. Additionally, gaging station sites are too far apart to define where ground water discharges into the Truckee River. Therefore, the USGS made seepage runs, which are serial, nearly concurrent streamflow measurements along the length of the river and some irrigation ditches to determine where flow is gained from or lost to ground water. On the basis of streamflow measurements from these seepage runs, ground-water discharge to the river was estimated between Derby Dam and Marble Bluff Dam. These estimates were assumed to be constant for the entire simulation period because data and studies defining the physical relations necessary to estimate daily or monthly time series of ground-water inflows were not available.

Evapotranspiration Losses from Phreatophytes

Time series of streamflow losses due to evapotranspiration from phreatophytes were estimated. The total monthly evapotranspiration rate for each designated channel reach was estimated by accounting for phreatophyte acreage, annual evapotranspiration rate for typical species, and the monthly distribution of annual evapotranspiration. The approximate extent of phreatophyte coverage and species composition along designated channel reaches of the Truckee River were determined during field reconnaissance and from photographs. Acreage of phreatophyte coverage was estimated assuming that phreatophytes within a 100-foot wide strip along the river affect streamflow. The annual evapotranspiration rate for each typical phreatophyte species was estimated using previous studies as a guideline (Robinson, 1958, 1970; Glancy, 1971; Maurer, 1986). The monthly distribution of average annual evapotranspiration rates was estimated using guidelines described by Duell (1990). The time series were applied only to the Truckee River downstream of Farad. Upstream of Farad, streamflow losses from phreatophyte evapotranspiration were accounted for within the same regression equations used to estimate flow data for ungaged tributaries upstream of Farad.

Climate Data

Simulation of streamflow gains and losses required input time series of precipitation and evaporation. These time series were applied only to the Truckee River downstream of Farad. Upstream of Farad, gains to streamflow from precipitation and losses from streamflow due to evaporation were accounted for within the same regression equations used to estimate flow data for ungaged tributaries upstream of Farad. Daily precipitation data were distributed to designated channel reaches based on observed measurements obtained from National Weather Service climate stations located near Boca Reservoir, Calif., and in Reno and Wadsworth, Nev. Average monthly evaporation rates along the river were estimated (Roderick L. Hall, Sierra Hydrotech, written commun., 1994).

Hydraulic Data

Hydraulic data necessary to determine routing parameters for the flow-routing models were measured or estimated either during field reconnaissance at 215 cross sections or directly from maps. Channel geometry was surveyed by the U.S. Army Corps of Engineers at 82 cross sections along the Truckee River in the Truckee Meadows (U.S. Army Corps of Engineers, written commun., 1992) and by the USGS at 133 cross sections elsewhere along the Truckee River and on Donner and Martis Creeks. Manning's roughness coefficients were estimated at all cross sections by the USGS. Most cross sections were selected as a representative sample of channel segments upstream and downstream from the cross section. Cross-section locations were always chosen at or near the downstream end of a designated channel reach, because HSPF simulates discharges at the downstream end of reaches. Cross sections in the Truckee Meadows were spaced an average of about 0.1 mi apart. All other cross sections were spaced an average of about 0.9 mi apart.

Geographic information system (GIS) coverages using 1:24,000-scale topographic maps provided data necessary to determine channel lengths and average channel slopes. Channel lengths were measured between all cross sections and reach boundaries. Average channel slopes were determined by measuring the length of channel segments between the points where altitude contours cross the river or creek channels. All cross sections in a given channel segment were assigned the average channel slope of that segment.

Channel geometry, roughness, slopes, and lengths measured or estimated at all cross sections provided the necessary information to determine the volume–discharge relations used by HSPF for streamflow routing from reach to reach. A description of the determination of volume-discharge relations for channel reaches from the measured hydraulic data is presented in the section "Hydraulic Characteristics of Reaches."

Division of River into Reaches

As described in the previous section, "Description of the Hydrological Simulation Program—FORTRAN," HSPF requires the division of the modeled drainage network into reaches for routing of streamflow. The 114-mi length of the Truckee River between the outlet of Lake Tahoe near the gaging station *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam was divided into 45 reaches. The 2.3-mi length of Donner Creek between the gaging station *Donner Creek near Donner Lake near Truckee, Calif.* (pl. 1, site 5), and its mouth at the Truckee River was designated as a single reach; as was the 1.6-mi length of Martis Creek between the gaging station *Martis Creek near Truckee, Calif.* (pl. 1, site 6), and its mouth at the Truckee River was designated as one reach, for a total of 47 reaches (figs. 2 and 3; pl. 1). Reaches were assigned three-digit identification numbers that increased from the upper to the lower parts of the basin. Each reach was chosen to have relatively uniform hydraulic characteristics. Reach boundaries were commonly designated at gaging stations and hydrographic features such as points of tributary inflow, points of diversion, or large riffles. Reach lengths averaged about 2.5 mi and ranged between about 1.1 and 3.7 mi.

Each reach may receive observed or estimated inflows from upstream connected reaches, tributaries, spills, returns, and ground water. Each reach may deliver outflows, as functions of volume or time, through up to five outlets to the downstream reach and to diversions. Simulated flows can be displayed for any outlet for any reach. Links between reaches and the inflows and outflows to each of the 47 reaches are diagrammed in figure 3 and listed in table 2.

In addition to the 47 reaches representing the mainstem Truckee River, Donner Creek, and Martis Creek, 15 peripheral reaches were defined for 8 lakes and reservoirs in the basin (Lake Tahoe, Donner Lake, Martis Creek Lake, Prosser Creek Reservoir, Independence Lake, Stampede Reservoir, Boca Reservoir, and Pyramid Lake) and 7 channel segments along the Little Truckee River, a major tributary of the Truckee River (pl. 1). Although these peripheral reaches were not used to route streamflow along the Truckee River as described in this report, they are a part of the defined river-reach network for the Truckee River Basin that can be used for other types of model simulations. Hereafter, these additional reaches will not be referred to in this report.

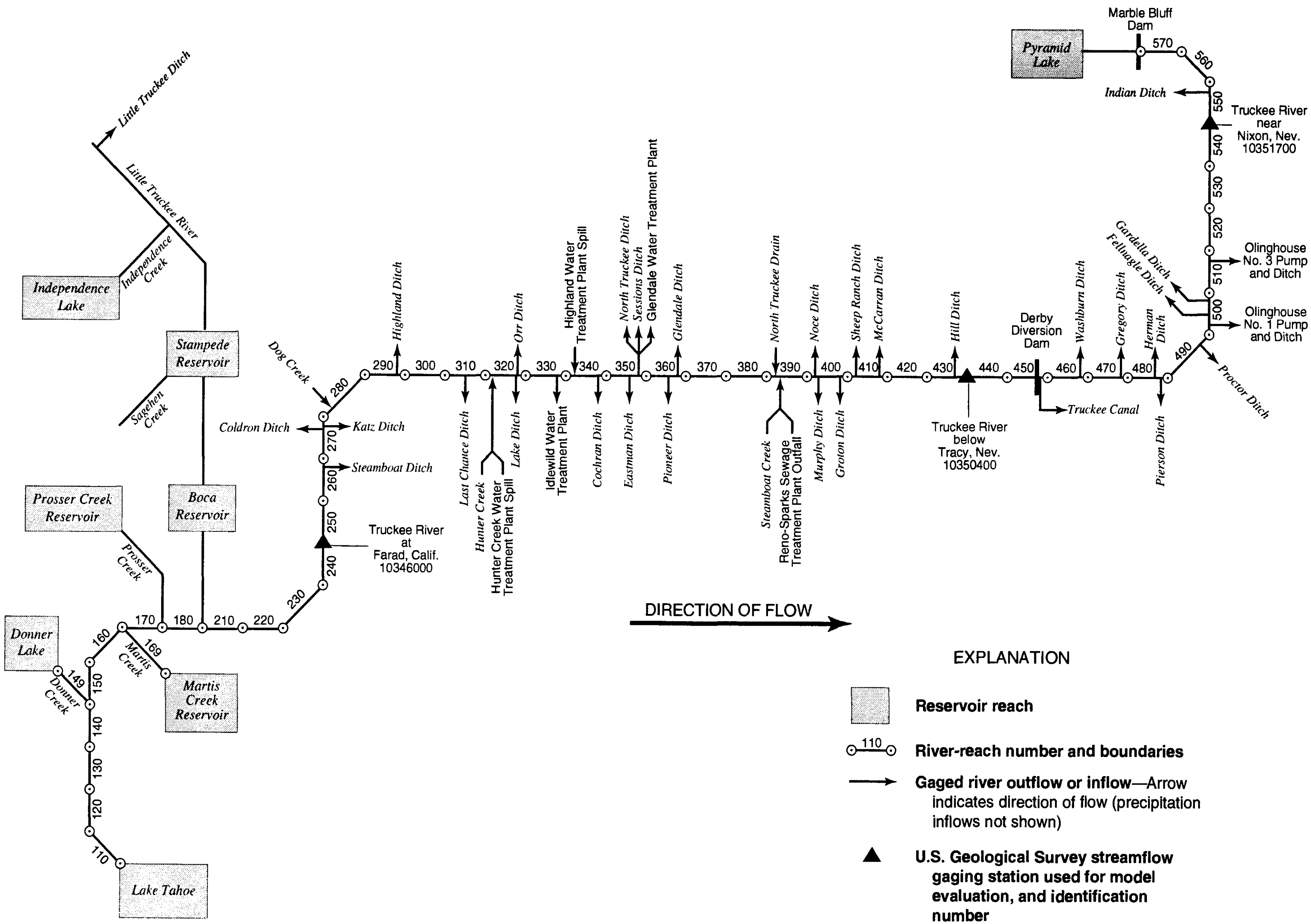


Figure 3. Schematic diagram showing the river reaches, gaged outflows, and gaged inflows for the Truckee River routing models.

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models

[Abbreviation: M&I, Municipal and Industrial]

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
110	Inflow	From Lake Tahoe	Measured	*Truckee River at Tahoe City, Calif.*
	Inflow	Ungaged	Estimated	
	Outflow	To reach 120	Simulated	
120	Inflow	From reach 110	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 130	Simulated	
130	Inflow	From reach 120	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 140	Simulated	
140	Inflow	From reach 130	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 150	Simulated	
149	Inflow	From Donner Lake	Measured	*Donner Creek at Donner Lake near Truckee, Calif.*
	Inflow	Ungaged	Estimated	
	Outflow	To reach 150	Simulated	
150	Inflow	From reaches 140 and 149	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 160	Simulated	
160	Inflow	From reach 150	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 170	Simulated	
169	Inflow	From Martis Lake	Measured	*Martis Creek near Truckee, Calif.*
	Inflow	Ungaged	Estimated	
	Outflow	To reach 170	Simulated	
170	Inflow	From 160 and 169	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 180	Simulated	
180	Inflow	From reach 170	Simulated	
	Inflow	From Prosser Creek Reservoir	Measured	*Prosser Creek below Prosser Creek Dam near Truckee, Calif.*
	Inflow	Ungaged	Estimated	
	Outflow	To reach 210	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (If measured)
210	Inflow	From reach 180	Simulated	
	Inflow	Boca Reservoir	Measured	*Little Truckee River below Boca Dam near Truckee, Calif.*
	Inflow	Ungaged	Estimated	
	Outflow	To reach 220	Simulated	
220	Inflow	From reach 210	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 230	Simulated	
230	Inflow	From reach 220	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 240	Simulated	
240	Inflow	From reach 230	Simulated	
	Inflow	Ungaged	Estimated	
	Outflow	To reach 250 (full model)	Simulated	
250	Inflow	From reach 240 (full model)	Simulated	
	Inflow	From upper Truckee River subunit (middle submodel)	Measured	*Truckee River at Farad, Calif.*
	Inflow	Precipitation	Measured	*Boca 4N near Boca Reservoir, Calif.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 260	Simulated	
260	Inflow	From reach 250	Simulated	
	Inflow	Precipitation	Measured	*Boca 4N near Boca Reservoir, Calif.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Steamboat Ditch (return flows measured at Steamboat Creek at Cleanwater Way near Reno, Nev.)	Measured	*Steamboat Ditch near Floriston, Calif.*
	Outflow	To reach 270	Simulated	
270	Inflow	From reach 260	Simulated	
	Inflow	Precipitation	Measured	*Boca 4N near Boca Reservoir, Calif.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Coldron Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Coldron Ditch at Verdi, Nev.*
	Outflow	Net diversion to Katz Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Katz Ditch at Verdi, Nev.*
	Outflow	To reach 280	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
280	Inflow	From reach 270	Simulated	
	Inflow	From Dog Creek	Measured	*Dog Creek near Verdi, Nev.*
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 290	Simulated	
290	Inflow	From reach 280	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Partial net diversion to Highland Ditch (estimated spills and return flows subtracted from gross diversion and some return flows measured at Highland Plant spill to Washington Street drain)	Measured and partially estimated	*Highland Ditch at Reno, Nev.*
	Outflow	To reach 300	Simulated	
300	Inflow	From reach 290	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 310	Simulated	
310	Inflow	From reach 300	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Last Chance Ditch (return flows measured at Steamboat Creek at Cleanwater Way near Reno, Nev.)	Measured	*Last Chance Ditch at Hunter Creek near Reno, Nev.*
	Outflow	To reach 320	Simulated	
320	Inflow	From reach 310	Simulated	
	Inflow	From Hunter Creek and Hunter Creek Water Treatment Plant spill.	Measured and partially estimated	*Hunter Creek near Reno, Nev.* *Steamboat Canal Diversion to Hunter Creek Water Treatment Plant.* *Hunter Creek Water Treatment Plant Delivery to M&I System.*
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Lake Ditch (return flows measured at Steamboat Creek at Cleanwater Way near Reno, Nev.)	Measured	*Lake Ditch at Mayberry Drive, near Reno, Nev.*
	Outflow	Diversion to Orr Ditch (return flows measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.)	Measured	*Orr Ditch near Reno, Nev.*
	Outflow	To reach 330	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
330	Inflow	From reach 320	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Idlewild Water Treatment Plant	Measured	*Idlewild Water Treatment Plant Delivery to M&I System.*
	Outflow	To reach 340	Simulated	
340	Inflow	From reach 330	Simulated	
	Inflow	From Highland Water Treatment Plant spill (receives some return water from Highland Ditch)	Measured	*Highland Plant Spill to Washington Street Drain.*
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Cochran Ditch (return flows measured at Steamboat Creek at Cleanwater Way near Reno, Nev.)	Measured	*Cochran Ditch at Reno, Nev.*
	Outflow	To reach 350	Simulated	
350	Inflow	From reach 340	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Eastman Ditch	Measured and partially estimated	*Eastman Ditch at Reno, Nev.*
	Outflow	Diversion to North Truckee Ditch (return flows measured at North Truckee Drain at Kleppe Lane near Sparks, Nev.)	Measured and partially estimated	*North Truckee Ditch at Reno, Nev.*
	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.*
	Outflow	Diversion to Glendale Water Treatment Plant	Measured	*Glendale Water Treatment Plant Delivery to M&I System.*
	Outflow	To reach 360	Simulated	
360	Inflow	From reach 350	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Pioneer Ditch (estimated returns delivered to reach 390)	Measured and partially estimated	*Pioneer Ditch at Reno, Nev.*
	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.*
	Outflow	To reach 370	Simulated	
370	Inflow	From reach 360	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 380	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
380	Inflow	From reach 370	Simulated	
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 390	Simulated	
390	Inflow	From reach 380	Simulated	
	Inflow	From estimated return flow from Pioneer Ditch	Estimated	
	Inflow	From North Truckee Drain (receives some return water from Orr Ditch, North Truckee Ditch, Sessions Ditch, and Glendale Ditch)	Measured and partially estimated	*North Truckee Drain at Kleppe Drain near Sparks, Nev.*
	Inflow	From Steamboat Creek (receives some return water from Steamboat Ditch, Last Chance Ditch, Lake Ditch, and Cochran Ditch)	Measured and partially estimated	*Steamboat Creek at Cleanwater Way near Reno, Nev.*
	Inflow	From Reno–Sparks Sewage Treatment Plant (currently called Truckee Meadows Water Reclamation Facility) (receives M&I system returns from water treated at Hunter Creek, Highland, Idlewild, and Glendale Water Treatment Plants)	Measured	*Reno–Sparks Sewage Treatment Plant Outfall at Reno, Nev.*
	Inflow	Precipitation	Measured	*Reno WSFO Airport at Reno, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 400	Simulated	
400	Inflow	From reach 390	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Noce Ditch (estimated spills and return flows subtracted from gross diversion.	Measured and partially estimated	*Noce Ditch near Vista, Nev.*
	Outflow	Net diversion to Murphy Ditch (estimated and measured spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Murphy Ditch near Vista, Nev.*
	Outflow	Net diversion to Groton Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Groton Ditch at Lockwood, Nev.*
	Outflow	To reach 410	Simulated	
410	Inflow	From reach 400	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Sheep Ranch Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Sheep Ranch Ditch near Lockwood, Nev.*
	Outflow	Net diversion to McCarran Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*McCarran Ditch near Patrick, Nev.*
	Outflow	To reach 420	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
420	Inflow	From reach 410	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 430	Simulated	
430	Inflow	From reach 420	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Hill Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Hill Ditch opposite Tracy Power Plant at Tracy, Nev.*
	Outflow	To reach 440	Simulated	
440	Inflow	From reach 430	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 450 (full model)	Simulated	
450	Inflow	From reach 440 (full model)	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Diversion to Truckee Canal	Estimated	
	Outflow	To reach 460 (full model)	Simulated	
460	Inflow	From reach 450 (full model)	Simulated	
	Inflow	From middle Truckee River subunit (lower submodel)	Measured	*Truckee River below Derby Dam near Wadsworth, Nev.*
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Washburn Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Washburn Ditch at Orchard, Nev.*
	Outflow	To reach 470	Simulated	
470	Inflow	From reach 460	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Gregory Ditch (estimated and measured spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Gregory Ditch near Wadsworth, Nev.*
	Outflow	To Reach 480	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (if measured)
480	Inflow	From reach 470	Simulated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Herman Ditch (estimated and measured spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Herman Ditch near Wadsworth, Nev.*
	Outflow	Net diversion to Pierson Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Pierson Ditch at Interstate 80 Bridge at Wadsworth, Nev.*
	Outflow	To reach 490	Simulated	
490	Inflow	From reach 480	Simulated	
	Inflow	Ungaged ground-water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Proctor Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Proctor Ditch at Wadsworth, Nev.*
	Outflow	To reach 500	Simulated	
500	Inflow	From reach 490	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion at Olinghouse #1 Pump (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Olinghouse #1 Pump near Wadsworth, Nev.*
	Outflow	Net diversion to Fellnagle Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Fellnagle Ditch near Wadsworth, Nev.*
	Outflow	Net diversion to Gardella Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Gardella Ditch near Wadsworth, Nev.*
	Outflow	To reach 510	Simulated	
510	Inflow	From reach 500	Simulated	
	Inflow	Ungaged ground-water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion at Olinghouse #3 Pump (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Olinghouse #3 Pump near Wadsworth, Nev.*
	Outflow	To reach 520	Simulated	

Table 2. River reaches, inflows, and outflows used in Truckee River flow-routing models—Continued

Reach	Inflow or outflow	Description	Type of data	Data-collection site (If measured)
520	Inflow	From reach 510	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 530	Simulated	
530	Inflow	From reach 520	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 540	Simulated	
540	Inflow	From reach 530	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 550	Simulated	
550	Inflow	From reach 540	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	Net diversion to Indian Ditch (estimated spills and return flows subtracted from gross diversion)	Measured and partially estimated	*Indian Ditch near Nixon, Nev.*
	Outflow	To reach 560	Simulated	
560	Inflow	From reach 550	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To reach 570	Simulated	
570	Inflow	From reach 560	Simulated	
	Inflow	Ungaged ground water	Estimated	
	Inflow	Precipitation	Measured	*Wadsworth 4N at Wadsworth, Nev.*
	Outflow	Evaporation	Estimated	
	Outflow	Phreatophyte evapotranspiration	Estimated	
	Outflow	To Pyramid Lake	Simulated	

Hydraulic Characteristics of Reaches

The RCHRES block of HSPF routes streamflow along connected reaches of a drainage network based on the hydraulic characteristics of the reaches. The hydraulic characteristics are defined by parameters in the function tables, or F-tables, of the RCHRES block. F-tables represent the relation of surface-water volume temporarily stored in the reach to surface-water discharge at the downstream end of a reach. HSPF uses this stored volume of water to simulate the discharge from a reach during a given time interval when outlet discharge from a reach is a function of volume.

Hydraulic properties, measured or estimated at cross sections, were used to determine volume–discharge relations for reaches represented in the F-tables. Each reach included at least 3 cross sections, but reaches in the Truckee Meadows included between 12 and 18 cross sections. Channel geometry, roughness, and slope were assessed for each cross section so that depth–discharge relations could be estimated using Manning's equation for open channels. A table of depth, surface area, cross-sectional area, and discharge could then be constructed for each cross section.

The downstream cross section of each reach was designated as the controlling cross section of that reach because that is where HSPF simulates discharge. Cross-section areas were determined at all cross sections in the reach for a specified range of discharges at the controlling cross section. The range of discharges at the controlling cross section was limited to a minimum of zero discharge and a "limiting" maximum discharge of the reach. This limiting maximum discharge was determined by: (1) comparing the maximum discharge of all cross sections in a given reach; and then (2) designating the lowest maximum discharge as the "limiting" maximum discharge of that reach.

The distances between all reach boundaries and cross sections, referred to as nodes, were measured from maps. Averages of the cross-sectional areas were computed between adjacent cross sections for each discharge at the controlling cross section. The average cross-sectional areas were multiplied by the channel lengths between nodes to determine the volume of water stored between nodes. Volumes were summed to determine the volume of water stored in the reach for each discharge. The F-table containing the volume-discharge relations could then be constructed for the reach.

The degree to which a change in the stored volume of a reach changes its discharge is represented in the F-tables. For example, an F-table for a reach that may store large volumes of water at high stages would have a large range of storage volumes corresponding to a small range of discharge volumes at the reach outlet during periods of high water. Thus, during periods of high water, discharge from a high-storage reach would be relatively insensitive to changes in storage volume—a large change in storage volume will correspond to only a small change in discharge at the reach outlet. Reaches 370 and 380 (pl. 1) in Sparks, Nev., are examples of such reaches.

Designation of Submodels and Full Model

Three submodels and one full model were constructed to simulate Truckee River streamflow. The submodels represent three segments of the Truckee River that have different hydrographic characteristics and different demands on water use. The boundaries of the submodels roughly correspond with the boundaries of the upper, middle, and lower Truckee River subunits (see section "Description of Study Area"). The full model combines the three submodels into one model. Although simulation results were compared to observed flow records at almost all USGS gaging stations along the Truckee River, only the results evaluated at three gaging stations—the most downstream gaging station in each of the three river subunits—are presented in this report.

The upper Truckee River submodel simulates streamflows along 14 reaches (reaches 110-140, 150, 160, 170, 180, and 210-240 defined on the Truckee River mainstem, reach 149 defined on Donner Creek, and reach 169 defined on Martis Creek; pl. 1) between the gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* The 14 peripheral reaches defined for 7 lakes and reservoirs and 7 channel segments along the Little Truckee River (reaches 100, 145, 168, 178, and 185-209) were not included in the upper submodel. Lake Tahoe outflow data obtained at the Tahoe City gaging station were used to define the upstream inflow for both the Truckee River submodel and the full model. Simulation results were evaluated by comparison with records from the Farad gaging station.

The middle Truckee River submodel simulates streamflow along 20 reaches (reaches 250-440) between the Farad gaging station and the downstream end of reach 440 (located about 2.2 mi upstream from Derby Dam). Simulated outflow from reach 440 represents inflow to Derby Dam (within reach 450) because of the short distance between those two points (2.2 mi) and because no diversions or tributaries exist between these two points. Upper Truckee River subunit outflow data obtained at the Farad gaging station defined upstream inflow for the middle Truckee River submodel. Streamflow data obtained at the gaging station *Truckee River below Tracy, Nev.* (about 3.5 mi upstream from the downstream boundary of the submodel and about 5.7 mi upstream from Derby Dam), were used to evaluate simulation results from the middle Truckee River submodel.

The lower Truckee River submodel simulates streamflow along 12 reaches (reaches 460-570) between the gaging station *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam. Simulated outflow from reach 570 represents inflow to Marble Bluff Dam and approximates inflow to Pyramid Lake (located about 3.5 mi downstream of Marble Bluff Dam). Middle Truckee River subunit outflow data obtained at the gaging station below Derby Dam defined upstream inflow for the lower Truckee River submodel. Streamflow data obtained at the most downstream gaging station on the lower Truckee River *Truckee River near Nixon, Nev.* (pl. 1, site 59), located about 9.5 mi upstream from Marble Bluff Dam, were used to evaluate simulation results. Model accuracy is uncertain for the 9.5 mi of the Truckee River downstream of the Nixon gaging station to Marble Bluff Dam, because no observed streamflow data were available to evaluate simulation results.

