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

Rec'd 11/2/99

River-Operations Model for Upper Carson River Basin, California and Nevada

Water-Resources Investigations Report 98-4240

USGS
science for a changing world

COVER PHOTOGRAPH. Carson River and Vivian Mill in the deep canyon east of Carson City, Nev., 1876. Photograph by C.E. Watkins, San Francisco, Calif. Courtesy of Nevada State Museum, Carson City, Nevada.

River-Operations Model for Upper Carson River Basin, California and Nevada

By Glen W. Hess *and* R. Lynn Taylor

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 98-4240

Carson City, Nevada
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

For additional information contact:

District Chief
U.S. Geological Survey
333 West Nye Lane, Room 203
Carson City, NV 89706-0866

email: usgsinfo_nv@usgs.gov

http://nevada.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre foot per acre (acre-ft/acre)	0.3048	cubic meter per 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
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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.

NOTICE

The customized software application and supporting materials (data and documentation) presented herein are made available by the U.S. Geological Survey (USGS) to be used in the public interest and for the advancement of science. The authors, USGS, or the United States Government assume no liability for the contents or the use thereof. This documentation does not constitute a standard, specification, or regulation.

River-Operations Model for Upper Carson River Basin, California and Nevada

By Glen W. Hess and R. Lynn Taylor

Abstract

The Truckee-Carson Program of the U.S. Geological Survey, to support U.S. Department of Interior implementation of Public Law 101-618, is developing a modeling system to support efficient water-resources planning, management, and allocation. The operations model documented herein is a part of a modeling system that includes a data base management program, a graphical user interface program, and a program with modules which simulate river/reservoir operations and a variety of hydrologic processes. A physically based operations model using Hydrological Simulation Program - FORTRAN was constructed. This model simulates streamflow and diversions in the Carson River at daily time intervals. A description of the operational practices in the upper Carson River is given to provide an insight into how the river is operated. The Alpine Decree, which adjudicates the surface-water rights of the Carson River, separates the Carson River Basin into eight segments. Each segment is operated autonomously with respect to diversions.

The construction of each segment model included modules with flow routing and operational (diversions and return flows) functions. The flow-routing module characterizes the movement of water into and through the reaches of the drainage network. The operations module simulates the manmade regulation of water movement within and out of the drainage network. The previously developed flow-routing module uses hydraulic characteristics for 48 stream reaches from the gaging stations *East Fork Carson River near Markleeville, Calif.*, and *West Fork Carson River at Woodfords, Calif.*, downstream to the gaging station *Carson River near Fort Churchill, Nev.* The operations model requires the operations module for the Carson River to be run with the flow-routing module that was previously developed.

Most data used to simulate operations of the upper Carson River are based on Alpine Decree irrigated acreage and water duties, Price Decree water rights, and off-river storage rights. A general description of logic governing the simulation of river diversions along the upper Carson River is discussed. Many simplifying assumptions are required and are provided to guide user application of the model and interpretation of the results. The U.S. Geological Survey upper Carson River Basin operations model was designed to provide simulations which allow comparison of the effects of alternative management practices, alternative allocations on streamflow, and alternative reservoir storages over time. This operations model is not intended to reproduce historical streamflow or reservoir-storage values.

Observed streamflow data from three gaging stations were compared with simulated data to determine whether the model could reliably predict conditions throughout the Carson River. These three sites are *East Fork Carson River near Gardnerville, Nev.*; *Carson River near Carson City*, Nev.; and *Carson River near Fort Churchill, Nev.* Graphical comparisons of observed and simulated streamflow traces are similar for the years 1978-95. These comparisons between observed and simulated streamflows indicated that the differences were mostly due to (1) inadequate simulation of ground-water outflows from the ground-water reservoir in Carson Valley during the autumn of dry years, and (2) undersimulation of tributary inflows in the spring during high-flow years.