The full Truckee River model simulates streamflow along 47 reaches between the gaging station *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upstream inflow representing outflow from Lake Tahoe was defined at the gaging station *Truckee River at Tahoe City, Calif.* Simulation results were evaluated using streamflow data obtained at the same three gaging stations used to evaluate simulated streamflow for the submodels: (1) *Truckee River at Farad, Calif.*, (2) *Truckee River below Tracy, Nev.*, and (3) *Truckee River near Nixon, Nev.*

Selection of Simulation Periods

The simulation period for the daily flow-routing models was designated as water years 1978-92, a period of 15 years. This period was chosen because streamflow data were collected at more gaging stations during this period than during previous periods, and these data represent a variety of streamflow conditions.

Regulation and monitoring of diversions began to change in 1985 (Jeff Boyer, Office of Federal Water Master, oral commun., 1993). Beginning in 1985 and extending through the 1987 irrigation season, diversions from the Truckee River to irrigators began to be more restricted to duties specified in the Orr Ditch Decree of 1926. After the transition period, more complete data on irrigation diversions and returns enabled better accounting of inflows and outflows to the Truckee River than before the 1988 irrigation season.

Differences between observed streamflow in the Truckee River and that simulated by the model were computed for two periods because of improvements in data collection on irrigation diversions and returns beginning in 1988. These differences were computed (1) for the entire simulation period from water years 1978-92 and (2) for a part of the simulation period from water years 1988-92 (called the drought-evaluation period because this period coincided with a period of drought).

SIMULATION OF STREAMFLOW USING A DAILY FLOW-ROUTING MODEL

The constructed flow-routing models used the time series of observed and estimated daily mean streamflow described in the previous section to simulate Truckee River streamflow. The time-series data base represents all available information on inflow to and outflow from the Truckee River. The following sections (1) describe the methods and goals of testing the flow-routing models, (2) provide the streamflow simulation results, and (3) discuss differences between observed and simulated streamflow and model limitations.

Model Testing

After the flow-routing models were constructed, they were tested by first simulating Truckee River streamflow and then evaluating simulation accuracy. As previously discussed, streamflow is simulated by making a water-budget analysis that accounts for inflows, outflows, and volume of water stored in each reach for a given time interval. Inflows are specified by time-series data and outflows are specified either by time-series data when outlet discharge from a reach is a function of time or determined by model parameters when outlet discharge is purely a function of volume of water stored in the reach. Volume of water stored in a given reach at the end of a time interval is determined by the initial volume stored at the beginning of that time interval plus the difference between inflow and outflow over that time interval. Available channel storage in a reach is determined by parameters representing hydraulic characteristics. For the models, streamflow routed through an outlet to a downstream reach is always a function of volume; whereas, streamflow diverted through an outlet to irrigation ditches or water-treatment plants is always a function of time. Inflow and outflow data determine the volume of streamflow; whereas, the hydraulic characteristics represented by model parameters determine the timing and attenuation of streamflow as that volume is routed from an upstream reach to a downstream reach.

In addition to simulating Truckee streamflow, model testing involves evaluating simulation results with observed streamflow data before the models can be relied upon to predict conditions along the mainstem Truckee River. The models were evaluated by determining how closely simulated streamflow matched observed streamflow. The accuracy of the models in simulating monthly mean streamflow and daily mean streamflow was assessed by comparing hydrographs of observed and simulated flow and by computing statistical measures of differences between observed and simulated flow.

The goal of traditional calibration of models is to adjust values of model parameters to minimize the differences between observed and simulated streamflow. However, for the Truckee River daily flow-routing models, parameters were not calibrated to improve streamflow simulations. The model parameter values were "fixed" to their assigned values. The value of 0.5 assigned to the time-weighting parameter, *KS*, theoretically gives the most accurate results. The model parameters representing hydraulic properties of channel reaches are physically based; determined by measurements and estimates from field reconnaissance and from maps. Because the model parameters were not calibrated, the models were not validated with streamflow observed in a period other than the selected simulation period.

The goal of model testing, in contrast to calibration and subsequent validation, was to determine if differences between observed and simulated streamflow were a result of inadequate data characterizing the hydraulic properties of the Truckee River or a result of inadequate flow data characterizing inflows to and outflows from the river. Differences related to the timing and attenuation of streamflow would indicate that the fixed parameters may not be adequately characterizing the river hydraulics. However, differences related to flow volumes over extended periods, such as weeks or months, would indicate that streamflow data may not be adequately characterizing inflows and outflows.

Comparison of Observed and Simulated Streamflow

Hydrographs and statistical measures comparing observed and simulated streamflow were used to evaluate the accuracy of the daily flow-routing models. Hydrographs and scatterplots provide graphic comparisons between observed and simulated streamflow. Statistical analyses of differences between observed and simulated annual mean streamflow, monthly mean streamflow, and daily mean streamflow are described in the following three sections. Three statistical measures of difference were useful in evaluating the simulations: the mean absolute error, the bias, and the standard error of estimate. The mean absolute error is the arithmetic average of the differences between observed and simulated streamflow without regard to whether differences are positive or negative. The bias is the arithmetic average of the actual differences between observed and simulated streamflow. Unless outliers are extremely large, a large positive bias usually means that a model is overestimating streamflow, and a large negative bias means that it is underestimating streamflow. The standard error of estimate is the standard deviation of differences between observed and simulated streamflow after accounting for the bias, and it indicates that two-thirds of the simulated values are within this range (plus or minus) of the observed values, if the differences are normally distributed. The statistical measures of difference also are expressed in terms of percent relative to the observed values. A mean absolute difference of 25 percent, for instance, means that the simulated values of monthly mean streamflow differ, on average, 25 percent from their corresponding observed values. (See footnotes 2-4 in table 5 for formal definitions of the statistical measures of difference.)

Annual Mean Streamflow

Observed and simulated annual mean streamflow and mean annual streamflows (the arithmetic average of the annual mean streamflow for a specific period) from the most downstream gaging stations in each of the river subunits were compared for the entire evaluation period (water years 1978-92) and for the drought-evaluation period (water years 1988-92), the latter coinciding with a period of drought as well as more closely monitored diversions and allocations from the Truckee River (tables 3 and 4). The comparisons are based on simulation results from the full model and the three submodels. Simulation results at the Farad gaging station are identical for the full model and the upper submodel because both models use daily mean streamflow collected at the same gaging station, *Truckee River at Tahoe City, Calif.*, as upstream inflow.

For the 15-yr simulation period, bias of simulated annual mean streamflow from the full model and submodels ranges from -12.9 to 2.0 percent of the observed annual mean streamflow—the largest measure of bias corresponds to simulation results from the full model for the gaging station *Truckee River near Nixon, Nev.* For the 5-yr drought-evaluation period, after regulation and monitoring of diversions changed (discussed in the section "Selection of Simulation Periods"), measures of bias are similar to those for the entire evaluation period—between -5.8 and 4.4 percent for all comparisons except for the results from the full model for the Nixon gaging station, where the bias increases from -12.9 to 16.5 percent.

Table 3. Observed and simulated mean annual streamflows and bias of simulated annual mean streamflows for Truckee River flow-routing models, October 1, 1977, through September 30, 1992

[Observed, observed mean annual streamflow value; simulated, simulated mean annual streamflow value]

Station name and number	Observed (cubic feet per second)	Model[1]	Simulated (cubic feet per second)	Bias[2]	
				Average (cubic feet per second)	Percent
Truckee River at Farad, Calif., 10346000	797	Full	813	16.1	2.0
		Upper	813	16.1	2.0
Truckee River below Tracy, Nev., 10350400	827	Full	784	-42.3	-5.1
		Middle	768	-58.4	-7.1
Truckee River near Nixon, Nev., 10351700	577	Full	502	-74.5	-12.9
		Lower	534	-42.9	-7.4

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper submodel simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and the downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] $\text{Average} = \sum (S - O)/n$ for all O values greater than 0, and $\text{percent} = 100 \times \{\sum [(S-O)/O]/n\}$ for all O values greater than 0, where S is simulated annual mean streamflow, in cubic feet per second; O is observed annual mean streamflow, in cubic feet per second; and n is number of pairs of annual values for which O values greater than 0 in simulation period. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

Table 4. Observed and simulated mean annual streamflows and bias of simulated annual mean streamflows for Truckee River flow-routing models, October 1, 1987, through September 30, 1992

[Observed, observed mean annual streamflow value; simulated, simulated mean annual streamflow value]

Station name and number	Observed (cubic feet per second)	Model[1]	Simulated (cubic feet per second)	Bias[2]	
				Average (cubic feet per second)	Percent
Truckee River at Farad, Calif., 10346000	336	Full	350	14.6	4.4
		Upper	350	14.6	4.4
Truckee River below Tracy, Nev., 10350400	305	Full	302	-2.7	-.9
		Middle	287	-17.6	-5.8
Truckee River near Nixon, Nev., 10351700	42.5	Full	49.5	7.0	16.5
		Lower	42.6	.1	.2

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper submodel simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] Average $= \sum (S-O)/n$ for all O values greater than 0, and percent $= 100 \times \{\sum [(S-O)/O]/n\}$ for all O values greater than 0, where S is simulated annual mean streamflow, in cubic feet per second; O is observed annual mean streamflow, in cubic feet per second; and n is number of pairs of annual values for which O values greater than 0 in the simulation period. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

Bias of simulated annual mean flows at the most downstream gaging stations closest to the downstream boundary of each river subunit is similar (within 6.0 percent) for the full model and submodels evaluated over the entire simulation period. Likewise, bias of simulated annual mean flows are similar (within 6.0 percent) for two of the three gaging stations evaluated for the drought-evaluation period. However, at the Nixon gaging station, the bias of simulated streamflow decreases from 16.5 percent for the full model to 0.2 percent for the lower submodel during the drought-evaluation period.

The rated accuracy of streamflow data collected from the USGS gaging stations used for evaluation of model simulations can be compared with the percent bias of simulated annual mean streamflow at those gaging stations. For water years 1978-92, observed streamflow records collected from the Farad gaging station, the Tracy gaging station, and the Nixon gaging station were rated, on average, "good" (U.S. Geological Survey, 1978-92). A good rating means that 95 percent of the computed streamflow records are accurate within 10 percent of their true values. The bias of simulated annual mean streamflow for both the entire evaluation period (table 3) and the drought-evaluation period (table 4) are below an absolute value of 10 percent for almost all models at almost all gaging stations evaluated in this report and are, therefore, within the reported accuracy of the data itself. At the Nixon gaging station, however, the full model underestimates annual mean streamflow -12.9 percent during the entire evaluation period and overestimates annual mean streamflow 16.5 percent for the drought-evaluation period. Therefore, simulations of annual mean streamflow at the Nixon gaging station in the full model are outside the reported accuracy of that gaging station.

Monthly Mean Streamflow

Accuracy of the full model and submodels in simulating monthly mean streamflow was assessed by (1) comparing observed and simulated hydrographs for the three gaging stations for both evaluation periods (figs. 4–8), (2) comparing observed and simulated monthly mean streamflow on scatterplots (figs. 9–13), and (3) computing statistical measures of difference between observed and simulated values of monthly mean streamflow (tables 5 and 6). As discussed in the previous section "Annual Mean Streamflow," the differences, usually largest at the Nixon gaging station for the full model and submodels, generally are similar for both evaluation periods. However, the differences, as percentages, are larger during the drought-evaluation period at the Nixon station. Differences generally are similar for the full model and submodels, except at the Nixon station, where differences were much smaller for the lower submodel than for the full model.

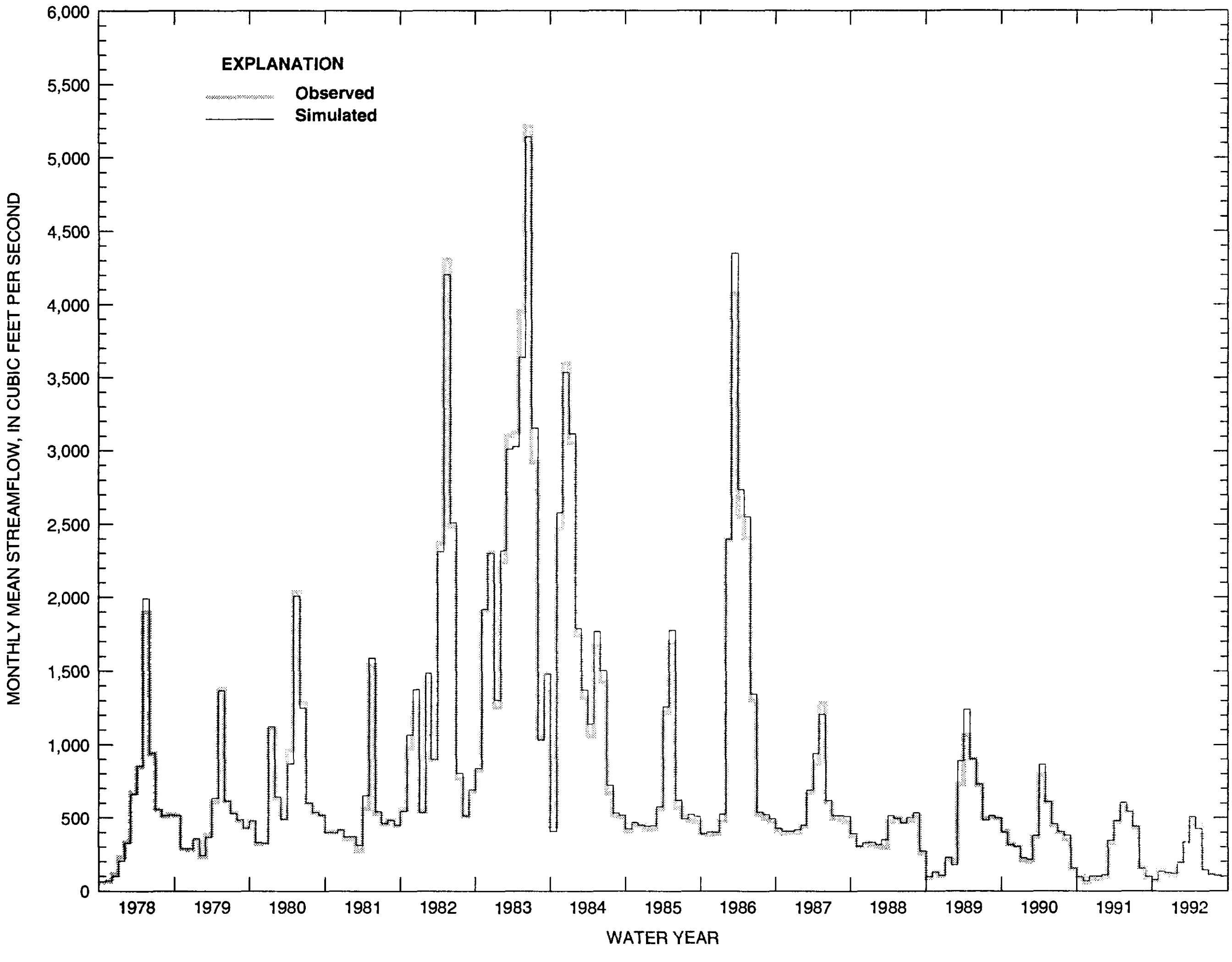


Figure 4. Observed and simulated monthly mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, October 1, 1977, through September 30, 1992.

For the entire evaluation period, mean absolute differences between observed and simulated monthly mean streamflow range from 4.7 to 36.0 percent for the full model and from 4.7 to 11.9 percent for the submodels (table 5). Standard errors range from 6.1 to 45.6 percent for the full model and from 6.1 to 16.8 percent for the submodels. The largest measures of difference are at the most downstream gaging station for the full model, the Nixon gaging station. These measures of difference are markedly smaller for the lower submodel than for the full model. Standard error at the Nixon gaging station, for example, was 45.6 percent for the full model and 16.8 percent for the lower submodel. Bias ranges from 3.1 to -14.4 percent for the full model and 3.1 to -9.0 percent for the submodels. The simulation models generally underestimated monthly mean streamflow at the Tracy and Nixon gaging stations, and slightly overestimated monthly mean streamflow at the Farad gaging station. Bias of monthly mean streamflow, as both average and percent values, is greatest for simulated streamflow from the full model when evaluated at the Nixon gaging station

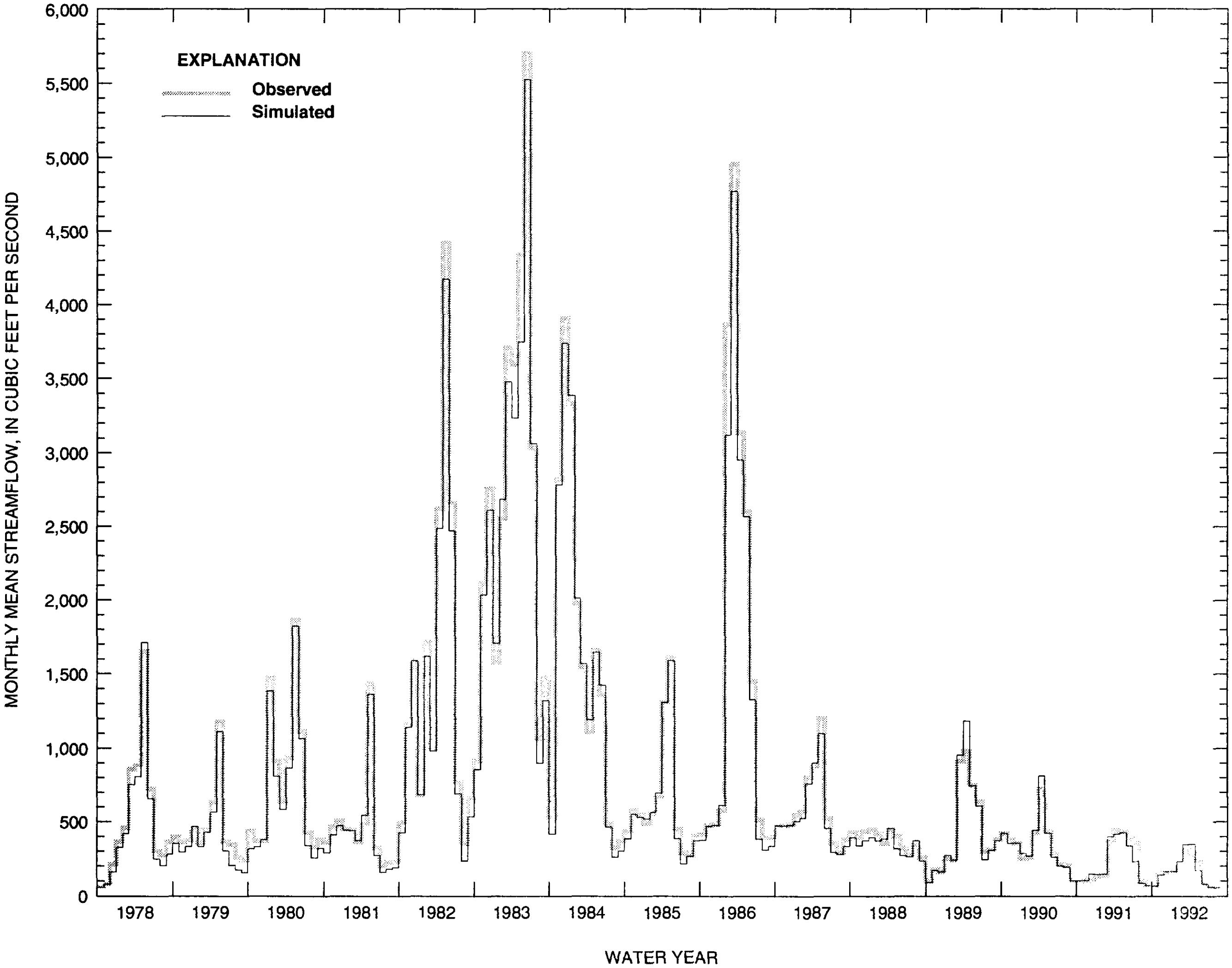


Figure 5. Observed and simulated monthly mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow from full model, October 1, 1977, through September 30, 1992.

for the entire evaluation period. The scatterplots shown in figures 9-13 may be used to detect bias. When a point representing the observed streamflow plotted against the simulated streamflow for a given month is below the 45-degree line of equality (representing a one-to-one correspondence between observed and simulated monthly mean streamflow), the model is underestimating mean streamflow for that month. Points representing observed versus simulated monthly mean streamflow at the Farad gaging station lie close to the 45-degree line, indicating little bias (fig. 9). (Note that for these types of scatterplots, many points evenly distributed above and below the 45-degree line indicate little overall bias, although the individual points may be biased.) However, as shown in figure 12, a large proportion of points for the Nixon gaging station lie below the 45-degree line, indicating an underestimation of monthly mean streamflow.

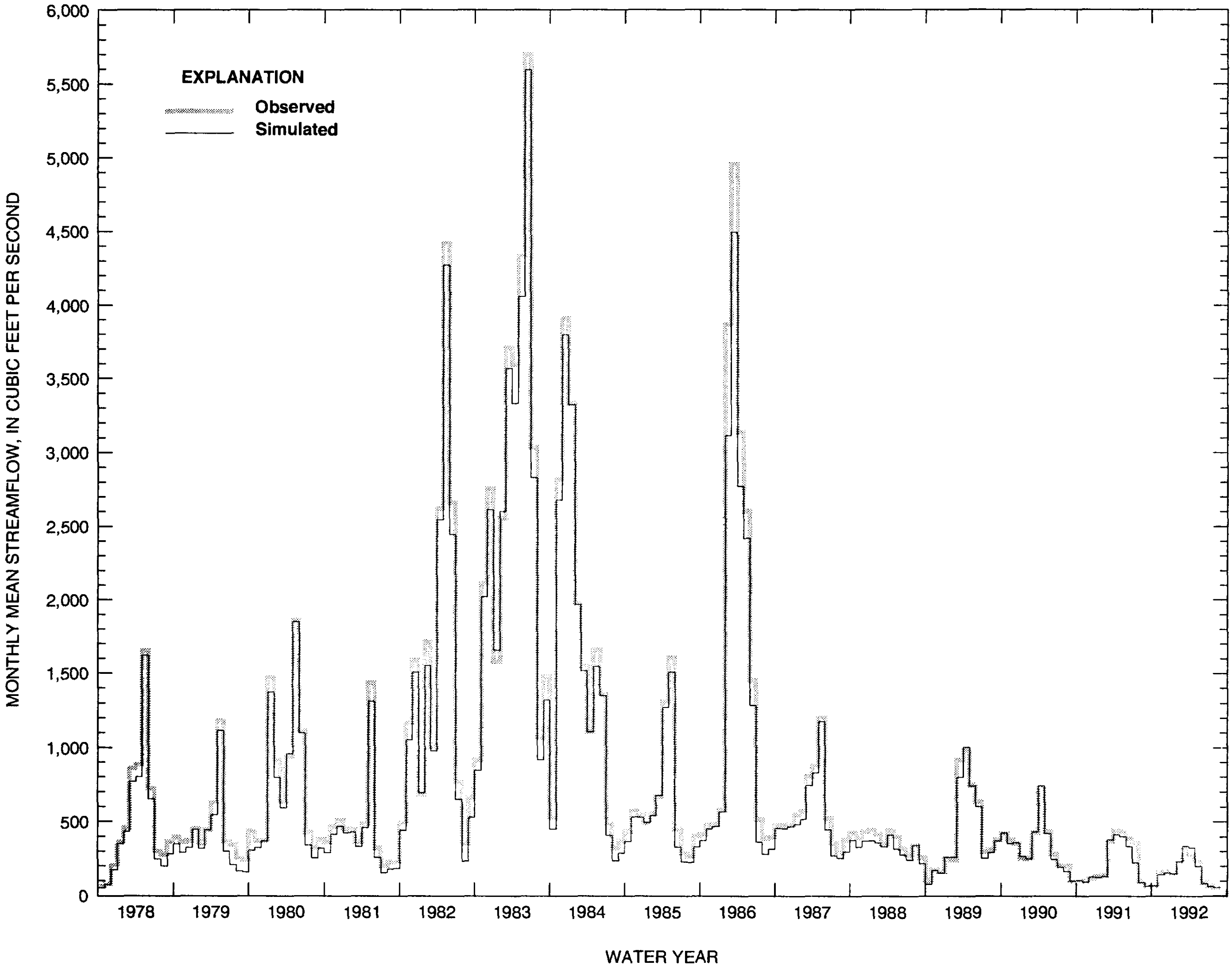


Figure 6. Observed and simulated monthly mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow from middle submodel, October 1, 1977, through September 30, 1992.

As expected for the smaller streamflow during the drought-evaluation period, the average statistical measures of difference, expressed as streamflows (table 6), are smaller than those same measures of differences from the entire evaluation period. However, the smaller differences from the drought-evaluation period may, in some cases, represent a large proportion of the total flow, resulting in increased percentage differences for some statistical measures of difference. For example, the standard error of estimate is larger during the drought-evaluation period (57.3 percent) than during the entire evaluation period (45.6 percent) for the full model at the Nixon gaging station. However, in average values, the standard error is smaller during the drought-evaluation period (35 ft^3/s) than during the entire evaluation period (155 ft^3/s). As with the entire evaluation period, measures of difference, as percentages, were largest for the full model at the Nixon gaging station.

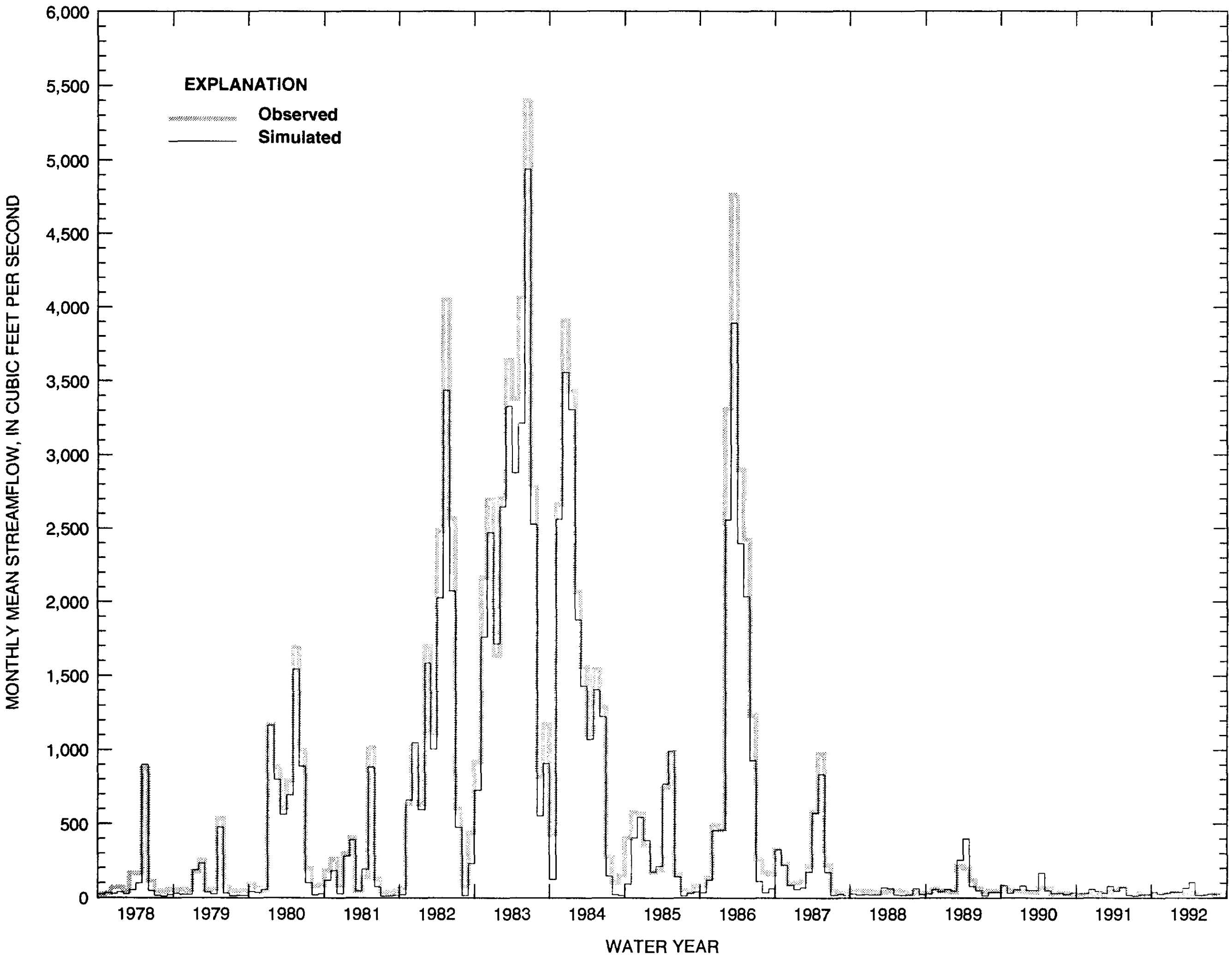


Figure 7. Observed and simulated monthly mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from full model, October 1, 1977, through September 30, 1992.

Graphic comparison between observed and simulated hydrographs (figs. 4-8) are useful to visually evaluate differences over time throughout the simulation period. Most hydrographs of observed and simulated monthly mean streamflow usually matched fairly well for both evaluation periods (figs. 4-8). The larger differences for the full model at the Nixon gaging station appear in figure 7 where the observed and simulated hydrographs are not as closely matched as the observed and simulated hydrographs in figures 4-6 and 8. The larger differences are especially apparent during years with many months of high streamflow. However, during the drought-evaluation period, with many months of low streamflow, small differences in average values appear as closely matched hydrographs, even though the simulation differences expressed as percentages are larger. The observed and simulated hydrographs (fig. 8) are more closely matched for the lower submodel than for the full model at the Nixon gaging station (fig. 7), as verified by the statistical measures of difference (tables 5 and 6).

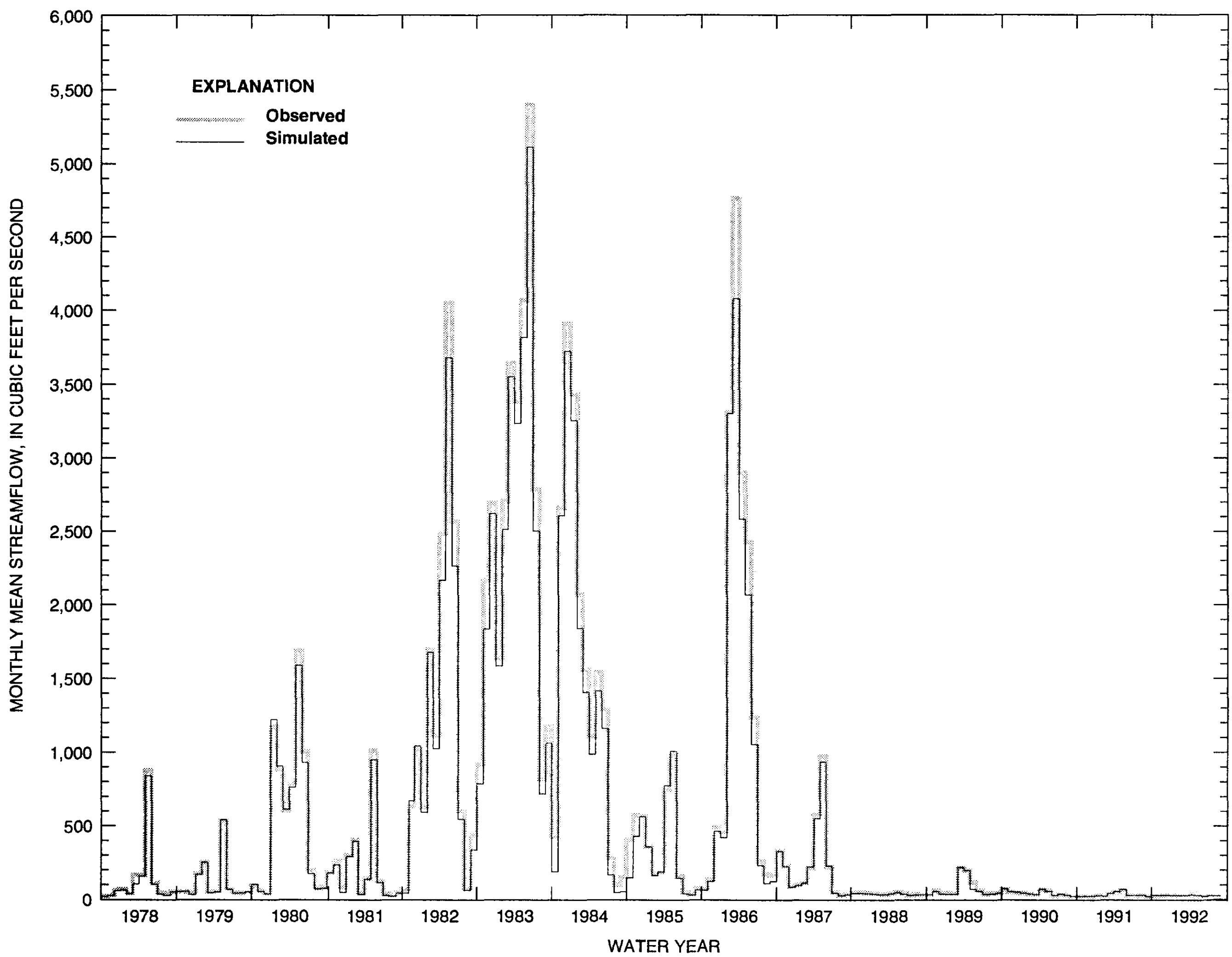


Figure 8. Observed and simulated monthly mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from lower submodel, October 1, 1977, through September 30, 1992.

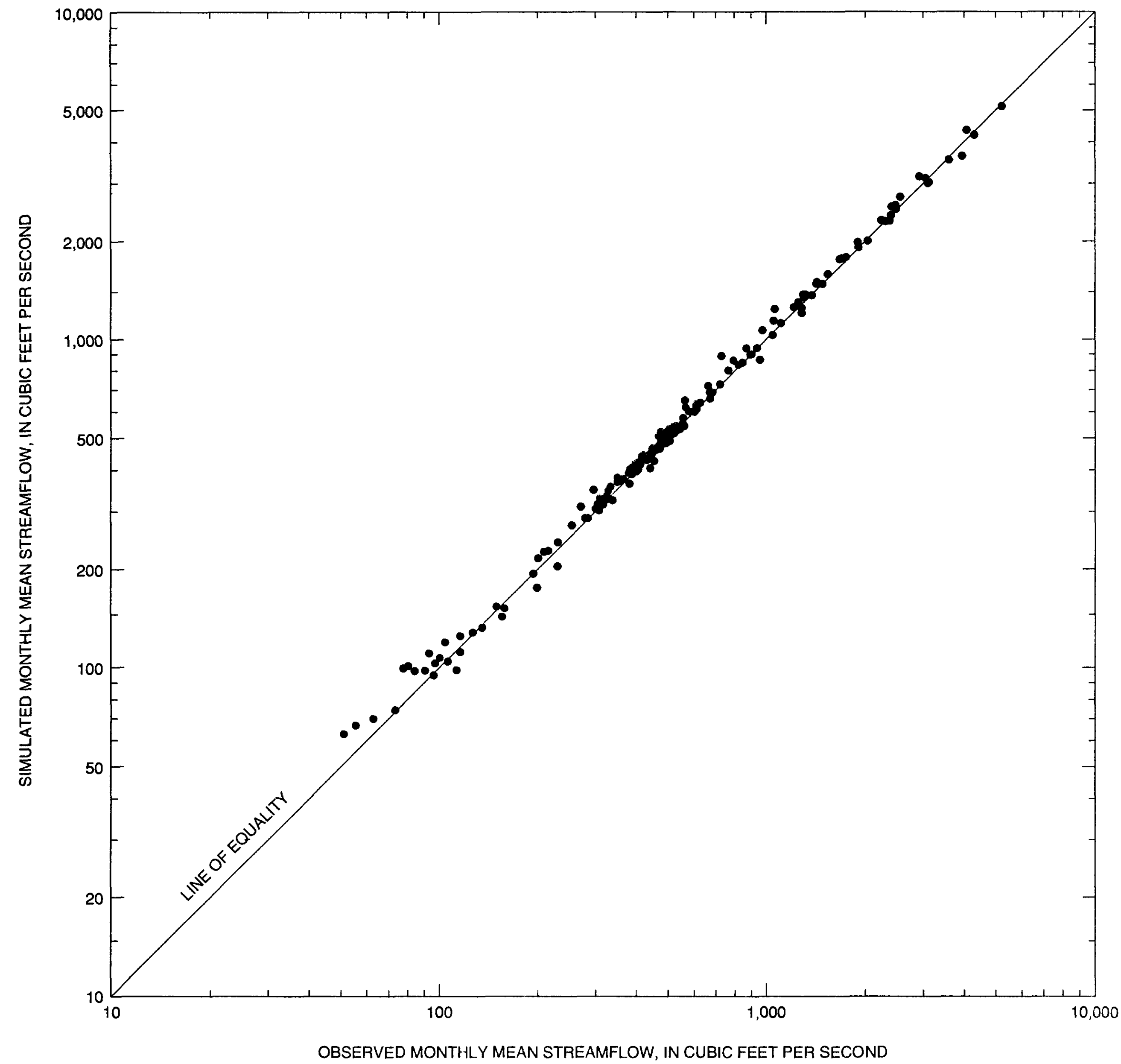


Figure 9. Relation between observed and simulated monthly mean streamflows from full model and upper submodel, *Truckee River at Farad, Calif.*, October 1, 1977, through September 30, 1992.

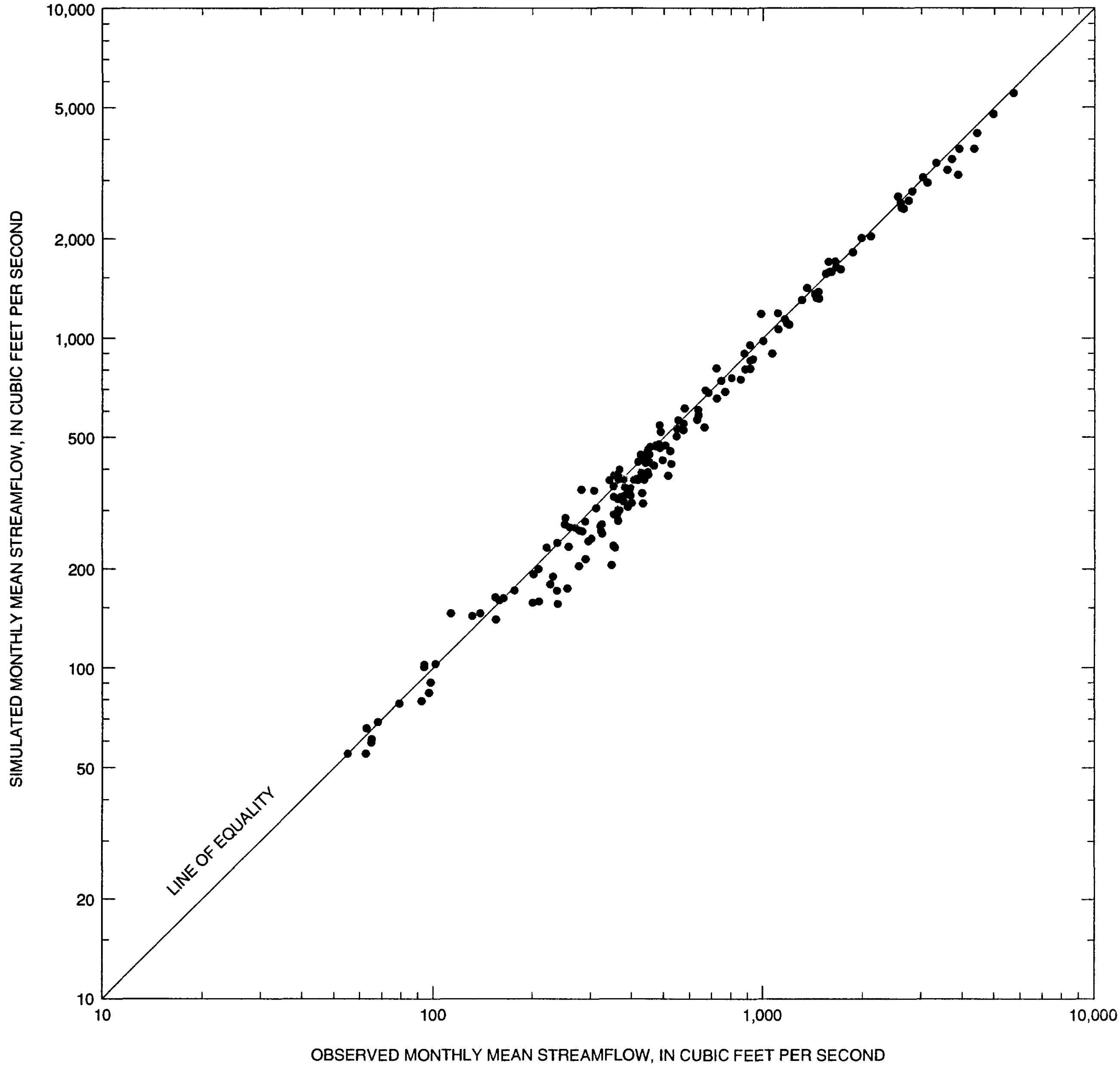


Figure 10. Relation between observed and simulated monthly mean streamflows from full model, *Truckee River below Tracy, Nev.*, October 1, 1977, through September 30, 1992.

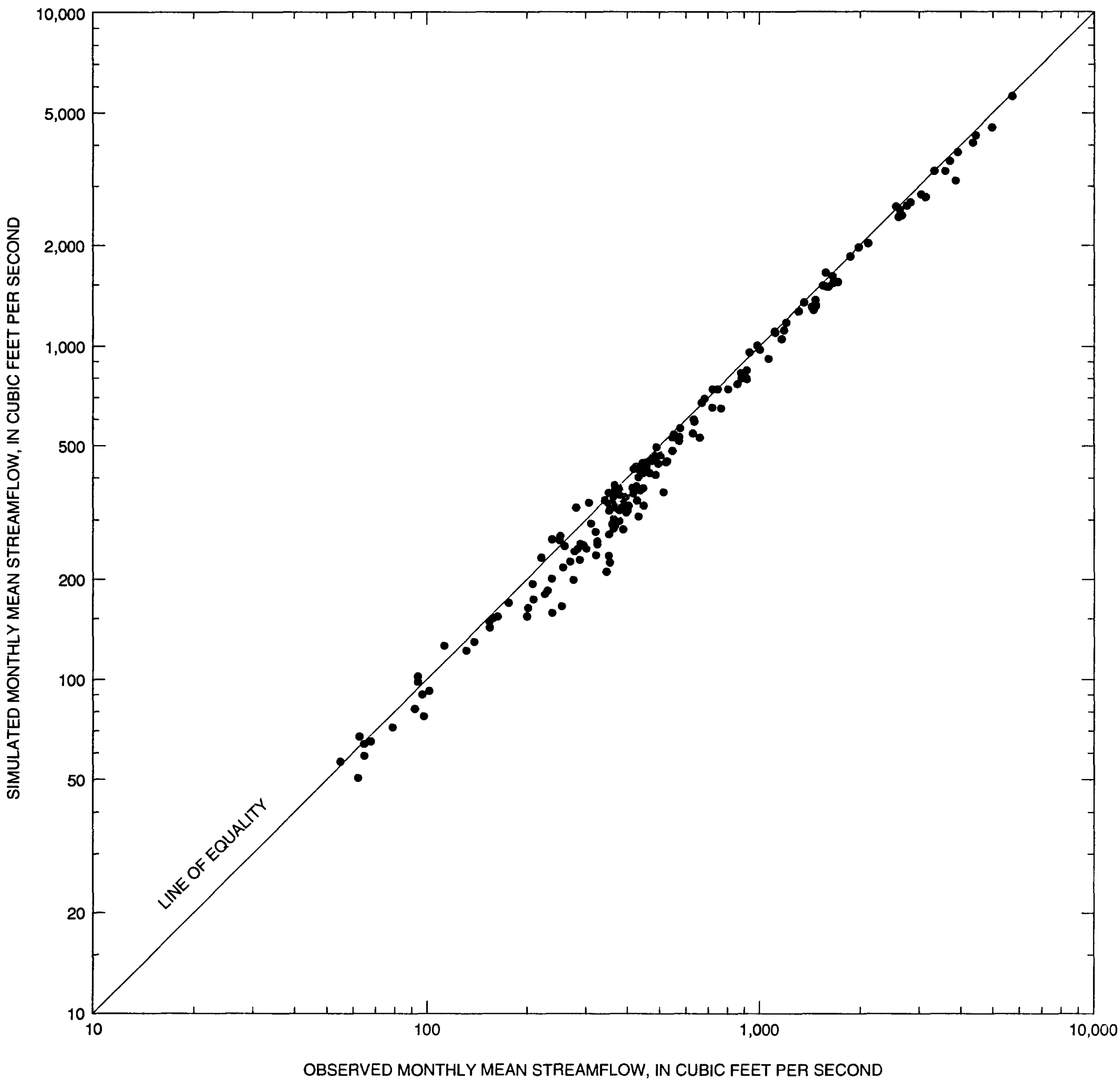


Figure 11. Relation between observed and simulated monthly mean streamflows from middle submodel, *Truckee River below Tracy, Nev.*, October 1, 1977, through September 30, 1992.

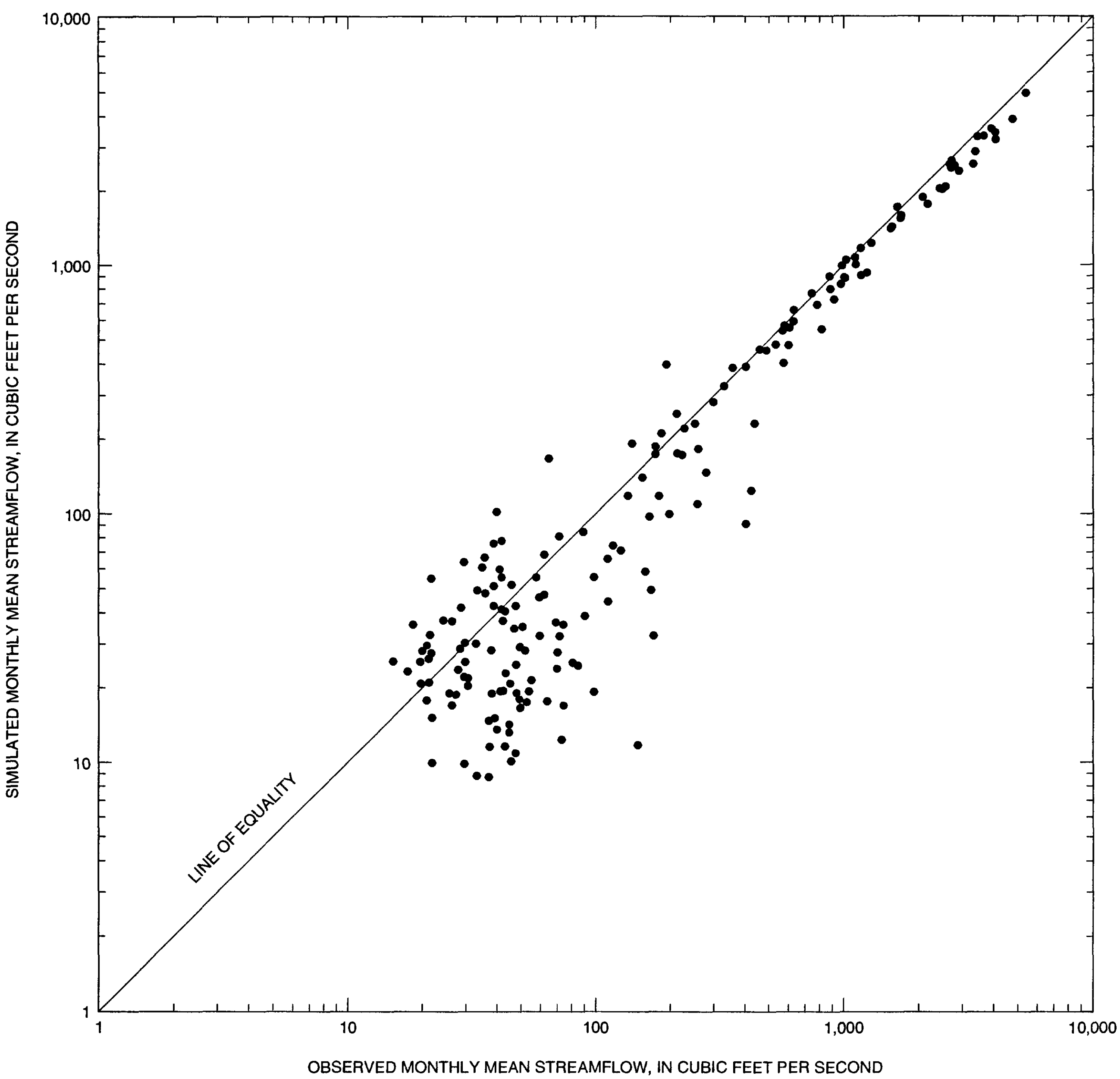


Figure 12. Relation between observed and simulated monthly mean streamflows from full model, *Truckee River near Nixon, Nev.*, October 1, 1977, through September 30, 1992.