Suggested improvements that could be made to the flow-routing and operational models include (1) additional information describing various hydrologic components, (2) more accurate estimates of the ground-water interaction with surface-water flows, (3) more accurate representation of return flows, and (4) additional tributary streamflow data. Some applications are described to illustrate use of the operations model for the upper Carson River to simulate complex river diversions. These applications include (1) varying the type of land use, (2) varying the amount of treated effluent, (3) varying the volume of storage rights, and (4) varying the amount of return flows.

INTRODUCTION

The Carson River, shared between California and Nevada (fig. 1), was involved in one of the longest water-rights cases in the Nation. This law suit lasted 55 years and led to the Alpine Decree and Alpine Decree Opinion (U.S. District Court, 1980a,b). The Alpine Decree adjudicates the surface-water rights for the Carson River. Water from the Carson River serves a variety of important economic and environmental needs within the Carson River Basin. These uses are agricultural irrigation and sufficient water to maintain wildlife refuge habitats in the lower part of the basin. Other uses include electrical power generation, recreation, and municipal and industrial (M&I) demands. The diversity of these competing interests creates a challenge in selecting alternatives for planning, allocating, and managing water resources and for operating various reservoir and diversion systems.

The Truckee River, also shared between California and Nevada, has had a similar history of public controversy over water-rights distribution. Negotiations among various interest groups finally coalesced in 1935 in the form of the Truckee River Agreement. This agreement established the basis for operation of the Truckee River. The Truckee River Agreement became an important element in a 1944 Federal court decree, informally known as the Orr Ditch Decree (U.S. District Court, 1944).

The Truckee–Carson–Pyramid Lake Water Rights Settlement Act (U.S. Congress, 1990), Public Law (P.L.)101-618, was legislated to allocate water between California and Nevada in the approximately 7,000-mi^2 Truckee and Carson River Basins and to develop effective operating criteria. These criteria are being developed using existing decrees, such as the Alpine Decree and Orr Ditch Decree, and new criteria based on negotiations between interested parties within the Truckee and Carson River Basins.