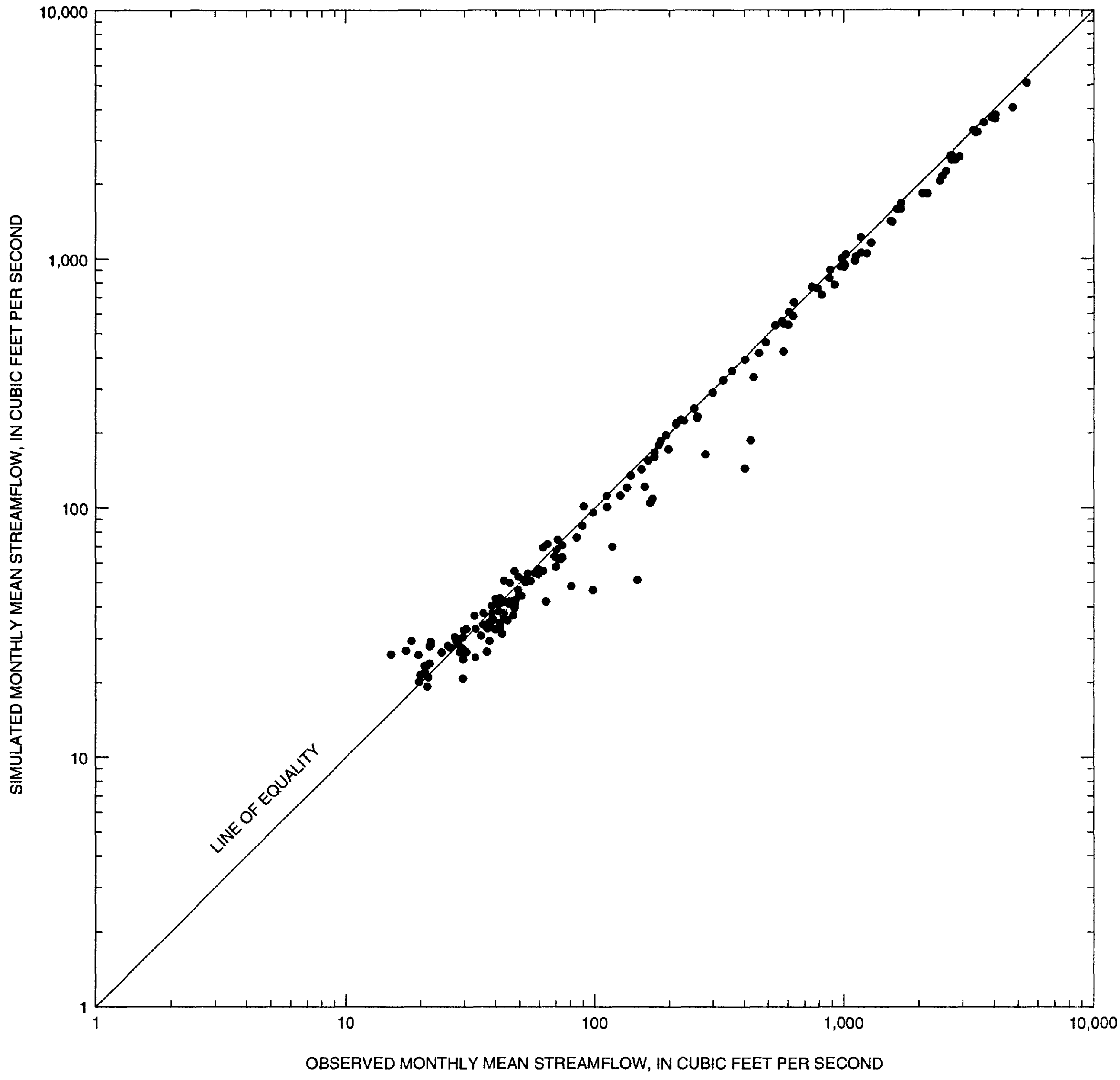


Figure 13. Relation between observed and simulated monthly mean streamflows from the lower submodel, *Truckee River near Nixon, Nev.*, October 1, 1977, through September 30, 1992.

Table 5. Measures of difference between observed and simulated monthly mean streamflows for full model and submodels, October 1, 1977, through September 30, 1992

Station name and number	Model [1]	Mean absolute error [2]		Bias [3]		Standard error of estimate [4]	
		Average (cubic feet per second)	Percent	Average (cubic feet per second)	Percent	Average (cubic feet per second)	Percent
Truckee River at Farad, Calif., 10346000.	Full.....	31.0	4.7	16.1	3.1	53.3	6.1
	Upper...	31.0	4.7	16.1	3.1	53.3	6.1
Truckee River below Tracy, Nev., 10350400.	Full.....	59.9	9.4	-42.3	-6.2	94.5	10.9
	Middle ..	63.1	10.3	-58.4	-9.0	85.1	9.5
Truckee River near Nixon, Nev., 10351700.	Full.....	87.2	36.0	-74.5	-14.4	154.8	45.6
	Lower...	47.1	11.9	-42.9	-5.3	94.8	16.8

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper submodel simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between the gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] Average $= \sum (|S-O|/(n))$ and percent $= 100 \times \langle \sum \langle |S-O|/O \rangle \rangle / n$ for all O values greater than 0, where S is simulated monthly mean streamflow in cubic feet per second; O is observed monthly mean streamflow in cubic feet per second; n is number of pairs of monthly values for which O values greater than 0 in the simulation period; and || is absolute value. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

[3] Average $= \sum (S-O)/n$ for all O values greater than 0, and percent $= 100 \times \{\sum [\langle S-O \rangle / O]/n\}$ for all O values greater than 0.

[4] Average $= \sqrt{\langle n/(n-1) \rangle \times \left[\{\sum \langle \langle S-O \rangle^2 \rangle / n\} - \{\text{average bias}\}^2 \right]}$ and

percent $= \sqrt{\langle n/(n-1) \rangle \times \left[100 \times \{\sum \langle \langle \langle S-O \rangle / O \rangle^2 \rangle / n\} - \{\text{percent bias}\}^2 \right]}$.

Table 6. Measures of difference between observed and simulated monthly mean streamflows for full model and submodels, October 1, 1987, through September 30, 1992

Station name and number	Model [1]	Mean absolute error [2]		Bias [3]		Standard error of estimate [4]	
		Average (cubic feet per second)	Percent	Average (cubic feet per second)	Percent	Average (cubic feet per second)	Percent
Truckee River at Farad, Calif., 10346000.	Full	18.2	6.2	14.6	4.7	32.9	7.7
	Upper	18.2	6.2	14.6	4.7	32.9	7.7
Truckee River below Tracy, Nev., 10350400.	Full	27.6	8.7	-3.1	-1.4	44.2	11.5
	Middle	26.0	8.7	-17.7	-5.3	32.8	9.5
Truckee River near Nixon, Nev., 10351700.	Full	20.1	45.9	7.0	14.9	35.1	57.3
	Lower	4.6	12.7	.1	4.6	7.8	18.4

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper-subunit model simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] Average $= \sum (|S-O|/(n))$ and percent $= 100 \times \langle \sum \langle |S-O|/O \rangle \rangle / n$ for all O values greater than 0, where S is simulated monthly mean streamflow in cubic feet per second; O is observed monthly mean streamflow in cubic feet per second; n number of pairs of monthly values for which O values greater than 0 in the simulation period; and || is absolute value. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

[3] Average $= \sum \langle S-O \rangle / n$ for all O values greater than 0, and percent $= 100 \times \{ \sum [\langle S-O \rangle / O] / n \}$ for all O values greater than 0.

[4] Average $= \sqrt{\langle n/(n-1) \rangle \times \left[\{ \sum \langle \langle S-O \rangle^2 \rangle / n \} - \{\text{average bias}\}^2 \right]}$ and

percent $= \sqrt{\langle n/(n-1) \rangle \times \left[100 \times \{ \sum \langle \langle \langle S-O \rangle / O \rangle^2 \rangle / n \} - \{\text{percent bias}\}^2 \right]}$.

Daily Mean Streamflow

Comparison of observed and simulated daily mean streamflow provide an additional way to evaluate the full model and submodels. Daily mean streamflow was evaluated by comparing observed and simulated hydrographs for the three gaging stations (figs. 14-23) and by computing statistical measures of difference between observed and simulated values of daily mean streamflow (tables 7 and 8) as in the previous section, "Monthly Mean Streamflow." Scatterplots of observed versus simulated daily streamflow were not made because more than 5,000 values are available for the evaluation period. However, the simulation bias is shown as a statistical measure of difference in tables 7 and 8.

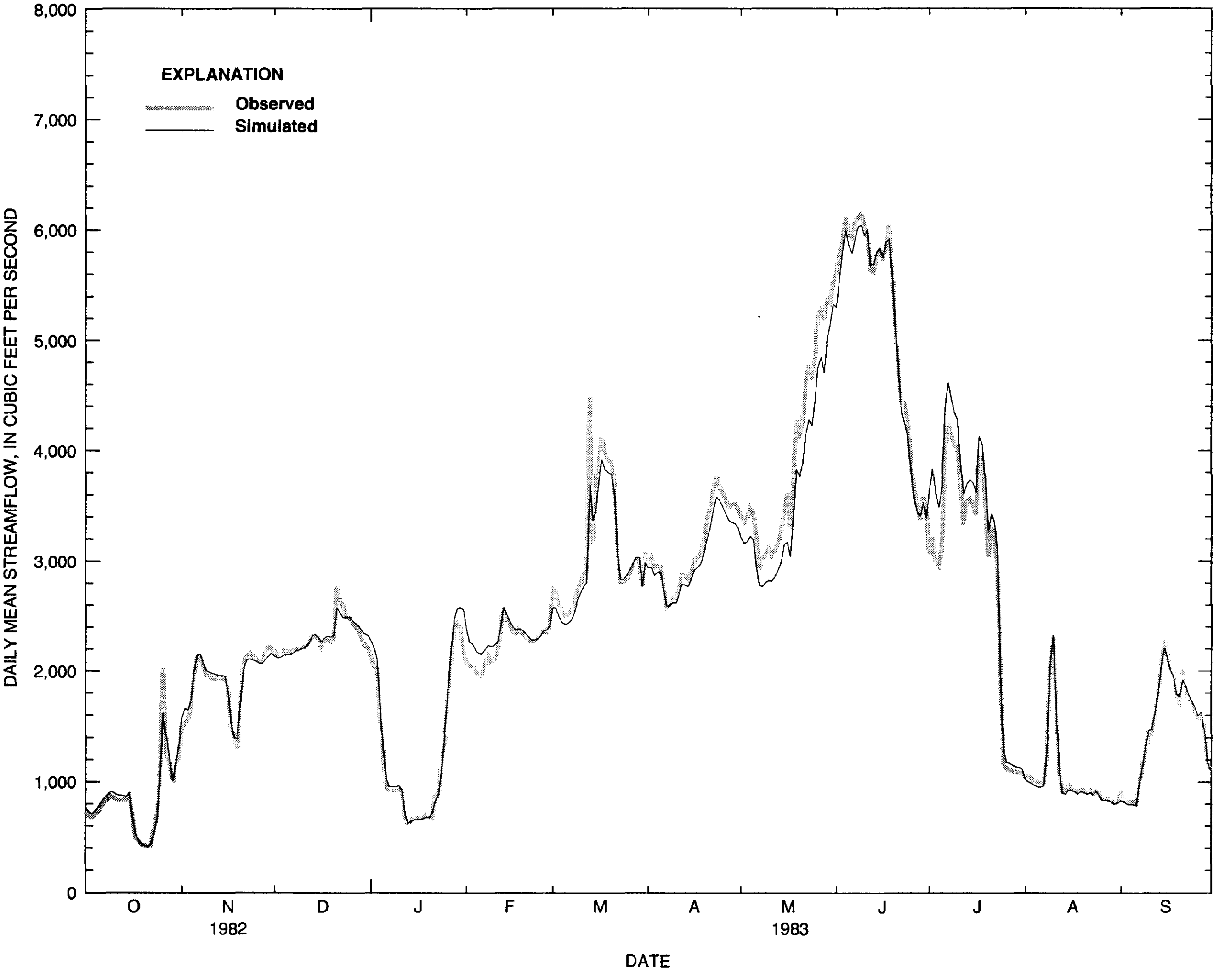


Figure 14. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, water year 1983.

Mean absolute errors for the daily mean streamflow range from 6.2 to 46.0 percent for the full model during the entire evaluation period and from 6.2 to 17.3 percent for the submodels during the same period. Standard errors range from 8.5 to 70.2 percent for the full model and from 8.5 to 32.5 percent for the submodels. Bias ranges from -12.5 to 3.5 percent for the full model and from -8.6 to 3.5 percent for the submodels.

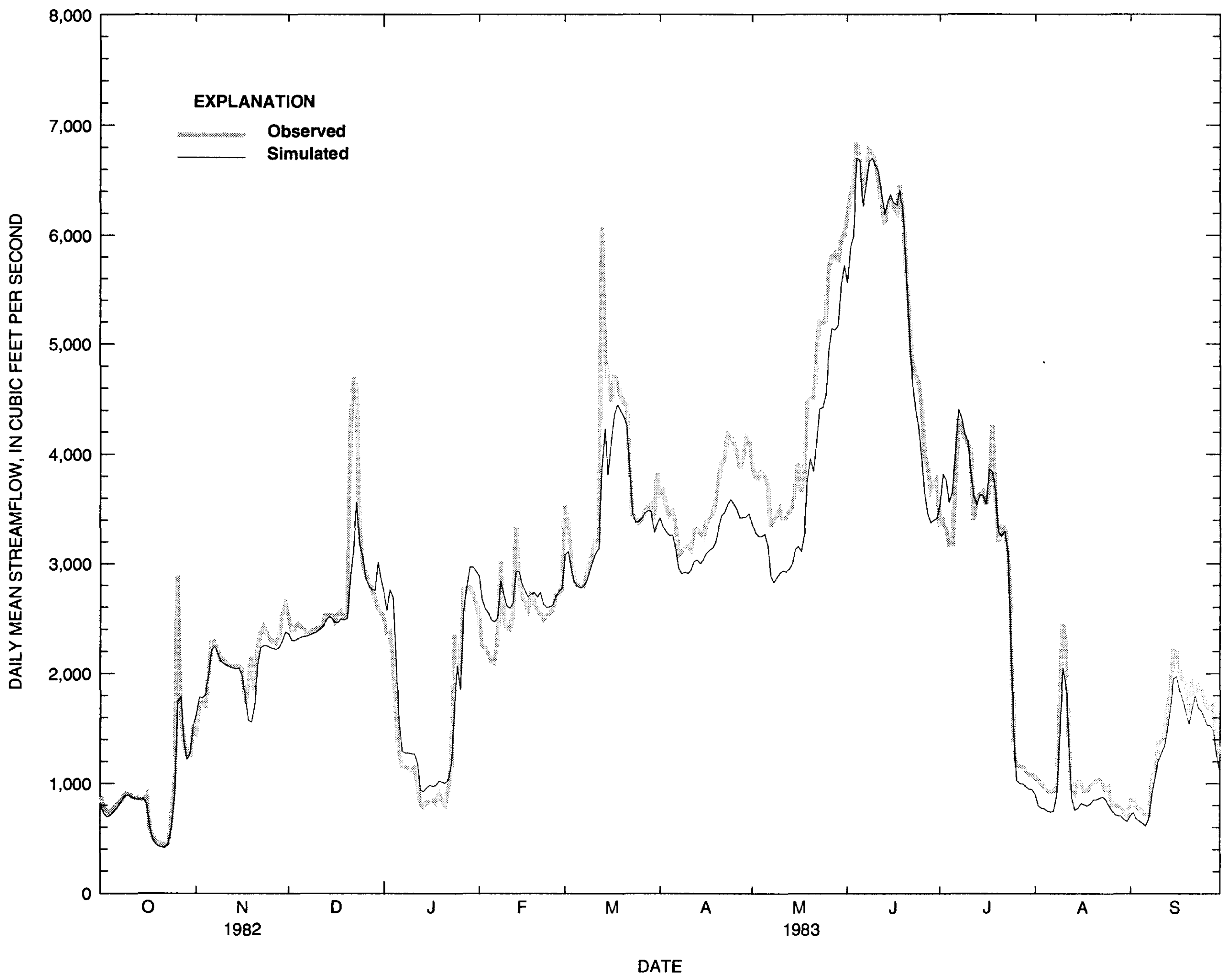


Figure 15. Observed and simulated daily mean streamflows for *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow is from the full model, water year 1983.

Measures of difference are usually larger for daily mean streamflow (table 7) than for monthly mean streamflow (table 5). For example, full model standard error for monthly mean streamflow is 45.6 compared to 70.2 percent for daily mean streamflow at the Nixon gaging station during the entire evaluation period and lower submodel standard error for monthly mean streamflow is from 16.8 percent compared to 32.5 percent for daily mean streamflow. However, the measure of bias did not substantially increase for daily mean streamflow. At the Nixon gaging station, for example, bias is -14.4 percent for monthly mean streamflow but is similar at -12.5 percent for daily mean streamflow. The largest differences of bias between monthly and daily mean streamflow is only 7.4 percent for the full model at the Nixon gaging station during the drought-evaluation period (tables 6 and 8).

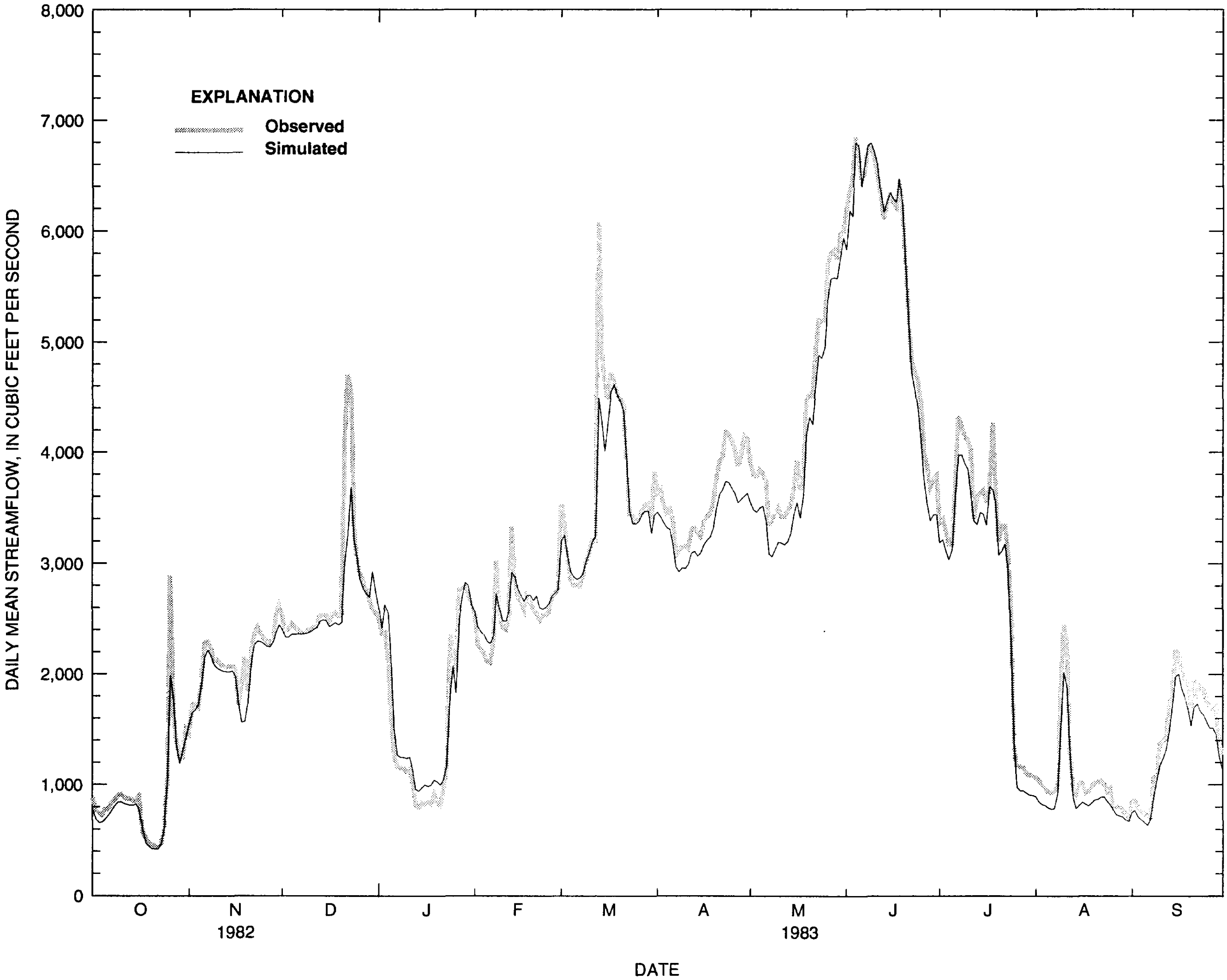


Figure 16. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow from middle submodel, water year 1983.

Similar patterns in the measures of difference are apparent for both monthly and daily mean streamflow. Measures of differences for daily mean streamflow at the Nixon gaging station are greater for the full model than for the lower submodel (table 7)—similar to those measures of difference for monthly mean streamflow (table 5). Additionally, percentage measures of difference, except bias for the lower submodel, are greater at the Nixon gaging station than for the Farad and Tracy gaging stations. Last, measures of difference, as percentages, are usually greater for the drought-evaluation period (table 8) than for the entire evaluation period (table 7). At the Nixon gaging station, for example, percentage bias for the drought-evaluation period is greater at 22.3 percent than for the entire evaluation period at -12.5 percent. However, in average values, bias is smaller for the drought-evaluation period at 7.0 ft^3/s than for the entire evaluation period at -74.3 ft^3/s.

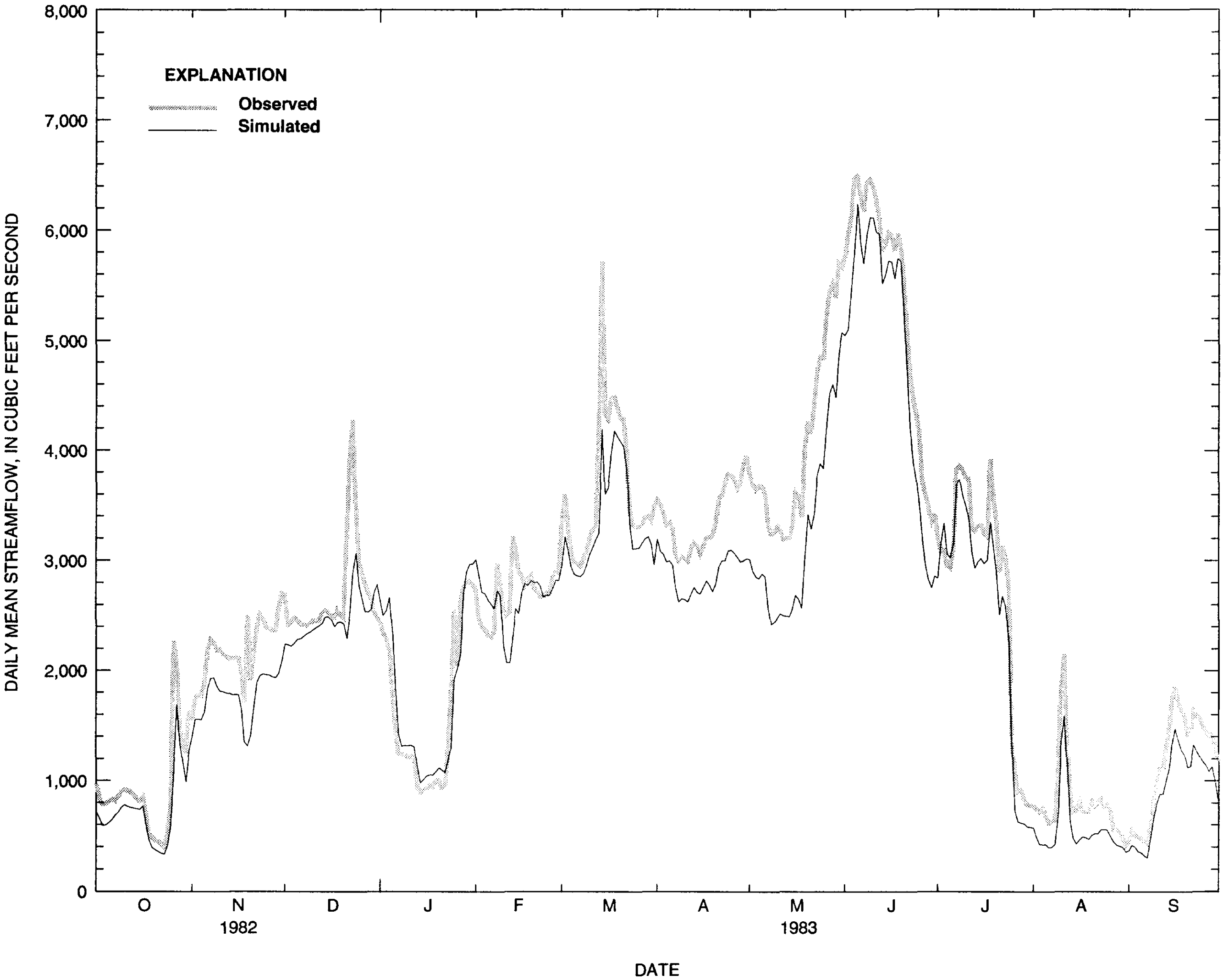


Figure 17. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from full model, water year 1983.