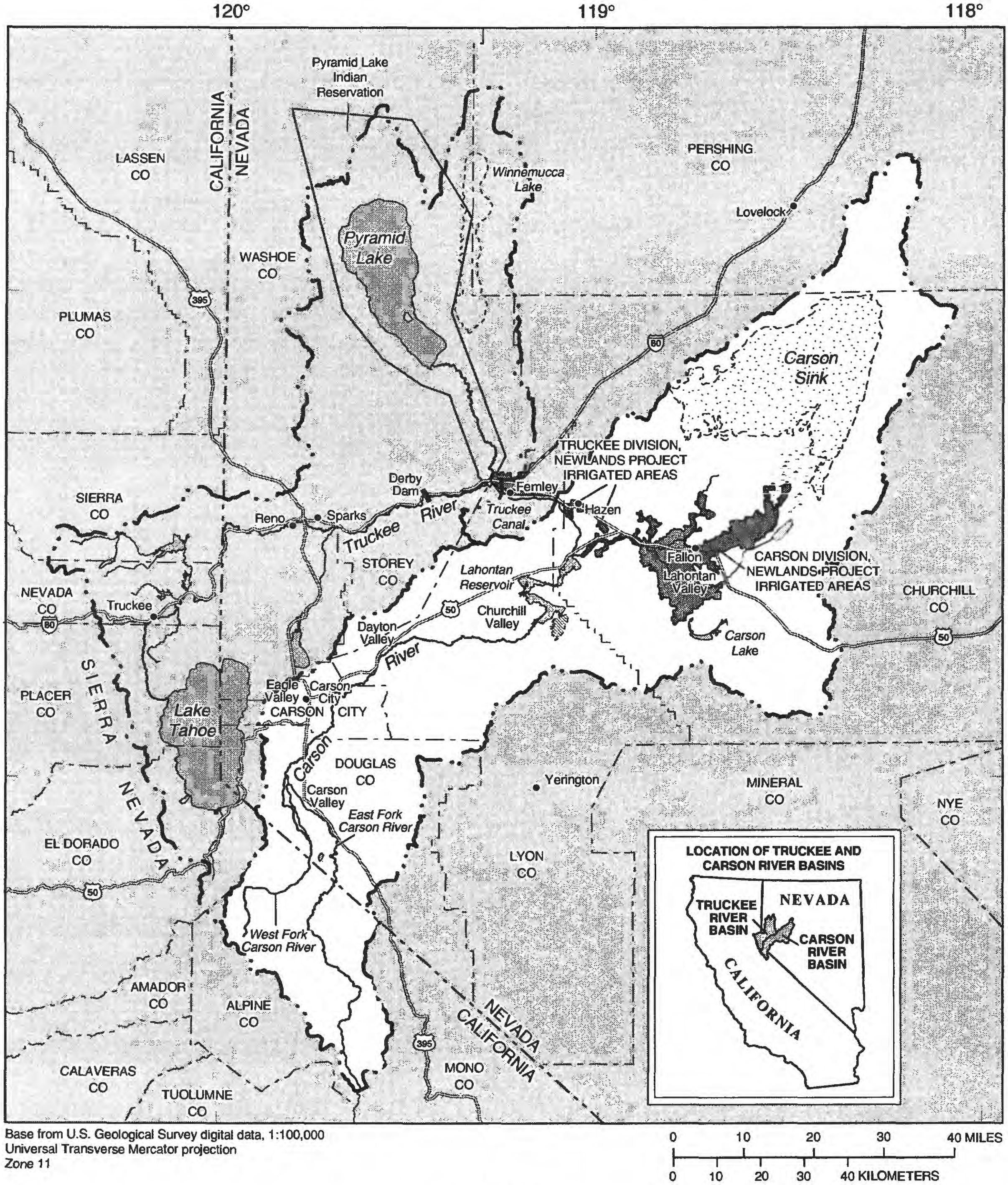
The Truckee–Carson Program of the U.S. Geological Survey

The Truckee–Carson Program of the U.S. Geological Survey (USGS) was established by the U.S. Department of the Interior to support implementation of P.L. 101-618 by (1) compiling records from a network of multiagency gaging stations to develop a consistent long-term data base that provides reliable data in support of modeling activities in the Truckee River and Carson River Basins, (2) establishing new streamflow and water-quality gaging stations for more complete water-resources information and more consistent support of river operations, and (3) developing a modeling system to support efficient water-resources planning, management, and allocation. Many of the planning, management, or environmental-assessment requirements of P.L. 101-618 need a detailed understanding of the hydrologic system. Existing data networks and interbasin modeling tools do not provide enough quantitative detail to address the broad spectrum of water-resources issues in the Truckee River and Carson River Basins for P.L. 101-618, particularly for documenting the short- and long-term variability in water supply in these basins. An interbasin-computer model that is physically based and is capable of simulating flow at a daily time interval would facilitate development of alternatives for water management, such as allocation of streamflow and maintenance of instream water-quality standards. Activities of this interbasin-computer model, either completed or underway by the USGS Truckee–Carson Program, include the following components:

- Flow-routing models of the Truckee River (Berris, 1996) and upper Carson River (upstream from Lahontan Reservoir; Hess, 1996), major tributaries, lakes/reservoirs, and the Truckee Canal.
- Precipitation-runoff models for the headwater source areas of both basins.
- Stream temperature and dissolved-solids models of the Truckee River (Taylor, 1998).
- Operation models for both basins to simulate lake/reservoir and river operations, including the Truckee Canal.

Purpose and Scope

The purpose of this report is to (1) briefly describe operational practices of the upper Carson River; (2) describe the modeling system; (3) document the construction of the daily operations model for the upper Carson River including flow-routing model, data used to simulate operations, and the operational logic and assumptions; and (4) discuss selected applications of the operations model.



EXPLANATION

Hydrographic boundary

Figure 1. Hydrologic features of the Carson and Truckee River Basins and adjacent areas, California and Nevada.

Operations governing streamflow were simulated using inflow data for water years 1978-95 (October 1, 1977, through September 30, 1995). The geographic boundaries (figs. 2*A-I*) for the model extend from operations on the *East Fork Carson River near Markleeville, Calif.*, and *West Fork Carson River at Woodfords, Calif.* (fig. 2*B*), to operations on the *Carson River near Fort Churchill, Nev.* (fig. 2*H*). These geographic boundaries are used to define the term "upper Carson River" as used in this report. The upper Carson River Basin operations model consists of five separate models that correspond to Alpine Decree segments 1, 2, 4 and 5, 6, and 7 (fig. 2*A*). Operations within segment 3 (upstream from the gage at West Fork at Woodfords) were considered insignificant and, therefore, were not modeled in this study. Segment 8 (the area downstream from Lahontan Reservoir) was not modeled because operations are extremely complex.

A daily operations model was developed to simulate streamflow and reservoir and river operations for the upper Carson River Basin. This model was constructed within a larger *modeling system* which includes a data base management program, a graphical user interface, and a program which simulates reservoir/river operations and a variety of hydrologic processes (Hydrological Simulation Program-FORTRAN (HSPF), Bicknell and others, 1997).

The upper Carson River Basin operations model was designed to provide simulations which allow comparison of the effects of alternative management practices, alternative allocations on streamflow, and alternative reservoir storages over time. This operations model is not intended to reproduce historical streamflow or reservoir-storage values. Thus, a traditional calibration with statistical comparisons of observed and simulated values is not considered appropriate with this operations model and data base. The reasons relate to the human element and flexibility in how operations are implemented in the upper Carson River Basin as well as the inadequacy of the model and input data to simulate all of the details and system interactions which characterize operations.

The rules governing operations for the upper Carson River are complex and unique. A general overview of upper Carson River daily operations is provided in this report. Supplemental documentation to this report, which consists of detailed flowcharts and operations model code, contains extensive internal documentation (see Appendix for file names and descriptions). The flowcharts provide a diagrammatic representation of the logical sequence of the code. The operations model code contains the detailed information on the logic used to simulate reservoir/river operations. A listing of variable names and definitions also is available to assist users of either the flowcharts or model code.[1]

These various forms of documentation should be used as follows depending on the level of understanding desired. This report should be used to get a broad overview of upper Carson River operations and the general way in which these operations are represented in the operations model. This report does not provide comprehensive information about how upper Carson River operations are coded in the operations model. The flowcharts should be reviewed by individuals in need of more detailed information about how upper Carson River operations are characterized by this model. Individuals who wish to examine the model code should use the flowcharts to become familiar with the code logic. These individuals should be familiar with upper Carson River operations and the modeling system used by the upper Carson River Basin operations model. The listing of variables should be obtained if the flowcharts or model code are going to be reviewed or modified.

Previous Investigations

Horton (1996a,b) compiled a pre-20th Century and 20th Century chronological history of the Carson River and related water issues. The significant judicial decisions and streamflow events are discussed back to the time before settlement of the area in the 1800's.

Two uncalibrated models of the Truckee River and Carson River Basins, the Bureau of Reclamation (BOR) Model and the Negotiations Model, simulated streamflow at monthly intervals using mass-budget accounting (Cobb and others, 1990), as opposed to flow routing that is physically based. The BOR and

[1]Paper copies of the flowcharts, model code, and variable listing are not included in this report due to their lengthy and technically complex nature. Interested readers can contact the Public Information Assistant at (775) 887-7649 or email request to <usgsinfo_nv@usgs.gov> to obtain information on how to procure electronic copies of the flowcharts, model code, and variable listing.