Examples of observed and simulated daily hydrographs for water year 1983—a period of high streamflow—and water year 1989—a period of low streamflow (figs. 14-23), show that differences between simulated and estimated hydrographs were largest for the full model at the Nixon gaging station. For most of the 1983 water year, the hydrograph of simulated flow lies below the hydrograph of observed flow, especially from March to June (fig. 17). For water year 1989 (fig. 22), the hydrograph of observed flow exceeds the hydrograph of simulated flow from mid-June through July. However, the observed and simulated hydrographs closely match for both water years for the lower submodel (figs. 18 and 23).

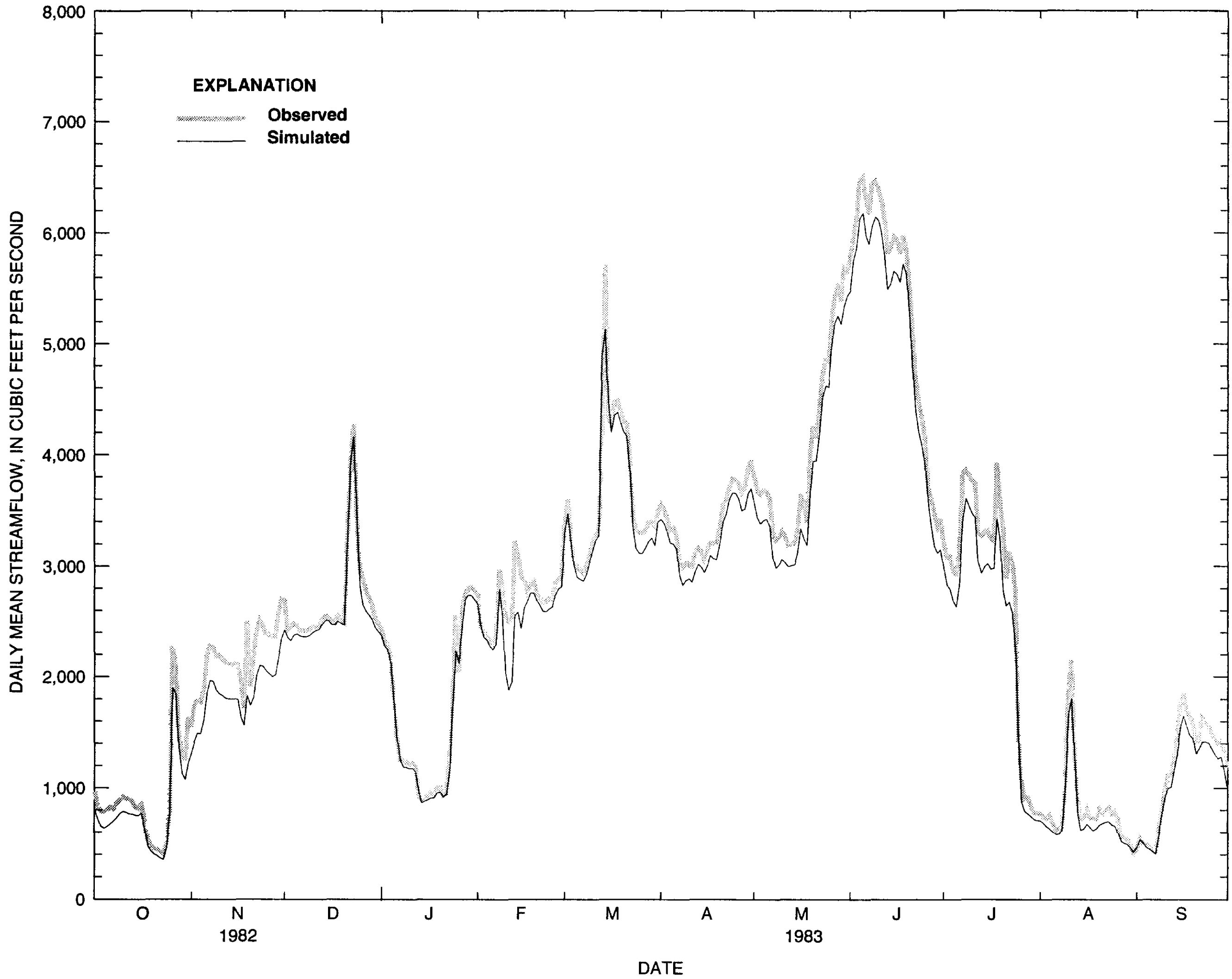


Figure 18. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from lower submodel, water year 1983.

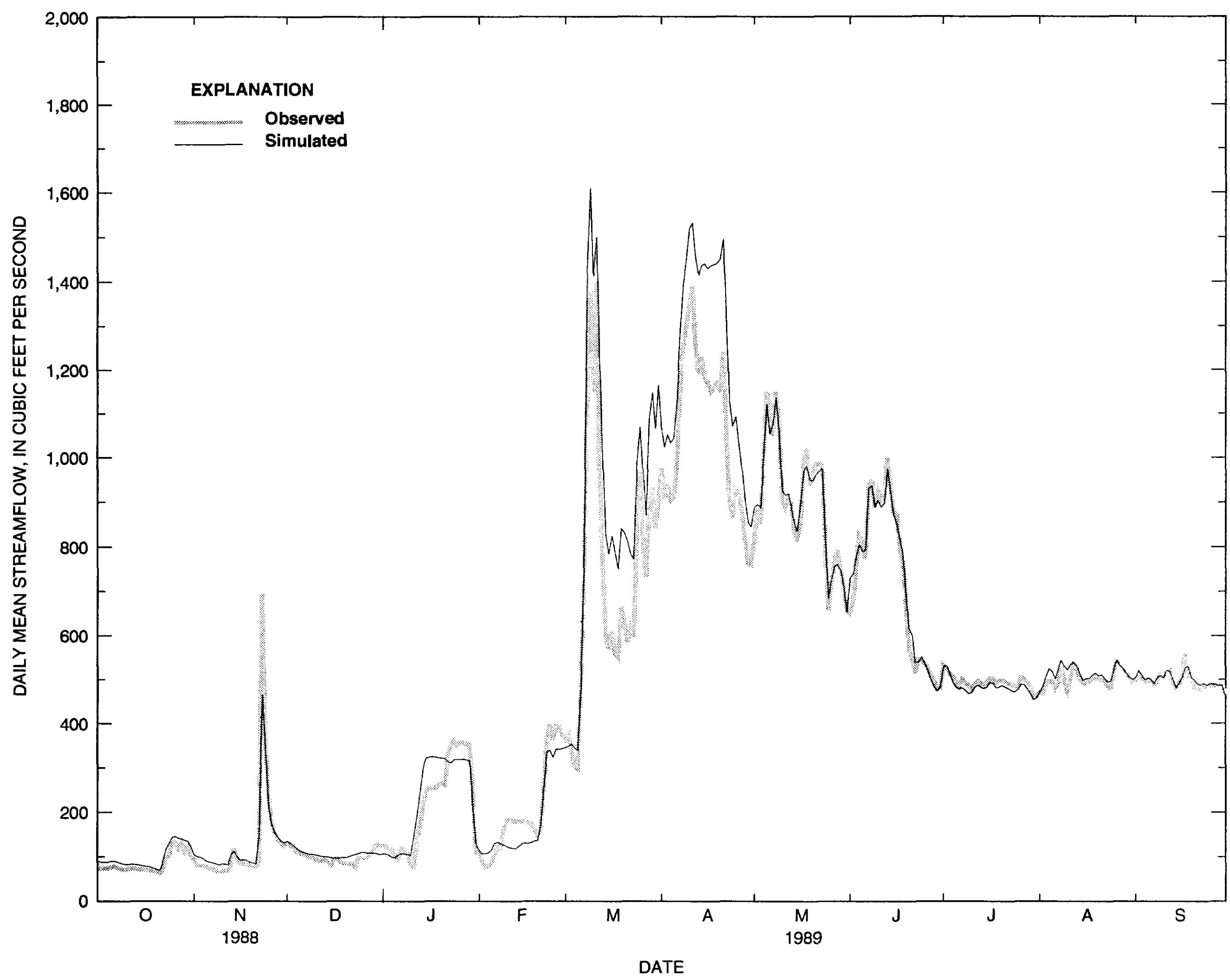


Figure 19. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, water year 1989.

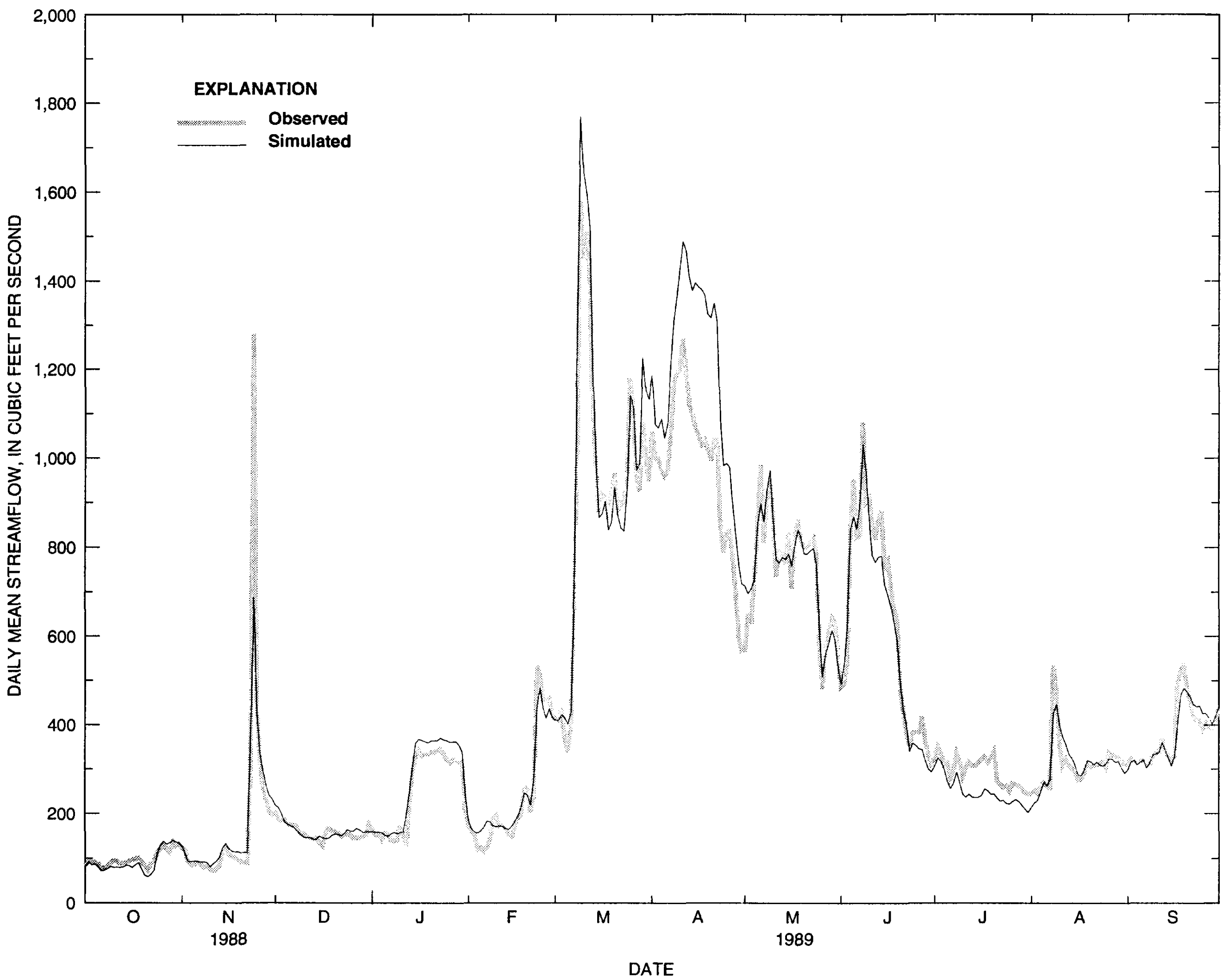


Figure 20. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow from full model, water year 1989.

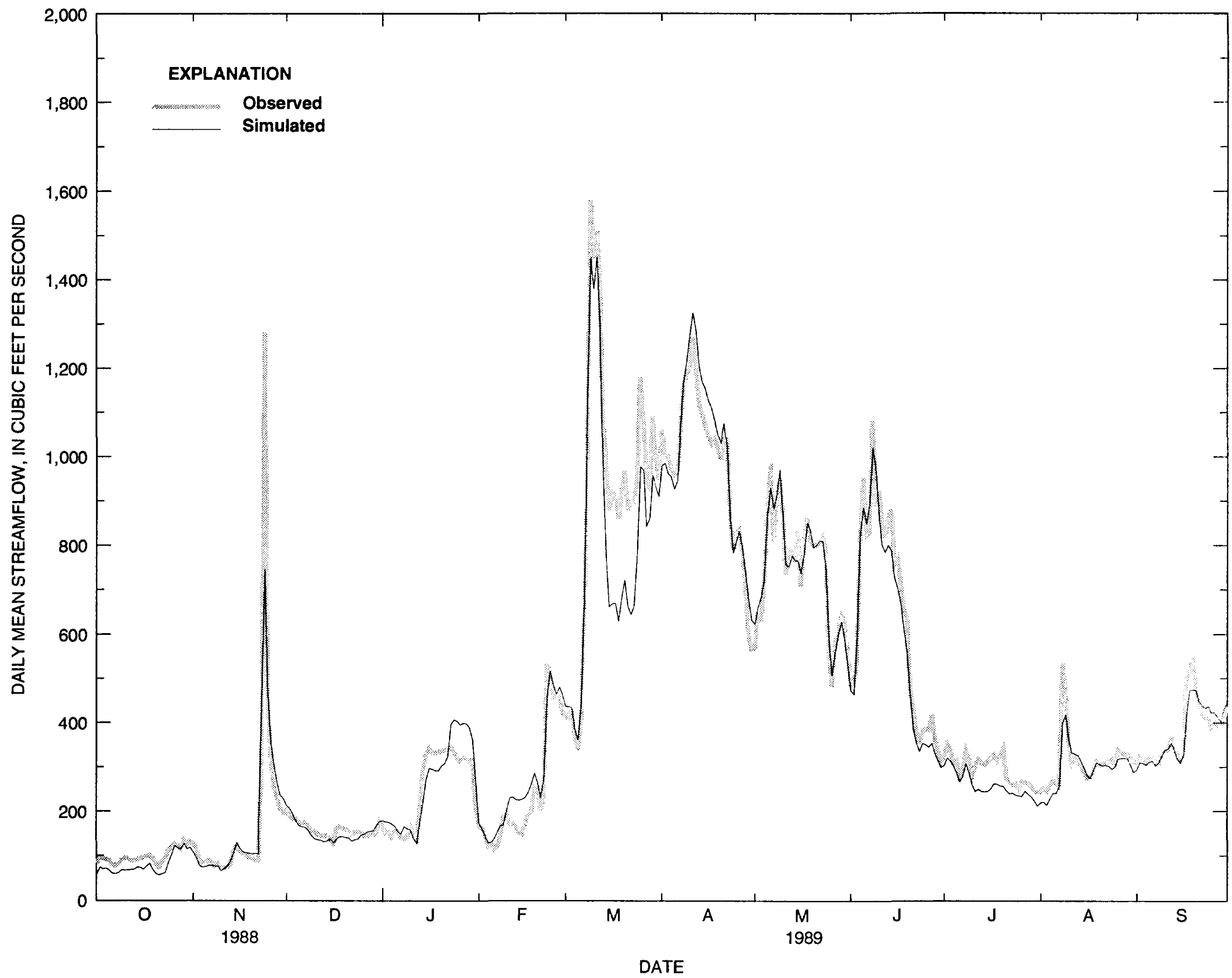


Figure 21. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflow from middle submodel, water year 1989.

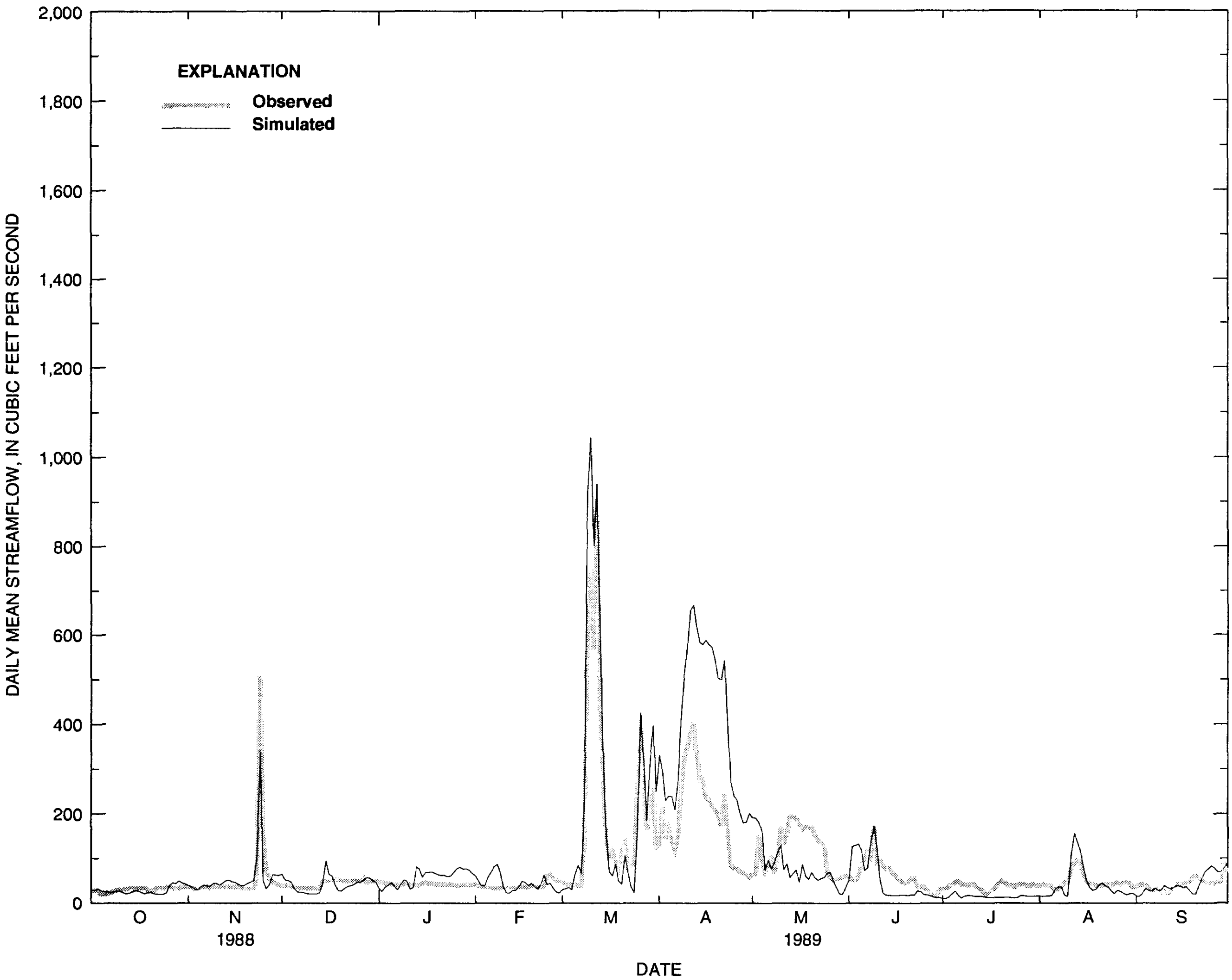


Figure 22. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from full model, water year 1989.

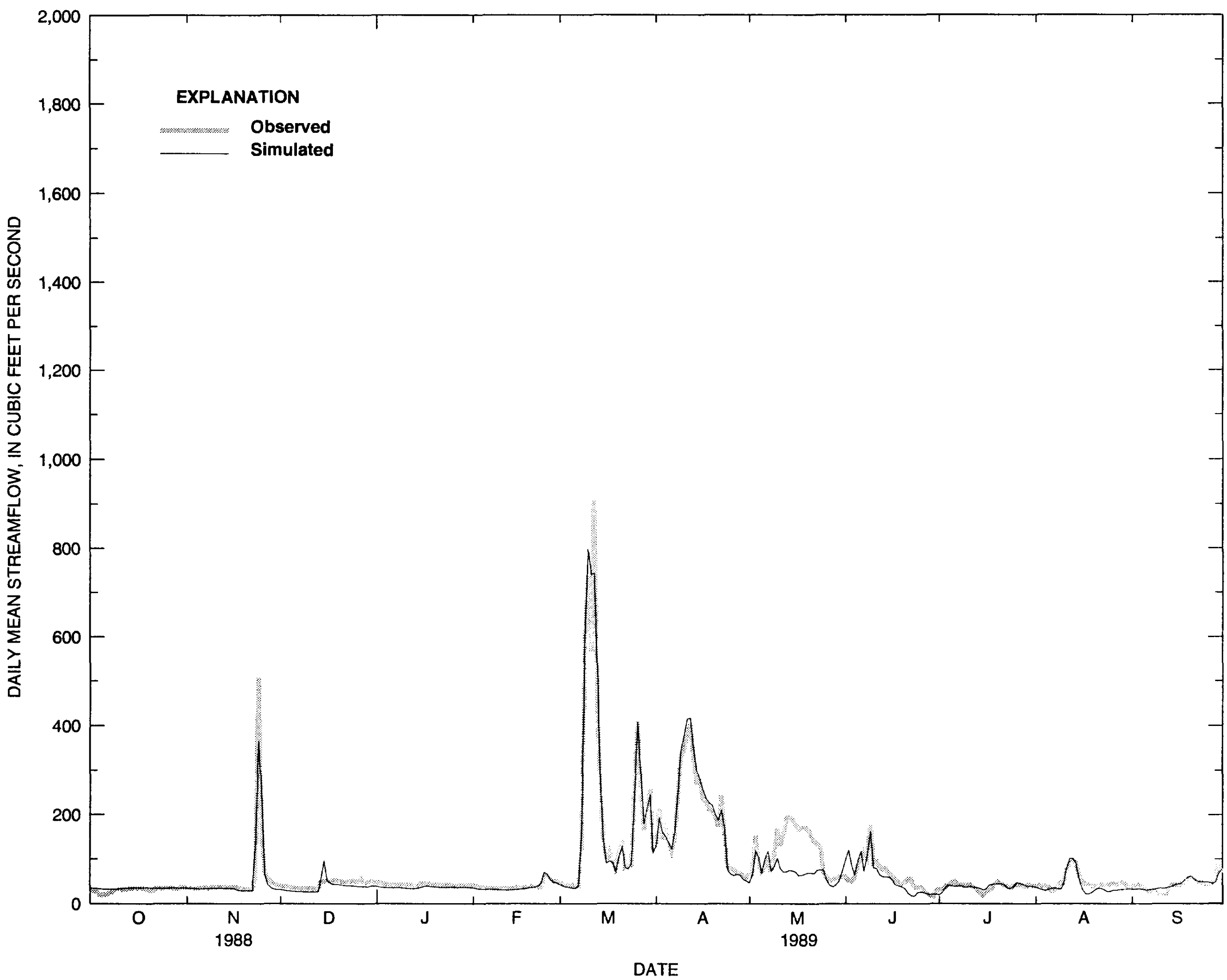


Figure 23. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflow from lower submodel, water year 1989.

Table 7. Measures of difference between observed and simulated daily mean streamflows for full model and submodels, October 1, 1977, through September 30, 1992

Station name and number	Model [1]	Mean absolute error [2]		Bias [3]		Standard error of estimate [4]	
		Average	Percent	Average	Percent	Average	Percent
Truckee River at Farad, Calif., 10346000 . .	Full	39.2	6.2	16.1	3.5	79.6	8.5
	Upper . .	39.2	6.2	16.1	3.5	79.6	8.5
Truckee River below Tracy, Nev., 10350400.	Full	73.8	11.5	-42.2	-5.6	179.6	14.7
	Middle. .	72.2	11.8	-58.2	-8.6	166.4	12.8
Truckee River near Nixon, Nev., 10351700. .	Full	97.6	46.0	-74.3	-12.5	212.9	70.2
	Lower . .	54.4	17.3	-42.9	-4.2	121.3	32.5

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper submodel simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] Average = $\sum (|S-O|/(n))$ and percent = $100 \times \langle \sum \langle |S-O|/O \rangle \rangle / n$ for all O values greater than 0, where S is simulated daily mean streamflow in cubic feet per second; O is observed daily mean streamflow in cubic feet per second; n is number of pairs of daily values for which O values greater than 0 in the simulation period; and || is absolute value. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

[3] Average = $\sum \langle S-O \rangle / n$ for all O values greater than 0, percent = $100 \times \{\sum [\langle S-O \rangle / O] / n\}$ for all O values greater than 0.

[4] Average = $\sqrt{\langle n/(n-1) \rangle \times \left[\{\sum \langle \langle S-O \rangle^2 \rangle / n\} - \{\text{average bias}\}^2 \right]}$

percent = $\sqrt{\langle n/(n-1) \rangle \times \left[100 \times \{\sum \langle \langle \langle S-O \rangle / O \rangle^2 \rangle / n\} - \{\text{percent bias}\}^2 \right]}$.