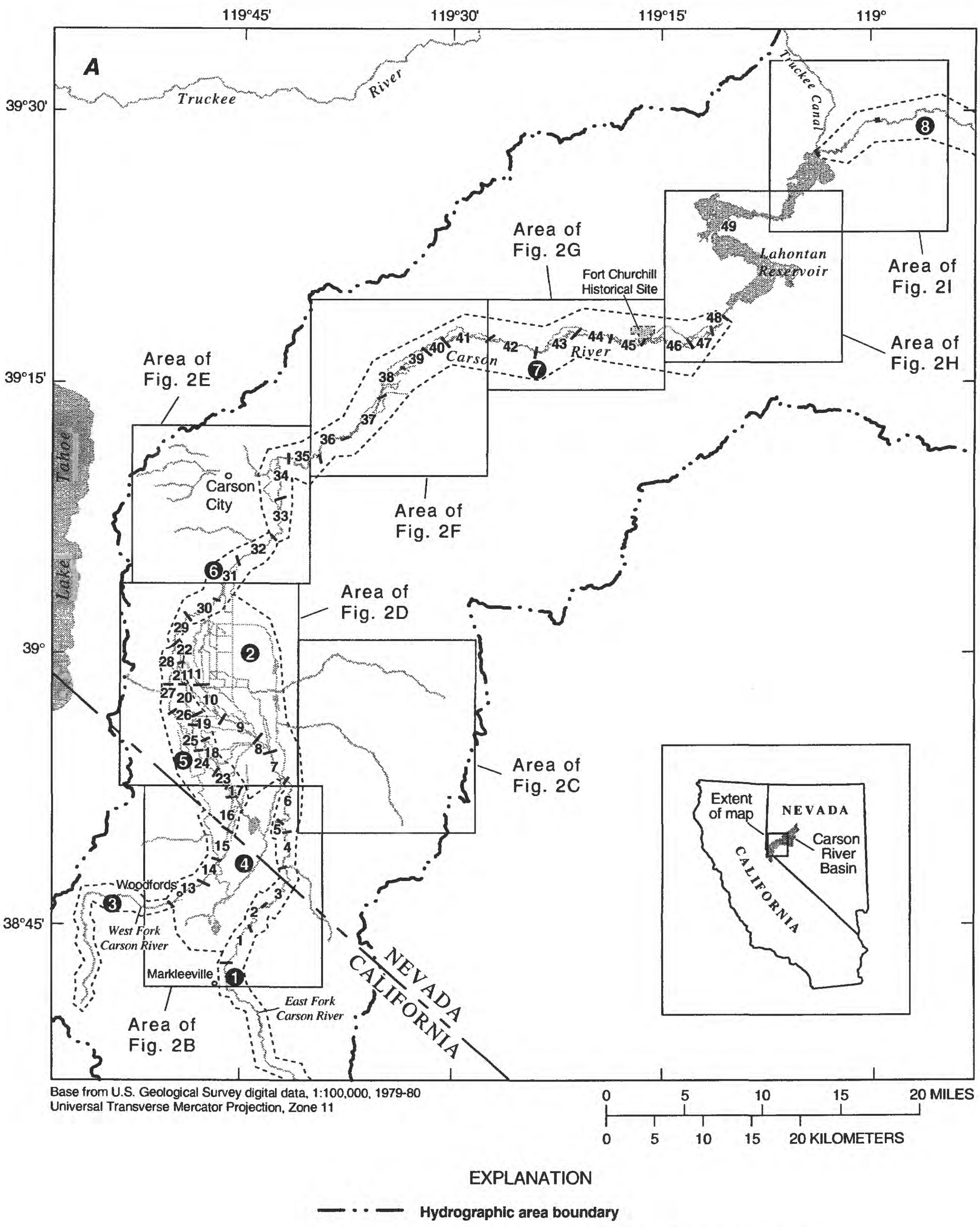


Figure 2. (*A-I*) Hydrologic features, data-collection network, and reaches of the Carson River Basin, California and Nevada.

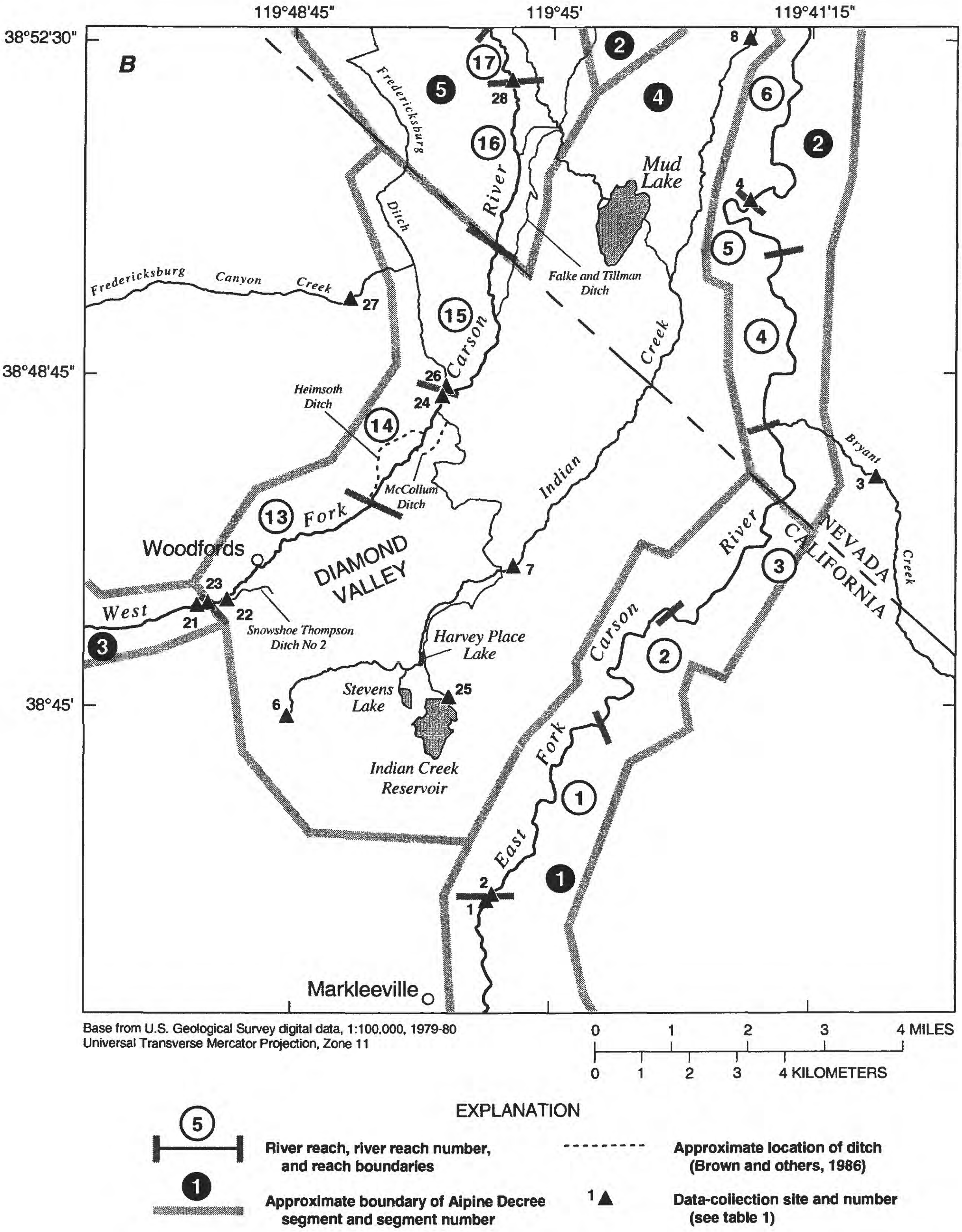


Figure 2. Continued.