Table 8. Measures of difference between observed and simulated daily mean streamflows for full model and submodels, October 1, 1987, through September 30, 1992

Station name and number	Model [1]	Mean absolute error [2]		Bias [3]		Standard error of estimate [4]	
		Average	Percent	Average	Percent	Average	Percent
Truckee River at Farad, Calif., 10346000	Full.	23.4	8.4	14.7	5.5	40.5	10.8
	Upper . . .	23.4	8.4	14.7	5.5	40.5	10.8
Truckee River below Tracy, Nev., 10350400 . .	Full.	34.6	11.8	-3.1	.4	55.7	16.8
	Middle . .	32.3	11.4	-17.8	-4.7	46.2	14.4
Truckee River near Nixon, Nev., 10351700 . . .	Full.	25.3	64.3	7.0	22.3	44.6	100.5
	Lower. . .	7.1	21.5	.1	8.1	14.8	45.3

[1] Full model simulates streamflows along 47 reaches between gaging station, *Truckee River at Tahoe City, Calif.*, and Marble Bluff Dam. Upper submodel simulates streamflows along 14 reaches between gaging stations, *Truckee River at Tahoe City, Calif.*, and *Truckee River at Farad, Calif.* Middle submodel simulates streamflows along 20 reaches between gaging station, *Truckee River at Farad, Calif.*, and downstream end of reach 440, about 2.2 miles upstream from Derby Dam. Lower submodel simulates streamflows along 12 reaches between gaging station, *Truckee River below Derby Dam, near Wadsworth, Nev.*, and Marble Bluff Dam.

[2] Average = $\sum (|S-O|/(n))$ and percent = $100 \times \langle \sum \langle |S-O|/O \rangle \rangle / n$ for all O values greater than 0 where S is simulated daily mean streamflow in cubic feet per second; O is observed daily mean streamflow in cubic feet per second; n is number of pairs of daily values for which O values greater than 0 in the simulation period; and || is absolute value. A positive bias indicates model simulation is overestimating streamflow and a negative bias indicates model simulation is underestimating streamflow.

[3] Average = $\sum \langle S-O \rangle / n$ for all O values greater than 0, and percent = $100 \times \{\sum [\langle S-O \rangle / O] / n\}$ for all O values greater than 0.

[4] Average = $\sqrt{\langle n/(n-1) \rangle \times \left[\{\sum \langle \langle S-O \rangle^2 \rangle / n\} - \{\text{average bias}\}^2 \right]}$ and

percent = $\sqrt{\langle n/(n-1) \rangle \times \left[100 \times \{\sum \langle \langle \langle S-O \rangle / O \rangle^2 \rangle / n\} - \{\text{percent bias}\}^2 \right]}$

Discussion of Differences Between Observed and Simulated Streamflow and Model Limitations

Based on the preceding results, observed streamflow was simulated reasonably well for the full model and submodels at the Farad and Tracy gaging stations, and for the lower submodel at the Nixon gaging station. For example, bias of simulated annual mean streamflow at these gaging stations for these models was less than -8.0 percent (tables 3 and 4) and bias of simulated daily mean streamflow was less than -9.0 percent (tables 7 and 8). In contrast, simulation results were less satisfactory for the full model at the Nixon gaging station. Bias of simulated annual streamflow at the Nixon gaging station was as large as 16.5 percent (table 4) and bias of simulated daily streamflow was as large as 22.3 percent (table 8).

General Sources of Differences

The following discussion describes the qualitative analysis of observed and simulated daily hydrographs to determine whether most of the general differences between observed and simulated streamflow were the result of (1) inadequate data characterizing inflows to and outflows from the Truckee River or (2) inadequate data characterizing the hydraulic properties of the river. As previously discussed in the sections, “Hydraulic Data” and “Hydraulic Characteristics of Reaches,” hydraulic data either measured during river surveys or determined from maps were characterized by physically-based parameters in F-tables. Although hydraulic parameters in F-tables were not adjusted in this study as discussed in the section, “Model Testing,” hydraulic parameters in F-tables can be adjusted, if necessary, to improve the timing and attenuation of streamflow. Differences between observed and simulated streamflow during short periods when simulated hydrographs lag behind or precede observed hydrographs are referred to as "time shifts." These time-shift differences can be adjusted through calibration of the hydraulic parameters. Such hydraulic-parameter adjustments, however, do not decrease differences between observed and simulated streamflow volume during extended periods. Differences in streamflow volume during extended periods are related more to insufficient data characterizing the volume of inflows to or outflows from the river. Qualitative analysis (visual comparison of hydrographs of observed and simulated streamflow) shows that most of the large differences between observed and simulated streamflow are related more to streamflow volume differences over periods of several days to months, rather than to streamflow timing and attenuation differences for shorter periods, such as the duration of most hydrograph peaks. Accordingly, the F-tables were not adjusted.

The daily hydrographs shown in figures 14-18 provide examples that indicate how differences between observed and simulated streamflow usually extend for long periods (months rather than days) and are not time shifts. For example, a continuous underestimation of streamflow is simulated by the full model during April and May 1983. At the Farad gaging station (fig. 14), streamflow is underestimated by the model from late April to the snowmelt peak in late May. At the Tracy gaging station (fig. 15), the underestimation is more pronounced and extends from early April through May; however, the timing of the simulated snowmelt peak in late May and early June is similar to the observed snowmelt peak. At the Nixon gaging station (fig. 17), the same underestimation extends from mid-March through the remainder of the water year. The same pattern of differences between observed and simulated streamflow during long periods can be seen for April 1989, comparing hydrographs from the full model with hydrographs of observed flow (figs. 19, 20, and 22). The hydrographs of observed and simulated streamflow more closely match for submodel simulations for 1983 (figs. 14, 16, and 18) and 1989 (figs. 19, 21, and 23).

Qualitative analysis of observed and simulated hydrographs shows that not all observed and simulated hydrographs match closely. However, many do, indicating that both streamflow timing and volumes are adequately simulated. Thus, for these periods of closely matching hydrographs, both the hydraulic properties of the Truckee River and volume of inflows to and outflows from the Truckee River are adequately represented by the models. The hydraulic properties of the river do not significantly change with time. Thus, the F-tables that represent the hydraulic properties are considered "fixed." In contrast, the accuracy of input data for Truckee River mainstem flow, inflows, and outflows does vary. Therefore, the variable and uncertain accuracy of input data could cause differences between observed and simulated streamflow volumes during periods when observed and simulated hydrographs do not closely match.

The following examples graphically demonstrate how observed and simulated hydrographs can be qualitatively analyzed to indicate that the timing and attenuation characteristics of streamflow are adequately simulated and, therefore, the hydraulic properties of the river are adequately represented by the models. In figures 14-18, the decrease in streamflow shown in late December 1982 and subsequent increase in late January 1983 are closely simulated by the full model and submodels. A hydrograph peak during a period of fairly low flow, during late November 1988, also indicates the hydraulic properties of the reaches are adequately represented by the F-tables in the models. The hydrographs in figures 24-26 for November 15 through December 15, 1988, graphically demonstrate that the timing of the simulated hydrograph peaks closely match the observed hydrograph peaks at the Farad, Tracy, and Nixon gaging stations, indicating that the hydraulic properties of the reaches were adequately represented in the models. Additionally, the timing of the hydrographs for observed and simulated streamflow follow similar patterns at the three gaging stations—the overall timing of the rise and fall of the hydrograph peak are close, especially at the Farad and Tracy gaging stations (figs. 24 and 25). At the Nixon gaging station (fig. 26), the timing of the hydrograph is less accurate for the full model than for the lower submodel, especially the timing of the fall of the peak. The hydrograph peak was underestimated by all of the models because inflow data did not provide adequate volumes of water to the Truckee River from tributaries and returns. Nonetheless, the timing and attenuation of the simulated hydrographs are close to the timing of observed hydrographs. Finally, figures 27-29 show two hydrograph peaks during a moderately high streamflow period in January and February 1980. Both of these peaks were closely simulated by the full model and submodels at the Farad, Tracy, and Nixon gaging stations.

For the full model and submodels, inflows to and outflows from the Truckee River are provided as input time series for simulations. Inadequate input data results in differences between observed and simulated streamflow. These differences originate at the point along the Truckee River where the inflow or outflow data are inadequate and continue as streamflow is routed downstream. Thus, if unrecorded irrigation returns flow into the Truckee River, and these returns are not provided to the model by a time series, then the model will begin to underestimate Truckee River streamflow beginning just downstream from that return. Inadequate flow data can create differences between observed and simulated streamflow at several locations, and these differences, added to the differences introduced upstream, may accumulate

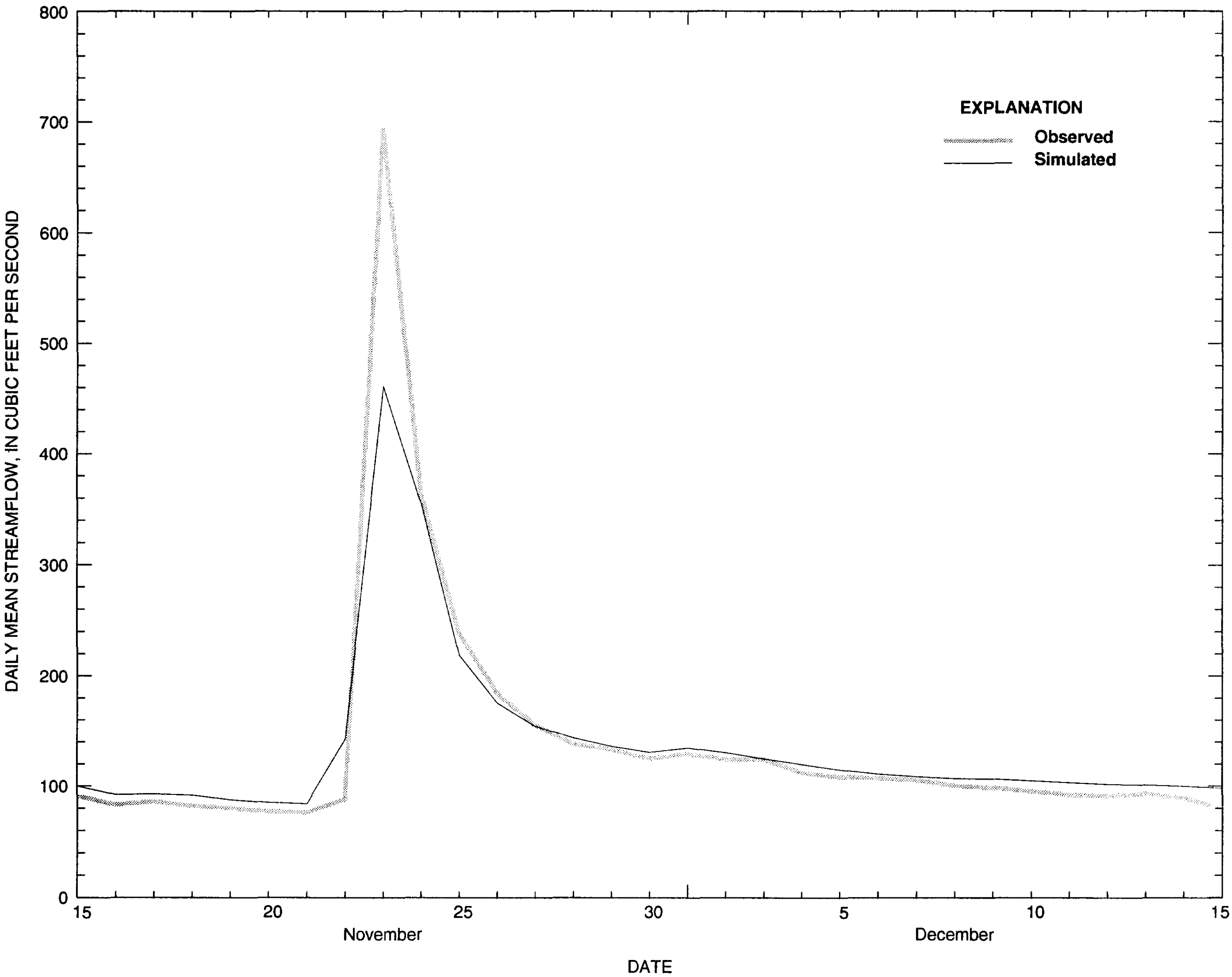


Figure 24. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, November 15 through December 15, 1988.

or compensate each other along the 114-mi length of the Truckee River. Thus, "model uncertainties" are created because it is not known when and where these differences accumulate or compensate each other along the Truckee River. These uncertainties are greater for the full model, which represents the full 114-mi length of the Truckee River, than for the submodels, which represent shorter lengths of the Truckee River. At the Nixon gaging station, for example, uncertainties are greater for the full model than for the lower submodel. Differences between observed and simulated streamflow at the Nixon gaging station also are greater for the full model than submodel because of such uncertainties (table 7).

Model uncertainties increase in the full model downstream from Derby Dam, especially when large amounts of water are diverted from the Truckee River to the Truckee Canal. As streamflow is routed through Derby Dam and Truckee River flow is diverted to the Truckee Canal, the simulation differences originating upstream from the dam, plus any errors in the estimated Truckee Canal flows, result in a proportionally larger difference from the observed (much lower) flows of the Truckee River downstream from the dam.

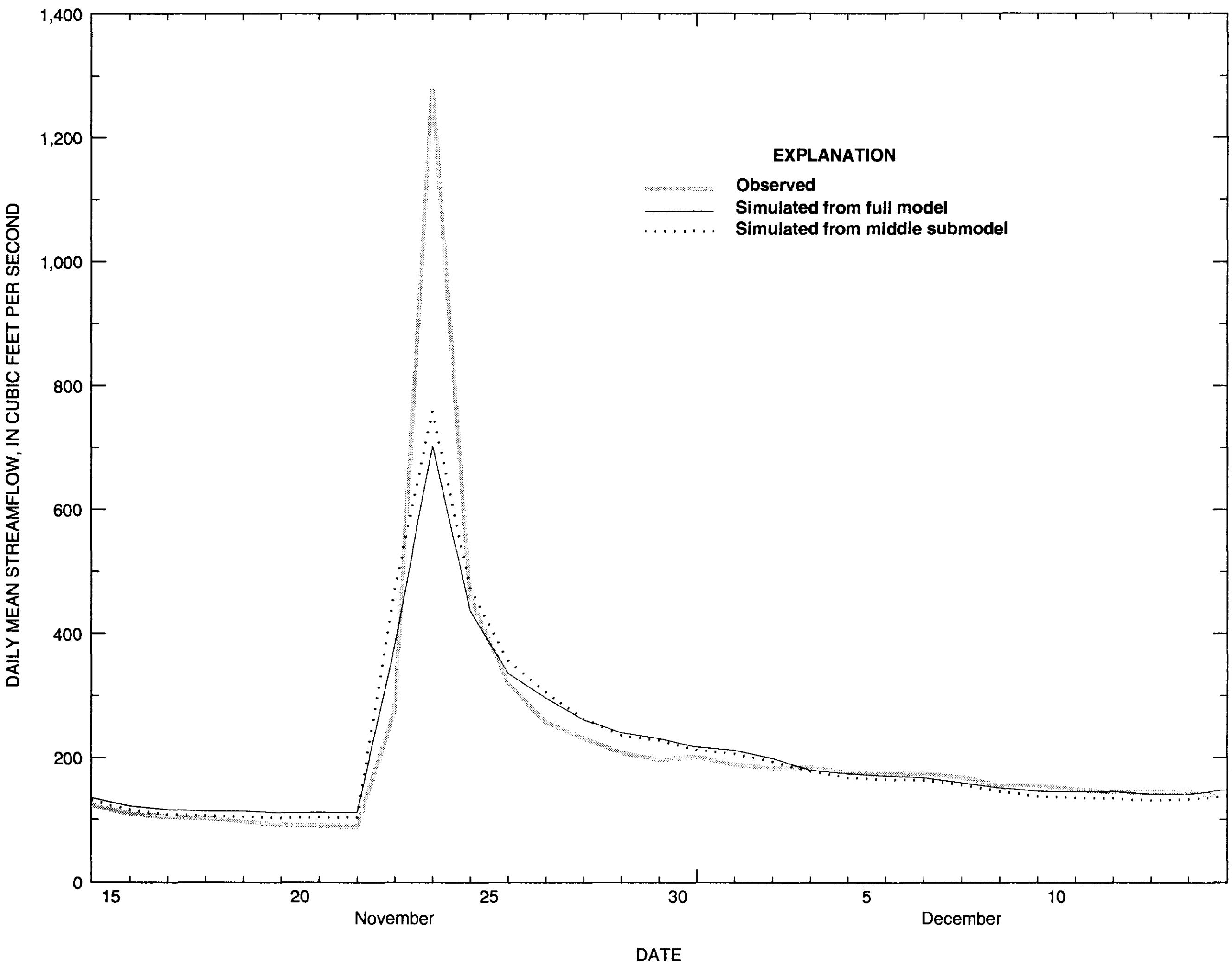


Figure 25. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflows from full model and middle submodel, November 15 through December 15, 1988.

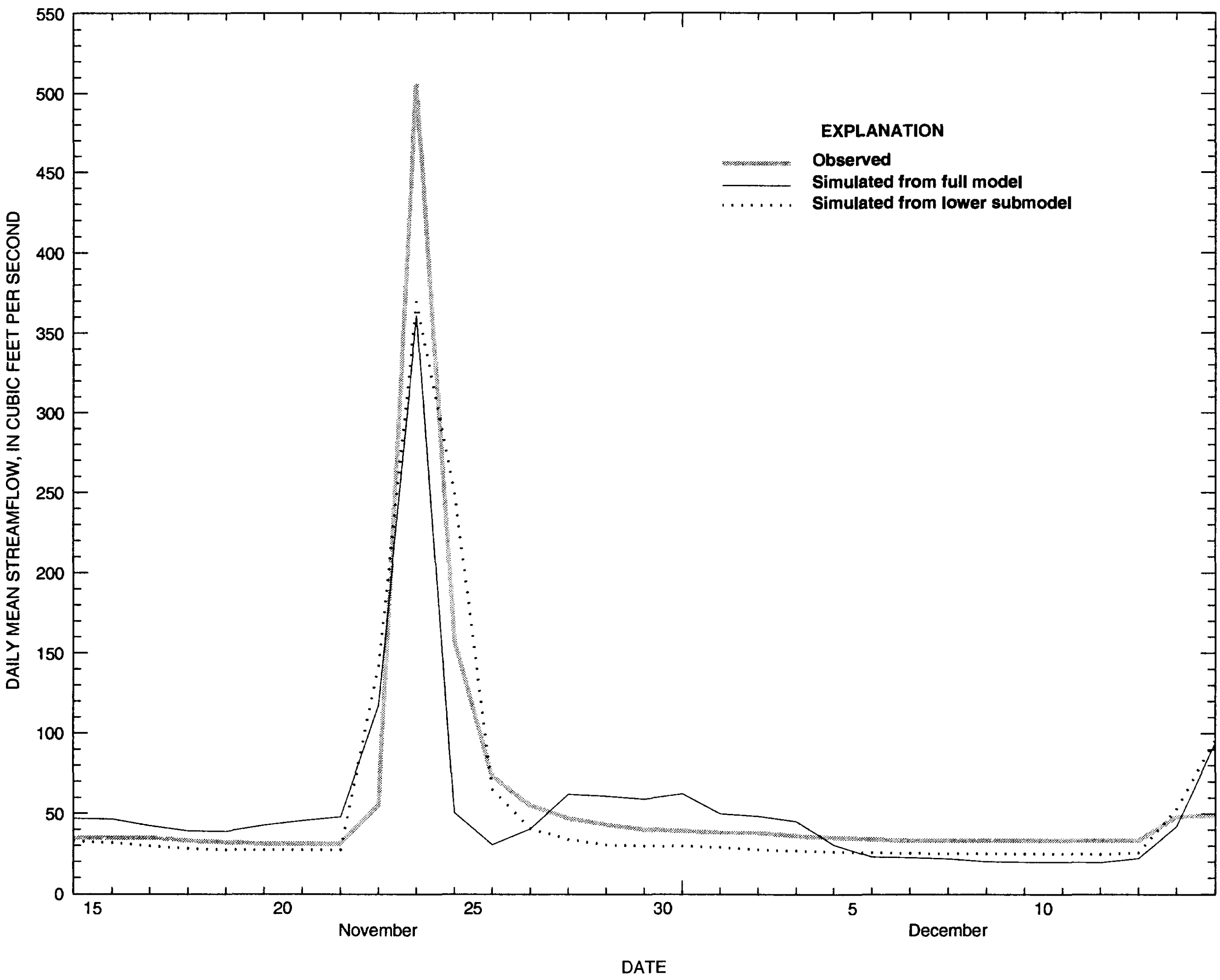


Figure 26. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflows from full model and lower submodel, November 15 through December 15, 1988.

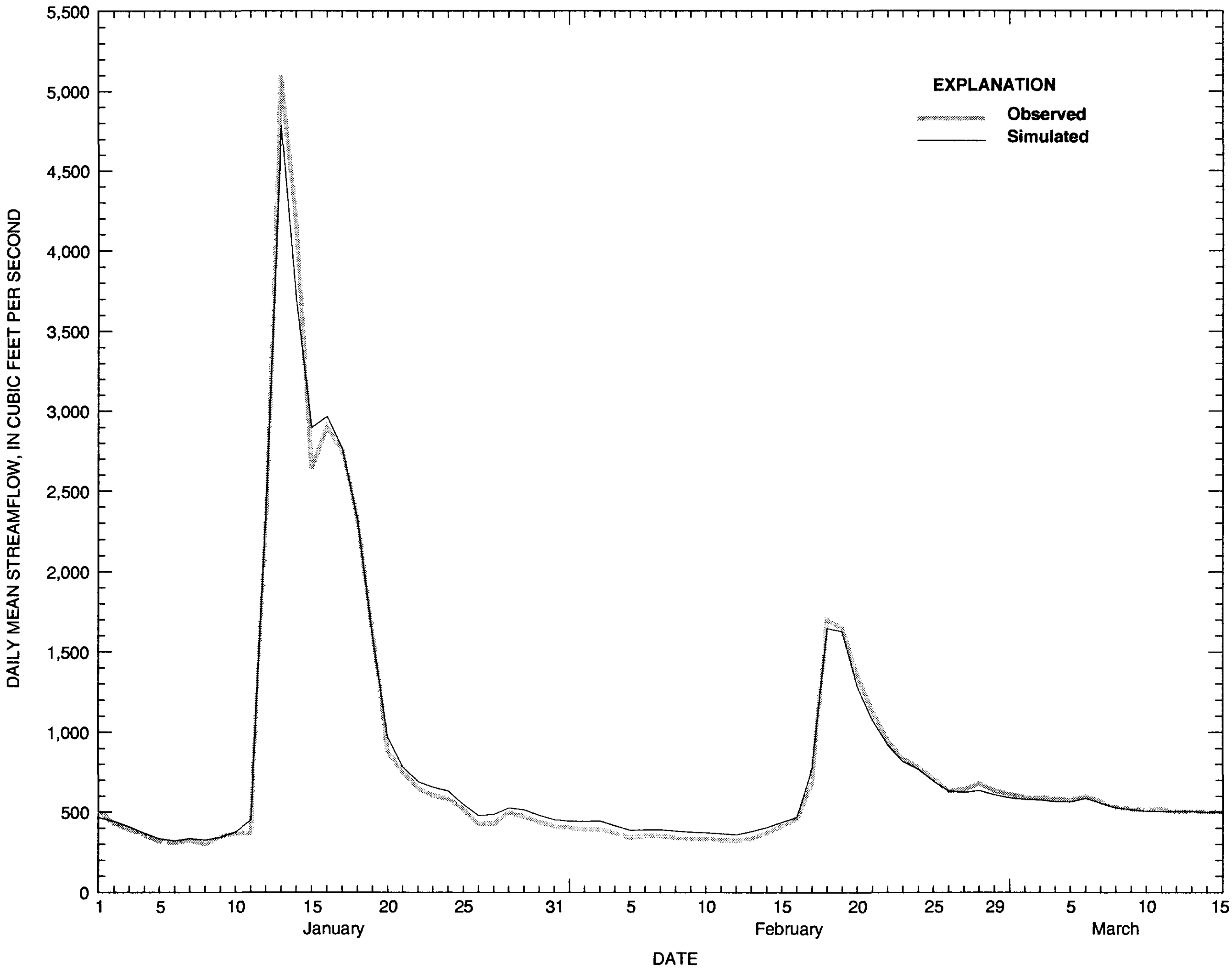


Figure 27. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, January 1 through March 15, 1980.

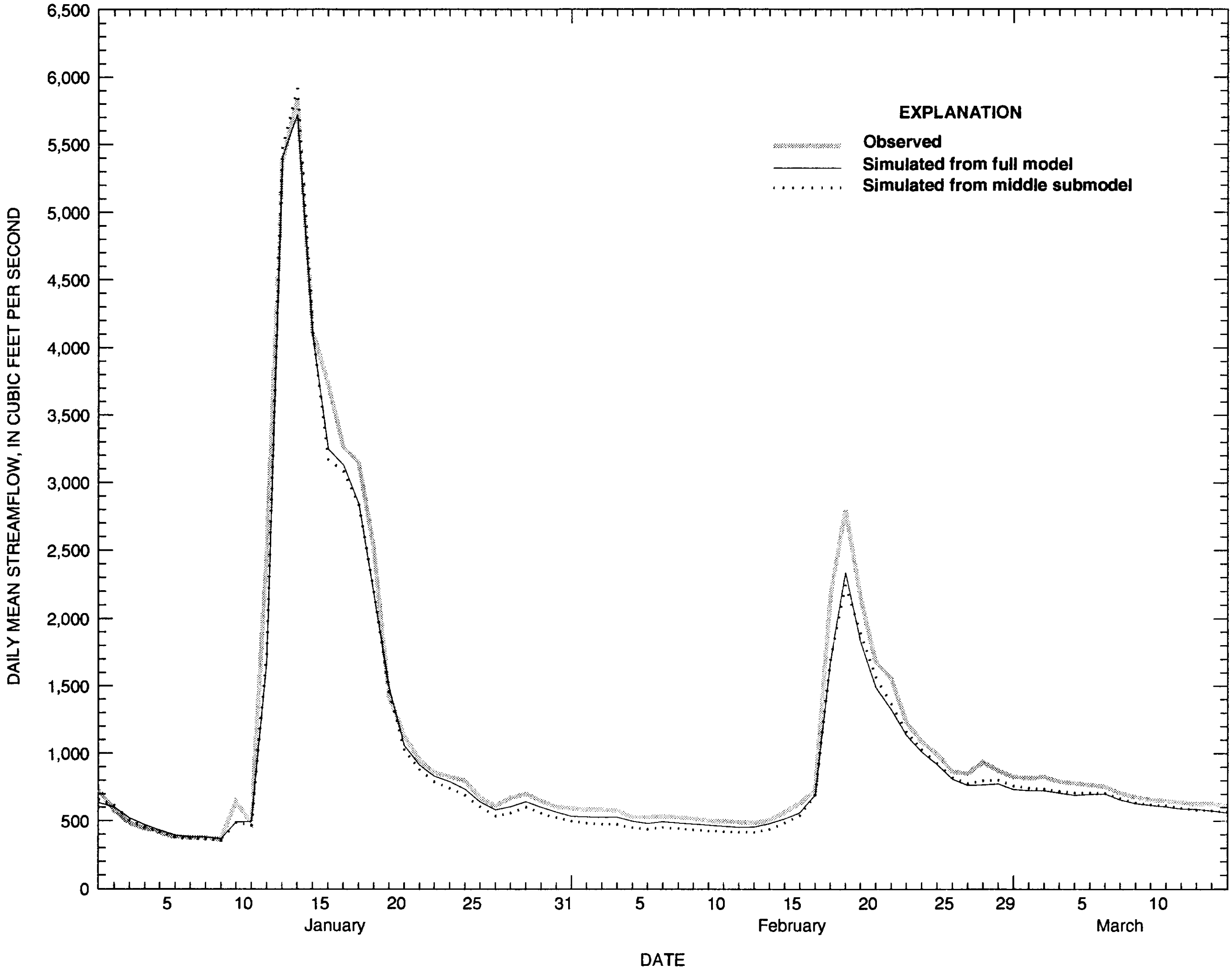


Figure 28. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflows from full model and middle submodel, January 1 through March 15, 1980.

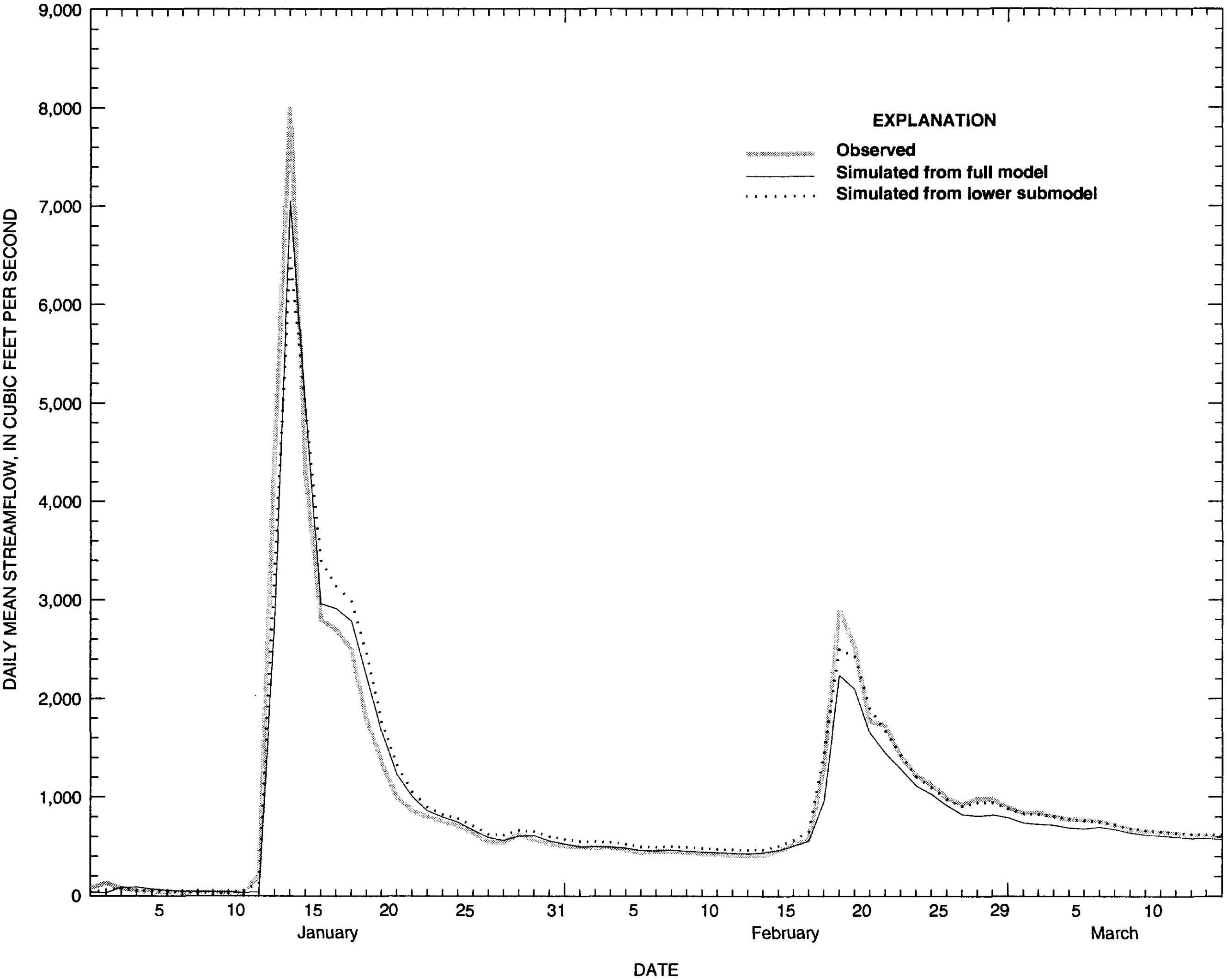


Figure 29. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflows from full model and lower submodel, January 1 through March 15, 1980.

Specific Source of Differences and Model Limitations

The preceding discussion demonstrated that the hydraulic characteristics of the Truckee River are adequately represented in the models for a variety of flow regimes. Most of the large differences between observed and simulated streamflow volumes over long periods are a result of inadequate Truckee River inflow and outflow data. Model accuracy, therefore, was limited by the adequacy of inflow and outflow data. This section will further describe this inadequacy by discussing specific sources of differences and model limitations.

The source of differences between observed and simulated streamflow cannot always be attributed to a specific component of the Truckee River water budget. Inaccurate or missing inflow and outflow data result in erroneous representation of these components in the models. Errors for two or more components could either compensate for one another or be additive, thereby masking or compounding actual differences. Because the interaction between components is unpredictable, isolating a specific error source is difficult. For example, inadequate data on ground-water inflow, spills, or irrigation return flows can be concurrent and, therefore, mask the specific sources of error during streamflow simulations. Depending on the magnitude of errors in the data for each component, differences caused by inadequate ground-water data may be masked by differences caused by inadequate spill and return-flow data. Thus, streamflow underestimated by the model at the Nixon gaging station could be the result of overestimated inflow from ground water masked by even greater underestimated inflow from spills and returns. More complex interactions make it difficult to attribute proportions of the total simulation differences to individual inadequacies of inflow or outflow data. A known source of inadequate data may not account for all differences during a simulation period. Therefore, in this discussion, the given source for simulation differences can be considered only a "probable or likely" cause when examining a specific period of simulation differences.

Model limitations arise when Truckee River inflows and outflows are inadequately described. The routing model cannot accurately simulate inflows and outflows without adequate input data. Inflows to and outflows from the Truckee River may be inadequately described for two reasons: (1) the flow data described by time series provided to the models are inaccurate, or (2) not all inflows to and outflows from the Truckee River are described by time series.

Inaccurate Flow Data

Inaccurate time series of flow data result from either poor-quality records from gaging stations or inadequate estimates of flow. Poor-quality records are caused by variable stage-discharge relations due to unstable channels, icy conditions, backwater conditions, and varying amounts of aquatic vegetation. If streamflow at these gaging stations is not frequently measured, the stage-discharge relations and streamflow data may not be accurate. The accuracy of records from such USGS gaging stations may be rated "fair" or "poor." As previously discussed in the section "Observed Streamflow Data," a fair rating means that 95 percent of the computed streamflow records are accurate only to within 15 percent of their true values. Less reliable streamflow records are rated poor. The accuracy of streamflow records from gaging stations operated and maintained by agencies other than the USGS is not typically rated.

Estimated flow data also can result in inaccurate time series. Flow data were estimated to provide as many inflow and outflow time series to the model as possible for completed simulations. Where possible, if continuous flow data were not observed at inflow and outflow points, these data were estimated. Estimated flow data are not as accurate as data computed from gaging station records, but result in less error in the model than would result from omitting the inflows and outflows.

Visual inspection of hydrographs can be helpful in determining periods for which flow data may be inaccurate. Three examples follow that show how inaccurate flow data cause differences between observed and simulated hydrographs.

The hydrograph peak during April 1989 is the first example (figs. 19-23). This peak was overestimated in model simulation for almost the entire month at the Farad gaging station (fig. 19). A probable reason was that the regression equations developed to estimate inflows from ungaged Truckee River tributaries were not accurate for this period. (See the section titled, "Ungaged Tributaries" for a discussion on the development of these equations.) Visual inspection of the observed and simulated hydrographs from the full model indicate that the overestimation of the April hydrograph peak continued downstream to the Tracy and Nixon gages (figs. 20 and 22). Thus, the overestimated peak is routed in the full model downstream along the entire length of the Truckee River. The overestimation does not appear on the Tracy and Nixon hydrographs from the middle and lower submodels because the data estimated from the regression equations to represent river inflows were not incorporated in these models (figs. 21 and 23).

The second example, June through December 1984, shows that flow data may not adequately characterize all inflows and outflows (figs. 30-32). At the Farad gaging station, the full and upper submodels (identical from the outlet of Lake Tahoe to the Farad gaging station) adequately simulated observed Truckee River streamflow (fig. 30). However, at the Tracy gaging station (fig. 31), the full and middle submodels underestimate streamflow from early August through late October. Although the exact sources of this underestimation are difficult to identify, one of the likely sources is that the estimated inflows from ungaged spills and returns from irrigation systems are different from the actual inflows from these sources. If the estimated spills and returns are lower than the actual spills and returns, then more water is simulated as permanently diverted from the Truckee River than actually was diverted, resulting in an underestimation of river flows. Flow records from ditches in the middle

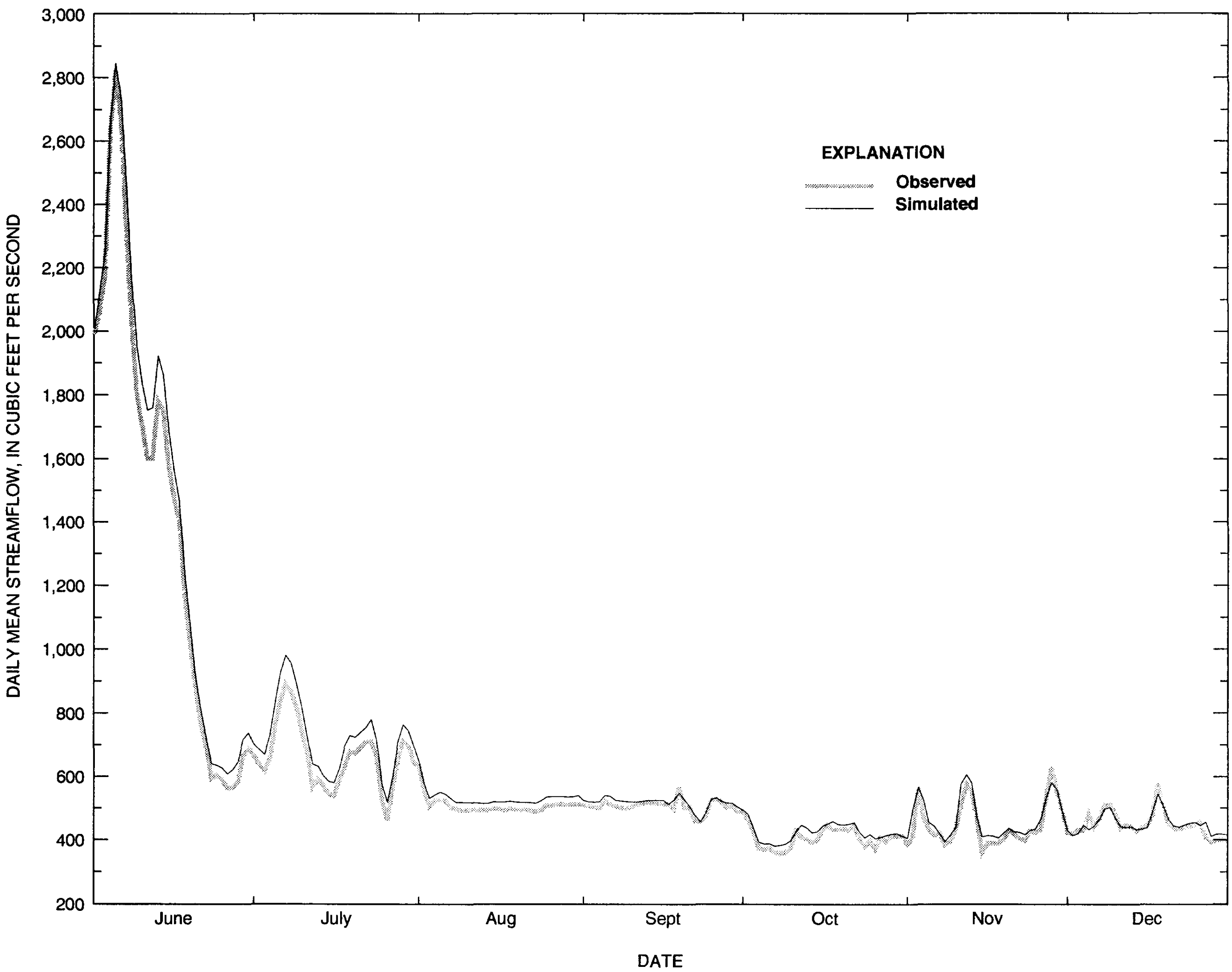


Figure 30. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflows from full model and upper submodel, June 1 through December 31, 1984.

subunit indicate that the irrigation season (the period in which flows were diverted from the river to irrigation ditches) began in mid-April and ended in late October. Inflows from many ungaged spills and returns were estimated for the model for this period. At the Nixon gaging station, both the full and lower submodels underestimated streamflow from July through late November (fig. 32). Underestimation was larger in the full model than in the lower submodel from August through October. The larger underestimation by the full model is probably a result of model uncertainties as the length of the modeled river increases. The differences likely resulted from not adequately estimating returns and spills, as previously discussed for the Tracy gaging station. However, a divergence is notable between the observed and simulated hydrographs from mid-September through mid-November, in contrast to that from the Tracy gaging station. The cause of this divergence may be that the Truckee Canal spilled water to the Truckee River during this period. The spills from the canal to the river are sometimes substantial, but no spill records exist and these spills could not be estimated. Thus, the estimated Truckee Canal flows, which represent the diverted flow from the Truckee River (discussed previously in the section, "Flow Data Affected by Backwater") do not account for any spills

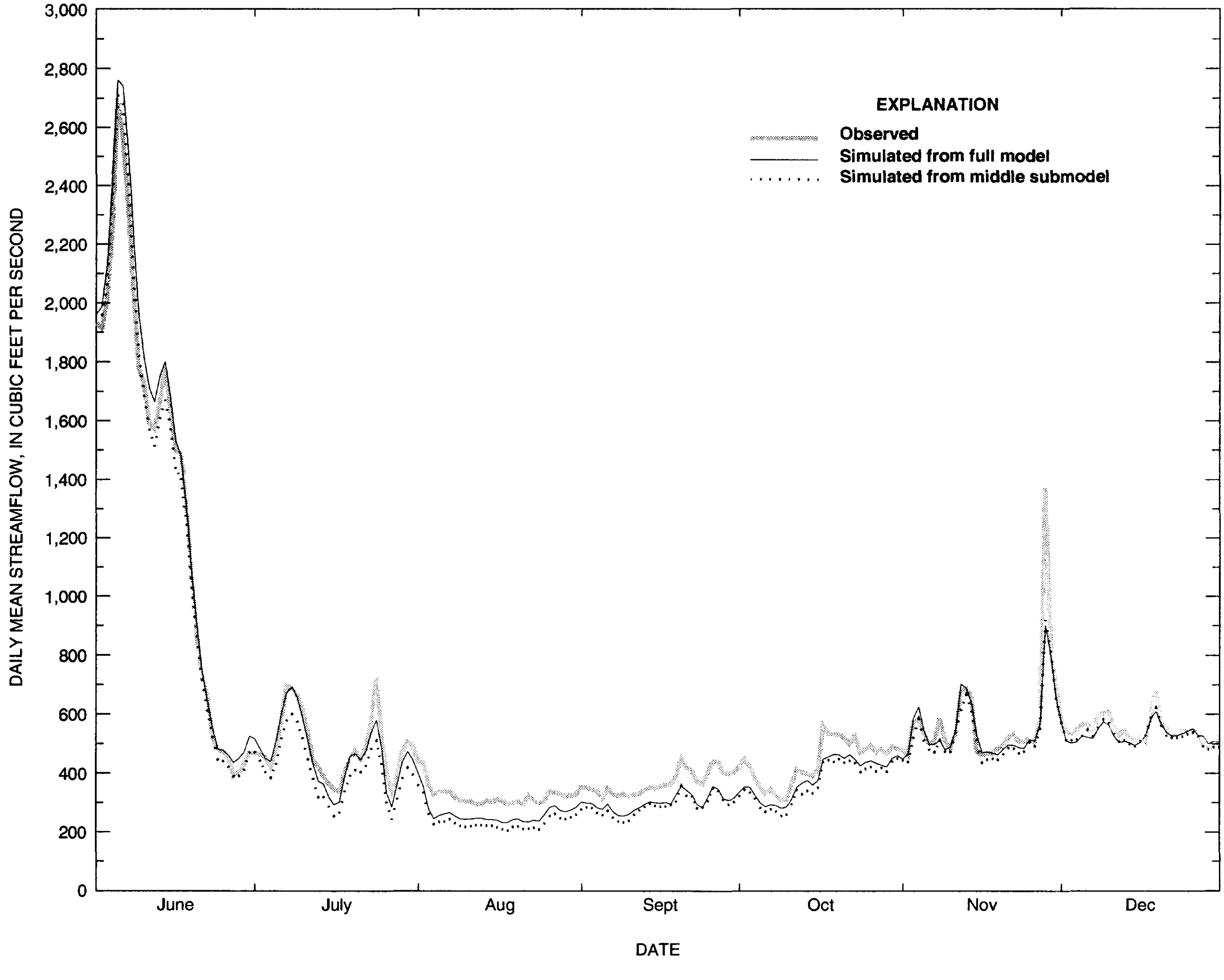


Figure 31. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflows from full model and middle submodel, June 1 through December 31, 1984.

back to the Truckee River. As a result, the full model did not account for Truckee Canal spills, and Truckee River flow therefore is underestimated downstream from Derby Dam during periods of spills. The lower submodel, with upstream inflows defined from records obtained at the gage, Truckee River below Derby Dam near Wadsworth, Nev., also does not account for Truckee Canal spills because the spills enter the river downstream from this gage.

The third example, June through August 1991, not only shows that the flow data may not adequately represent all inflows and outflows, but also shows the complexity in identifying all sources of simulation differences (figs. 33-35). At the Farad gaging station, the model adequately simulated observed Truckee River streamflow (fig. 33). As in the previous example, the full and middle submodels underestimated observed streamflow at the Tracy gaging station (fig. 34). Two likely sources of the underestimation include inaccurate streamflow data, and inaccurate inflow and outflow data. Other sources of the underestimation are likely, but more difficult to identify. Inaccurate streamflow records at the Tracy gaging station during early to middle July were detected by hydrographic comparison with the Vista and Sparks gaging stations. Results of the hydrographic comparison demonstrated that

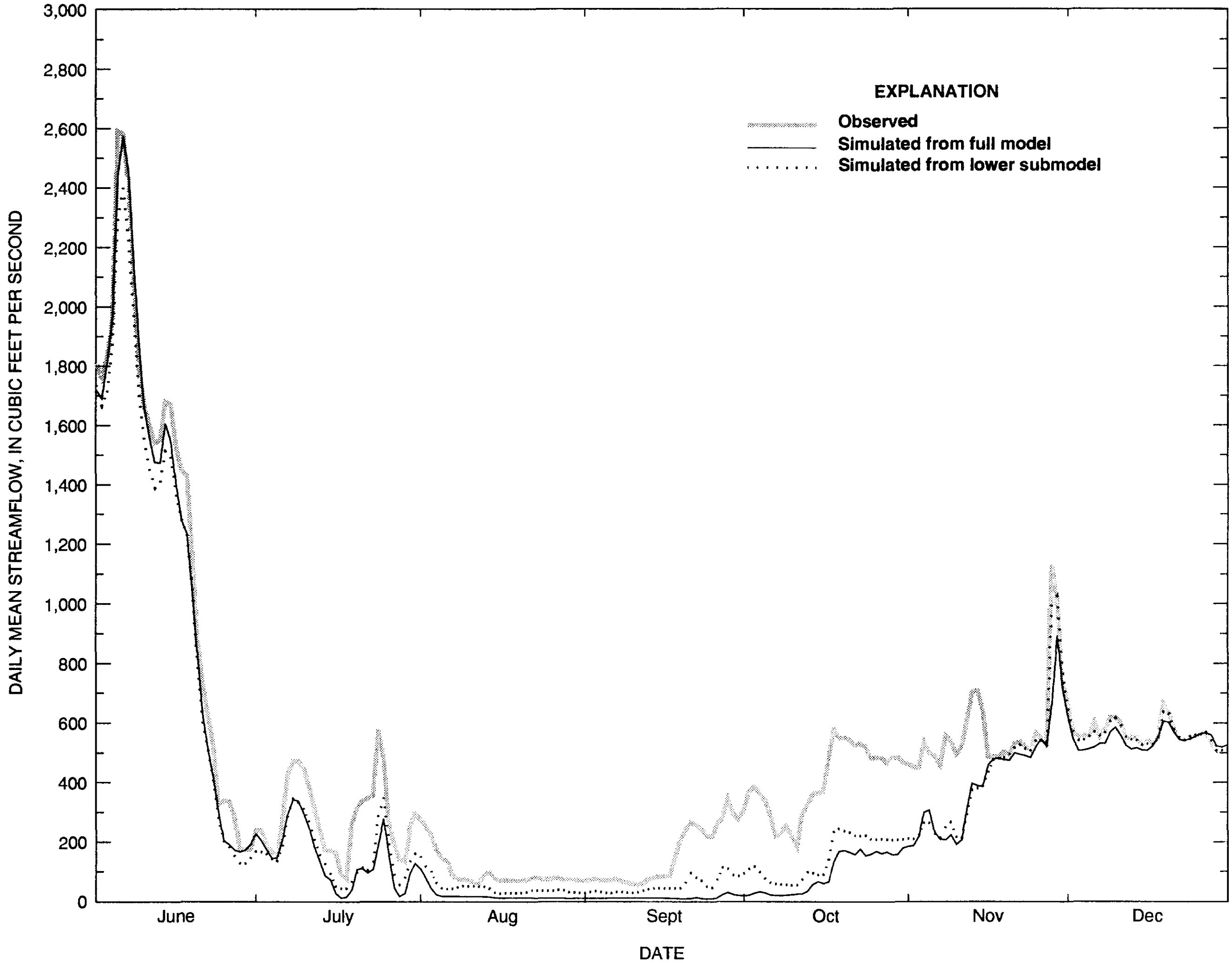


Figure 32. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflows from full model and lower submodel, June 1 through December 31, 1984.