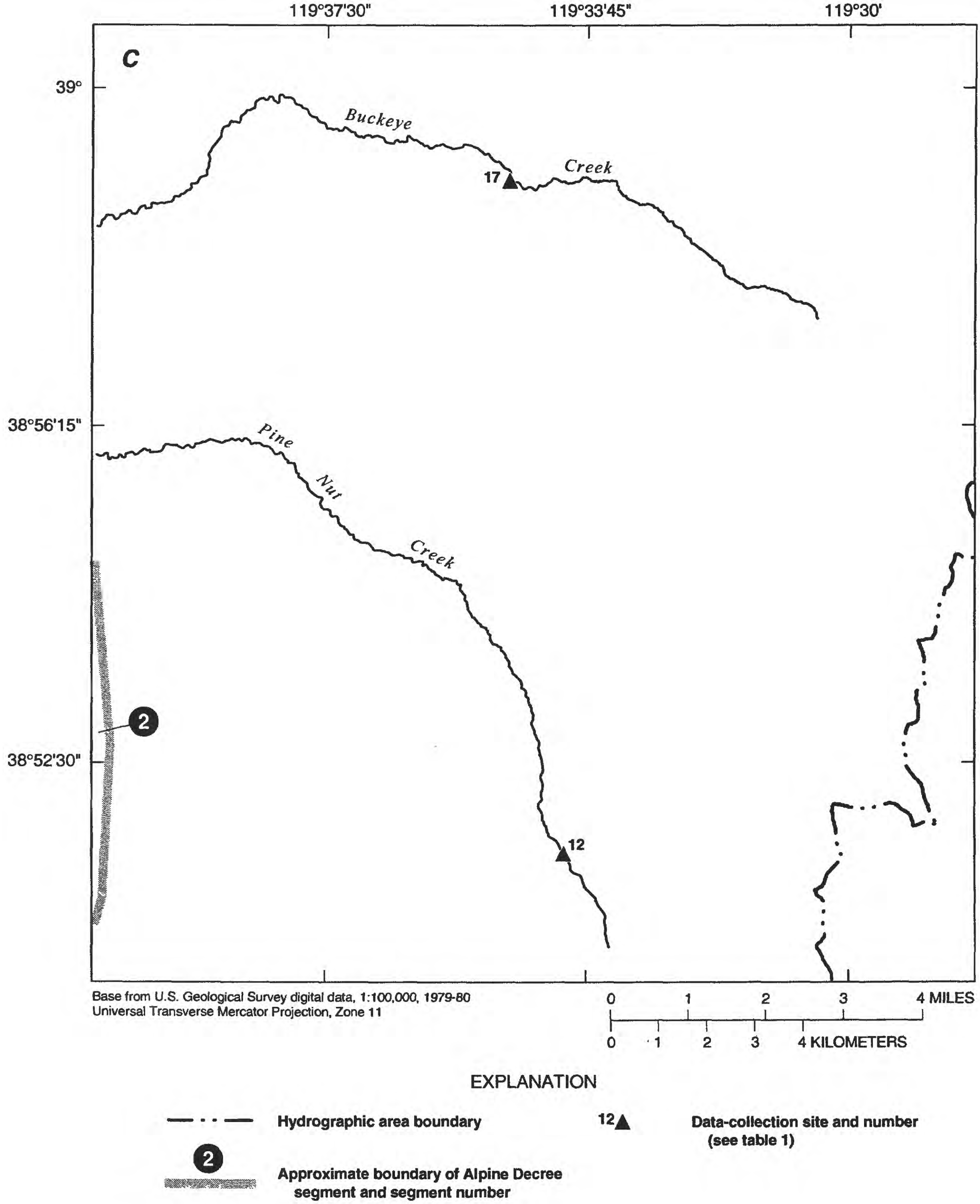


Figure 2. Continued.