streamflow measured at the Tracy gaging station may have been up to an average of 23 percent or 70 ft^3/s greater than actual streamflow. Although inaccurate data from the Tracy gaging station do not affect the quality of the simulations, they are used to evaluate the simulation accuracy. Thus, the resulting simulation differences are larger during this July period using the inaccurate streamflow data than if streamflow data were more accurate. Inaccurate characterization of inflows during hydrograph peaks on June 28-30 and July 20-22 were likely caused by inflows to the Truckee River from unmeasured sources. Such unmeasured inflows were not represented in the models and resulted in underestimation of observed streamflow. Other likely causes for underestimation are inadequately estimated spills and return flows to the Truckee River and larger flows simulated as permanently diverted from the Truckee River than actually were diverted until August, when many irrigation systems were turned off. At the Nixon gaging station, the simulation differences appear to be a result of complex interactions and combinations of at least three types of inadequate flow

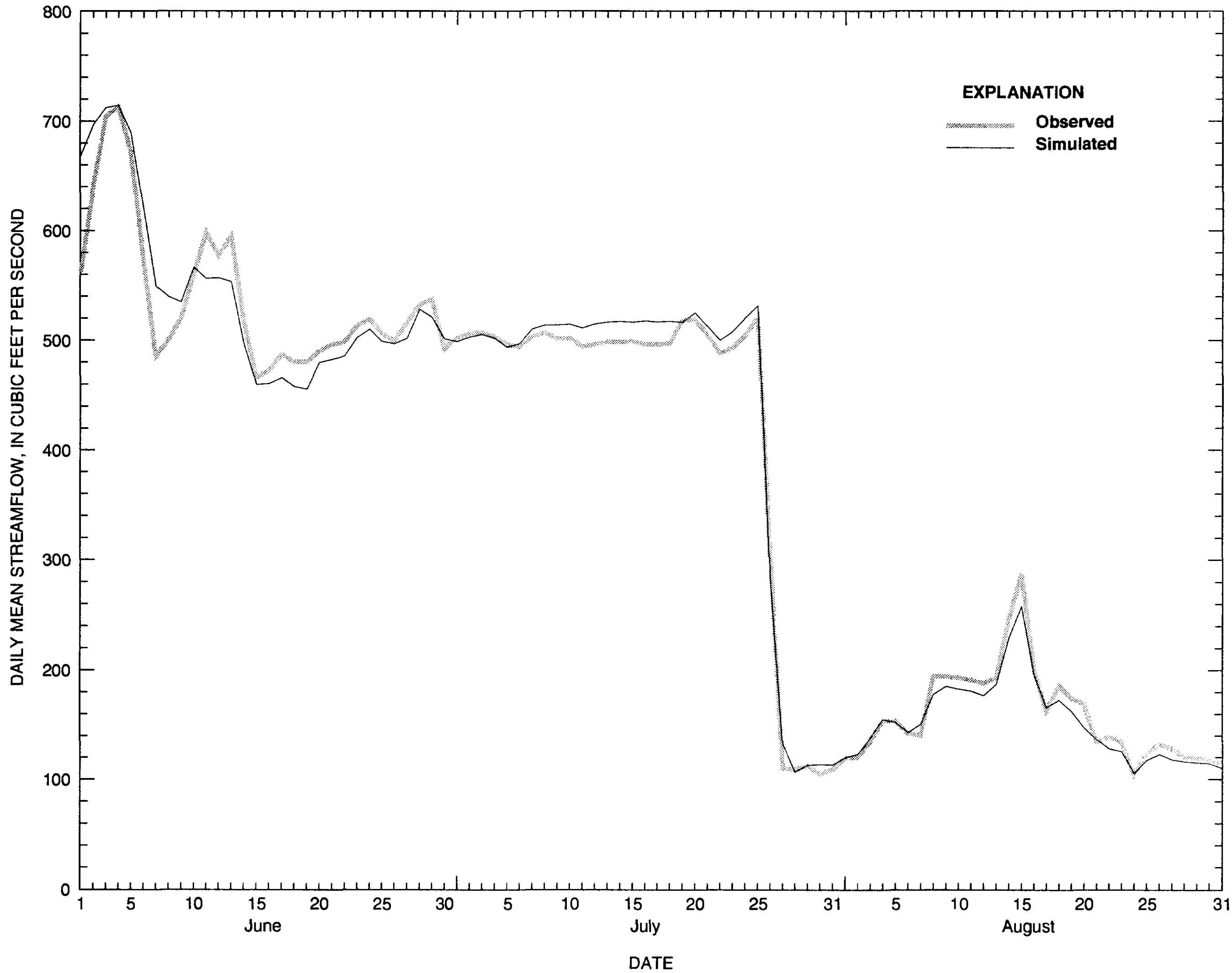


Figure 33. Observed and simulated daily mean streamflows, *Truckee River at Farad, Calif.* (station 10346000). Simulated streamflow from full model and upper submodel, June 1 through August 31, 1991.

estimates, coupled with model uncertainties originating upstream in the full model as previously discussed at the Tracy gaging station (fig. 35). The three types of inadequacies are as follows:

1. Inadequate estimation of unmeasured inflows to the Truckee River, and spills and return flows to the Truckee River from irrigation systems. This may be the explanation for underestimation of observed flow by the full model during June and July. Part of this underestimation originated from reaches in the middle Truckee River subunit, as shown in the hydrographs from the Tracy gaging station (fig. 34).
2. Inadequate estimation of diverted flow to the Truckee Canal. This may be the explanation for the overestimation of flow by the full model during the hydrograph peak in early June and the overestimation of flow by the full model during the hydrograph trough in early July. Note that the hydrograph peak in early June was adequately simulated at the Tracy gaging station (fig. 34).

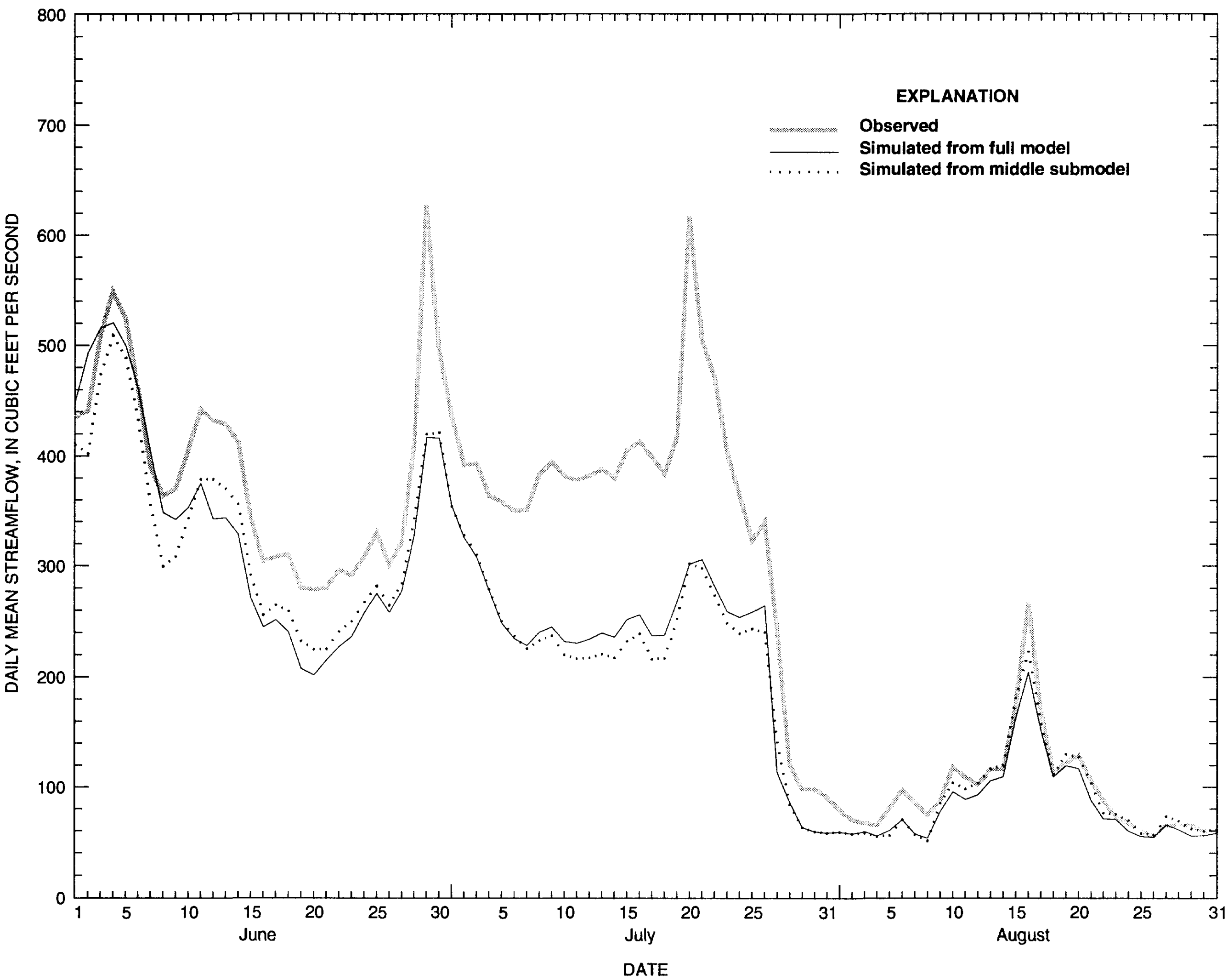


Figure 34. Observed and simulated daily mean streamflows, *Truckee River below Tracy, Nev.* (station 10350400). Simulated streamflows from full model and middle submodel, June 1 through August 31, 1991.

3. Inadequate estimation of ground-water inflows to the Truckee River (as discussed in the section, "Ungaged Ground-Water Inflows"). This may be the cause of the overestimation of flow by the lower submodel throughout the period of study. Additionally, this may be the cause of the positive bias of full and lower submodel simulations for the drought-evaluation period at the Nixon gaging station (tables 6 and 8).

The sources of simulation differences in the previous example probably interact. As a result, isolating and evaluating individual sources of simulation differences is difficult. For example, inadequate ground-water estimation (item 3) probably affects the simulated streamflow from the full model (fig. 35). However, the cause of simulation differences is masked by other inadequate representations of inflows from returns and spills.

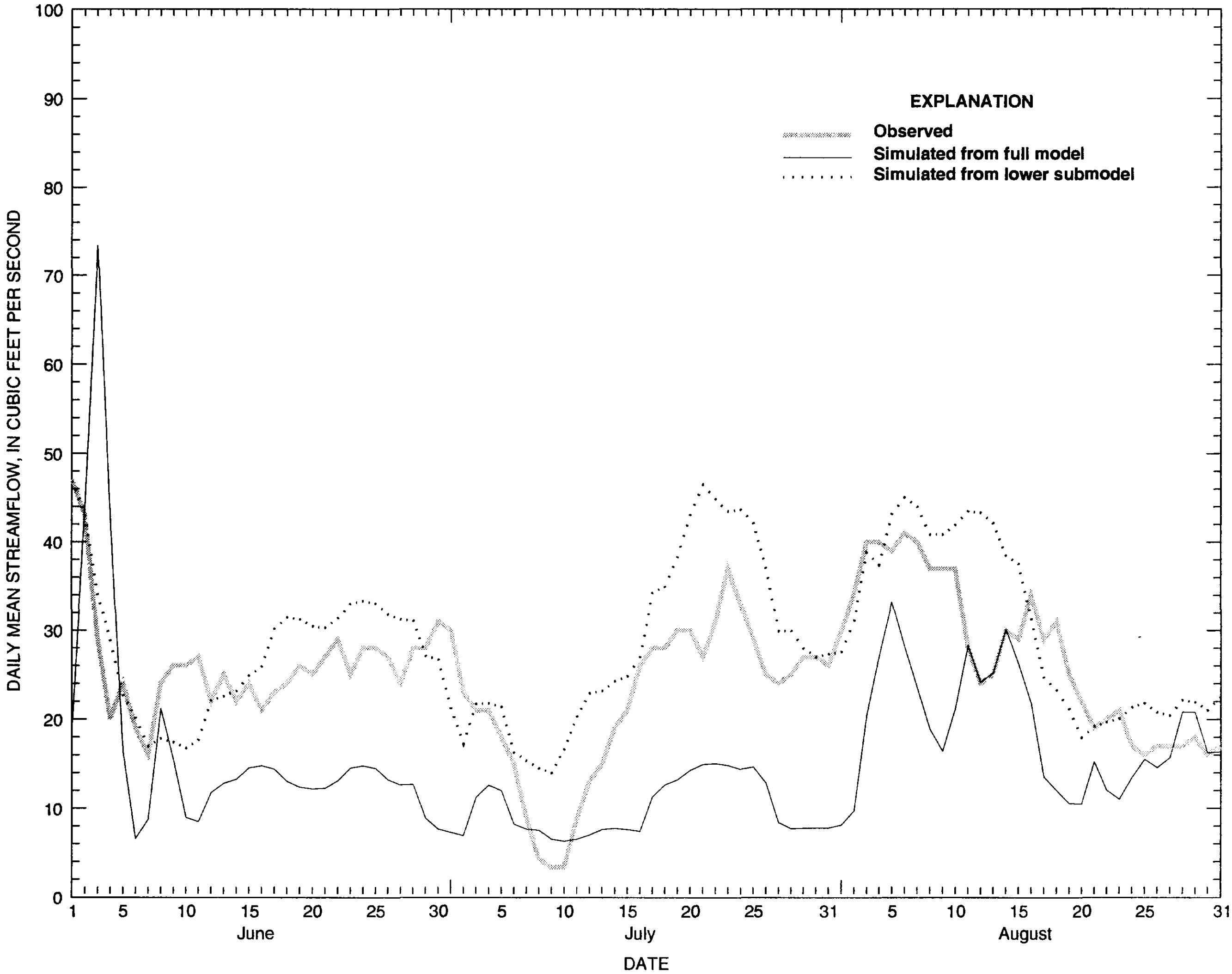


Figure 35. Observed and simulated daily mean streamflows, *Truckee River near Nixon, Nev.* (station 10351700). Simulated streamflows from full model and lower submodel, June 1 through August 31, 1991.

Unavailable Flow Data

Model limitations arise when inflows and outflows are not described by time series and, therefore, cannot be represented in the routing models. The routing model is limited because these undescribed inflows and outflows are not routed downstream. Differences between observed and simulated streamflow result. The magnitude of simulation differences arising from these model limitations is not fully known, but generalizations can be given. The inflows and outflows not described by time series include (1) undocumented spills and returns from ditches, (2) undocumented inflows from ephemeral tributaries, and (3) unaccounted ground-water/surface-water interactions.

Although many ditch spills and returns are either measured or estimated, many minor spills and returns may not have been represented in the model. Truckee River flow is underestimated during periods when flow spills back or returns to the Truckee River from these sources, because more water actually flows into the river than that simulated. The periods of underestimation typically are during the irrigation season. These underestimations are a possible reason for the negative bias of simulation results for the Tracy and Nixon gaging stations for many periods of moderate and low monthly mean streamflow (figs. 10-13).

Inflows to the Truckee River from many small, ungaged tributaries downstream from the gaging station, *Truckee River at Farad, Calif.*, were not described by time series and, therefore, not represented in the model. These small tributaries are generally ephemeral, and accurately estimating their flows is difficult. In the Truckee Meadows, flow from many of the tributaries consists of urban runoff flowing through storm-sewer networks. These inflows are generally in direct response to precipitation. The model would, therefore, underestimate Truckee River streamflow during these precipitation periods. For example, in figure 16, the model underestimates hydrograph peaks on December 21-23, 1982, and March 13, 1983. Both peaks were caused by storms when substantial inflows from ungaged tributaries likely entered the Truckee River. Much of the negative bias of simulation results at the Tracy and Nixon gaging stations, especially at the high and medium flow regimes, probably is caused by undocumented inflows from the ungaged tributaries downstream from the Farad gaging station in the full model and submodels (tables 5 and 7). The negative bias is apparent on the scatterplots (figs. 10-13) for moderate and high flow regimes where the simulated flow is less than the observed flow.

Ground-water discharge to the Truckee River and channel leakage to ground water occurs along various reaches of the Truckee River. Ground-water discharge to the river was crudely estimated downstream from Derby Dam. At all other locations along the river, ground-water/surface-water interactions were not represented in the routing model. Although flow is underestimated in model simulations when actual ground-water inflows are not represented and flow will be overestimated when actual channel leakage is not represented, many of these simulation differences tend to be "masked" by larger simulation differences from other sources. This masking makes quantification of simulation differences difficult.

SUMMARY

The demand for water in the Truckee River Basin, California and Nevada, commonly is greater than can be supplied. Water rights in the basin are fully or over-allocated with respect to average annual runoff volumes, and the surface-water systems cannot meet all demands during years of deficient precipitation. Truckee River water is used to generate power upstream from Reno, for municipal and industrial supply in the Truckee Meadows vicinity, for irrigation inside and outside the Truckee River Basin, for maintaining Pyramid Lake levels, and for providing flows for spawning of an endangered fish species, the cui ui lakesucker, and a threatened species, the Lahontan cutthroat trout. This diversity in interests results in a wide range of alternatives for planning, allocating, and managing the water resources and operating the various reservoirs and diversion systems.

Title II of Public Law (P.L.) 101-618, the Truckee-Carson-Pyramid Lake Water Rights Settlement Act of 1990, provides a framework for developing operating criteria to balance interstate allocation and demands for water rights among the many competing interests that use runoff from the Truckee River. Environmental assessments required by P.L. 101-618 will demand analytical modeling tools for the examination of cause-and-effect impacts of alternative management and operational scenarios connected with

Truckee River operations, water-rights transfers, and changes in irrigation practices. However, the available modeling tools are inadequate to fully address the broad spectrum of water-resources issues in the quantitative detail needed for evaluation of management options for implementing P.L. 101-618.

The U.S. Geological Survey, to support U.S. Department of the Interior implementation of P.L. 101-618, began development of a "modular modeling system," which is a computer model/data-management system that integrates many hydrologic-analysis models into a single tool for water-resource managers. Development of a flow-routing model, based on the hydraulic characteristics of the Truckee River, is the first step toward development of the modular modeling system.

This report describes the construction of a physically based flow-routing model, results of streamflow simulation, the differences between observed and simulated streamflow, and limitations of the model. Streamflow is routed along 114 mi of the mainstem Truckee River from the gaging station just downstream from Lake Tahoe to Marble Bluff Dam, just upstream from Pyramid Lake. Daily streamflow data used for model simulation and evaluation include the period from October 1977 through September 1992.

The computer program used to construct the routing models is known as the Hydrological Simulation Program-FORTRAN. Construction of the models involved collecting and estimating streamflow and hydraulic data, dividing the Truckee River and two tributaries into channel reaches, and determining hydraulic characteristics for each river reach.

Time series of flow data describing inflows and outflows to the Truckee River were required for simulation of streamflow. Additionally, flow data were used for evaluating the accuracy of the streamflow simulations. Observed and estimated flow data were used. Observed flow data generally were computed from gage-height records collected at gaging stations. Many flow data had to be estimated because continuous and accurate time series of tributary, diversion, or return-flow data were not available at all gaging stations, and not all inflows to the Truckee River were gaged. Estimated flow data were of questionable quality; probably not as accurate as observed flow data, but probably introduced less error to the models than would result if these inflows and diversions were ignored. Hydraulic data necessary to determine routing parameters were measured or estimated at 215 cross sections along the Truckee River and two tributaries.

The Truckee River and two tributaries were divided into 47 reaches, each with fairly uniform hydraulic characteristics. Reaches had an average length of 2.5 mi and ranged in length from 1.1 to 3.7 mi. To represent the hydraulic characteristics of each reach, volume-discharge relations determined from the collected hydraulic data were defined in function tables (F-tables) of the model.

The period from October 1, 1977, to September 30, 1992, was selected for model simulation. Differences between Truckee River streamflow simulated by the models and streamflow data collected at gaging stations were evaluated for two periods: (1) the full simulation period listed above (called the entire evaluation period) and (2) the part of the full period from October 1, 1987, to September 30, 1992 (called the drought-evaluation period). Channel reaches were combined to form three submodels (called the upper, middle, and lower submodels), encompassing three distinct segments of the Truckee River mainstem, and one full model, encompassing the 114-mi length of the Truckee River mainstem. The full model is a combination of the three submodels.

After the daily flow-routing models were constructed, they were tested by first simulating Truckee River streamflow and then evaluating how closely the simulated streamflow matched observed streamflow at gaging stations along the Truckee River. For this report, simulation results were reported using observed streamflow data at three gaging stations: *Truckee River at Farad, Calif.*, *Truckee River below Tracy, Nev.*, and *Truckee River near Nixon, Nev.* These gaging stations are the closest ones to the downstream boundary of each of the three subunits of the river. Statistical measures of differences between observed and simulated annual mean, monthly mean, and daily mean streamflow are presented. Bias of simulated annual mean streamflow ranges from -12.9 to 2.0 percent for the full model and from -7.4 to 2.0 percent for the submodels over the entire evaluation period, and ranges from -0.9 to 16.5 percent for the full model and from -5.8 to 4.4 percent for the submodels over the drought-evaluation period. Percent biases of simulated annual mean streamflow are within the reported accuracy of all the gaging stations except for the full model at the Nixon gaging station.

Mean absolute errors between observed and simulated monthly mean streamflow range from 4.7 to 36.0 percent for the full model and 4.7 to 11.9 percent for the submodels over the entire evaluation period. Bias ranges from 3.1 to -14.4 percent for the full model and 3.1 to -9.0 percent for the submodels. Defined as percentages, mean absolute errors were larger for the drought-evaluation period, but when defined as average values, mean absolute errors were smaller. As expected for low streamflow during the drought-evaluation period, the magnitude of all average flow values was smaller for the statistical measures of difference.

Most measures of difference were larger for daily mean streamflow than for monthly mean streamflow. Mean absolute errors for the daily mean streamflow range from 6.2 to 46.0 percent for the full model during the entire evaluation period and from 6.2 to 17.3 percent for the submodels. Bias ranges from -12.5 to 3.5 percent for the full model and from -8.6 to 3.5 percent for the submodels during the entire evaluation period. Measures of difference between observed and simulated streamflow, as percentages, were commonly greater for the drought-evaluation period than for the entire evaluation period. At the Nixon gaging station, for example, percentage bias increases from -12.5 percent for the entire evaluation period to 22.3 percent for the drought-evaluation period. However, in average values of flow, bias decreases from -74.3 cubic feet per second for the entire evaluation period to 7.0 cubic feet per second for the drought-evaluation period.

Simulation results showed that the routing models simulated streamflow reasonably well. Differences between observed and simulated streamflow commonly increased as the models tried to capture more detail, from monthly to daily means. Percent differences were greatest when they were evaluated at the gaging station farthest downstream, *Truckee River near Nixon, Nev.*, for both the full and lower submodels. At that station, percent differences between simulated flow from the full model and observed streamflow exceeded the percent differences from the lower submodel. Bias of monthly mean streamflow, as average values in cubic feet per second and as percent values, is greatest for simulated streamflow from the full model evaluated at the Nixon gaging station for the entire evaluation period. These bias measures, in addition to information on scatterplots, indicate that monthly mean streamflow simulated in the full model and submodels is underestimated at the Tracy and Nixon gaging stations and slightly overestimated at the Farad gaging station for the entire evaluation period.

Most of the differences between observed and simulated streamflow result from inadequate inflow and outflow data rather than from inadequate data characterizing the hydraulic properties of the Truckee River. Differences between observed and simulated streamflow originate at points along the Truckee River where inflows or outflows are not adequately described by the time series provided to the models. These differences may accumulate or compensate each other as streamflow is routed downstream, creating model uncertainties. These uncertainties are greater for the full model than for the submodels that represent shorter lengths of the river. Model uncertainties increase for the full model downstream from Derby Dam, especially when a large amount of water is diverted to the Truckee Canal. Differences between observed and simulated streamflow at the Nixon gaging station also are greater for the full model than lower submodel because of such uncertainties.

Model accuracy was limited by inadequate inflow and outflow data (1) at locations where (and for periods when) data provided to the model were inaccurate or (2) where data were not available. The routing model, therefore, is limited because it cannot simulate inflows and outflows without accurate, detailed input data. Data are lacking for (1) undocumented spills and returns from ditches, (2) undocumented inflows from ephemeral tributaries downstream from the Farad gaging station, and (3) unaccounted ground-water/surface-water interactions.

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Appendix

Appendix. Name, size, and description of files used in daily flow-routing 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 (Lumb and others, 1990)
fin.truckeeroute.wdm	2,621,440	binary file created by ANNIE which contains input and output data sets
fin.fullmodel.uci	86,283	UCI file for full model
fin.upper.submodel.uci	26,389	UCI file for upper submodel
fin.middle.submodel.uci	39,455	UCI file for middle submodel
fin.lower.submodel.uci	24,988	UCI file for lower submodel

[1] For more information, contact Public Information Assistant: phone (702) 887-7649; email mfogle@dnvcr1.wr.usgs.gov. The model and data base are available in several media, including disk and computer access.