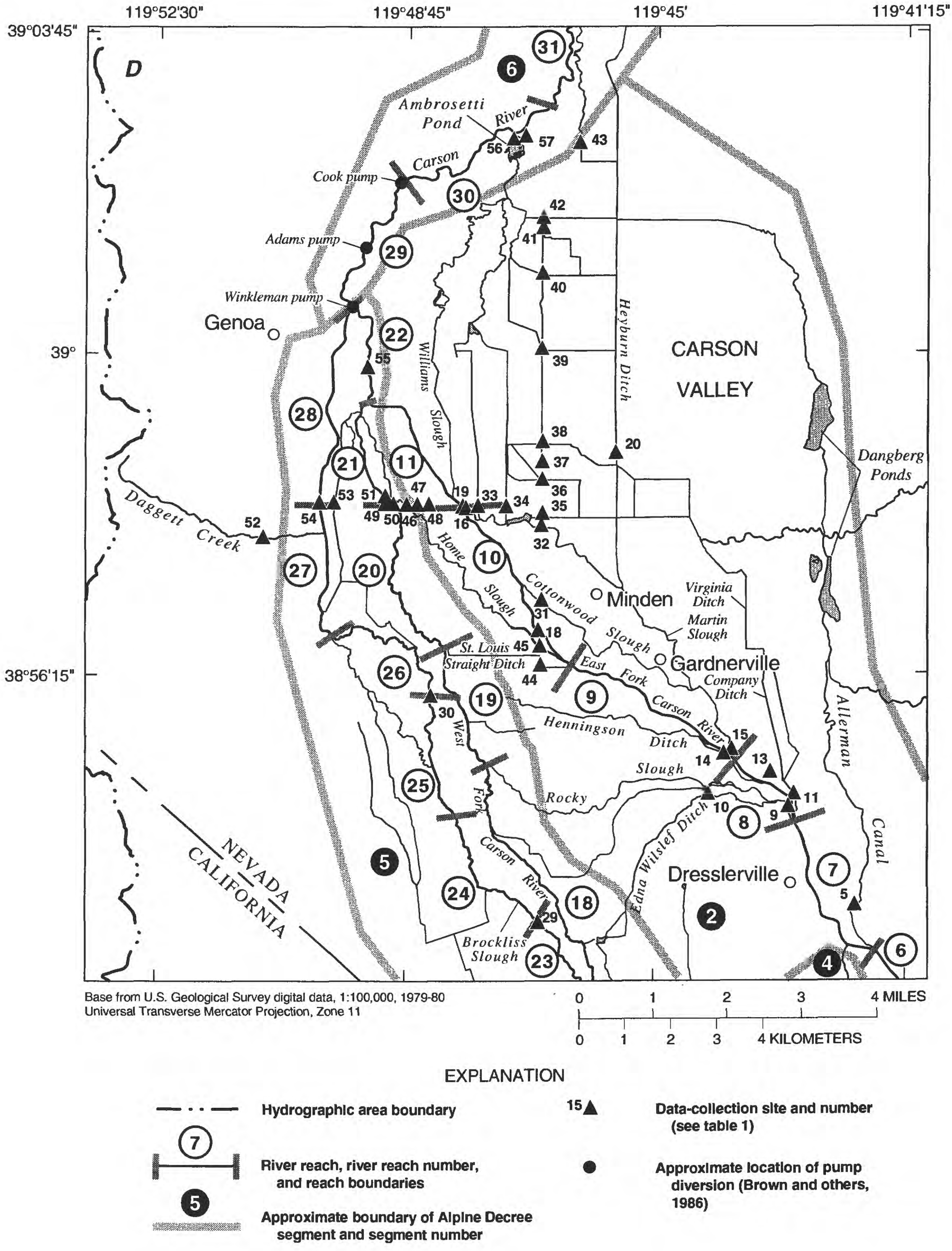


Figure 2. Continued.

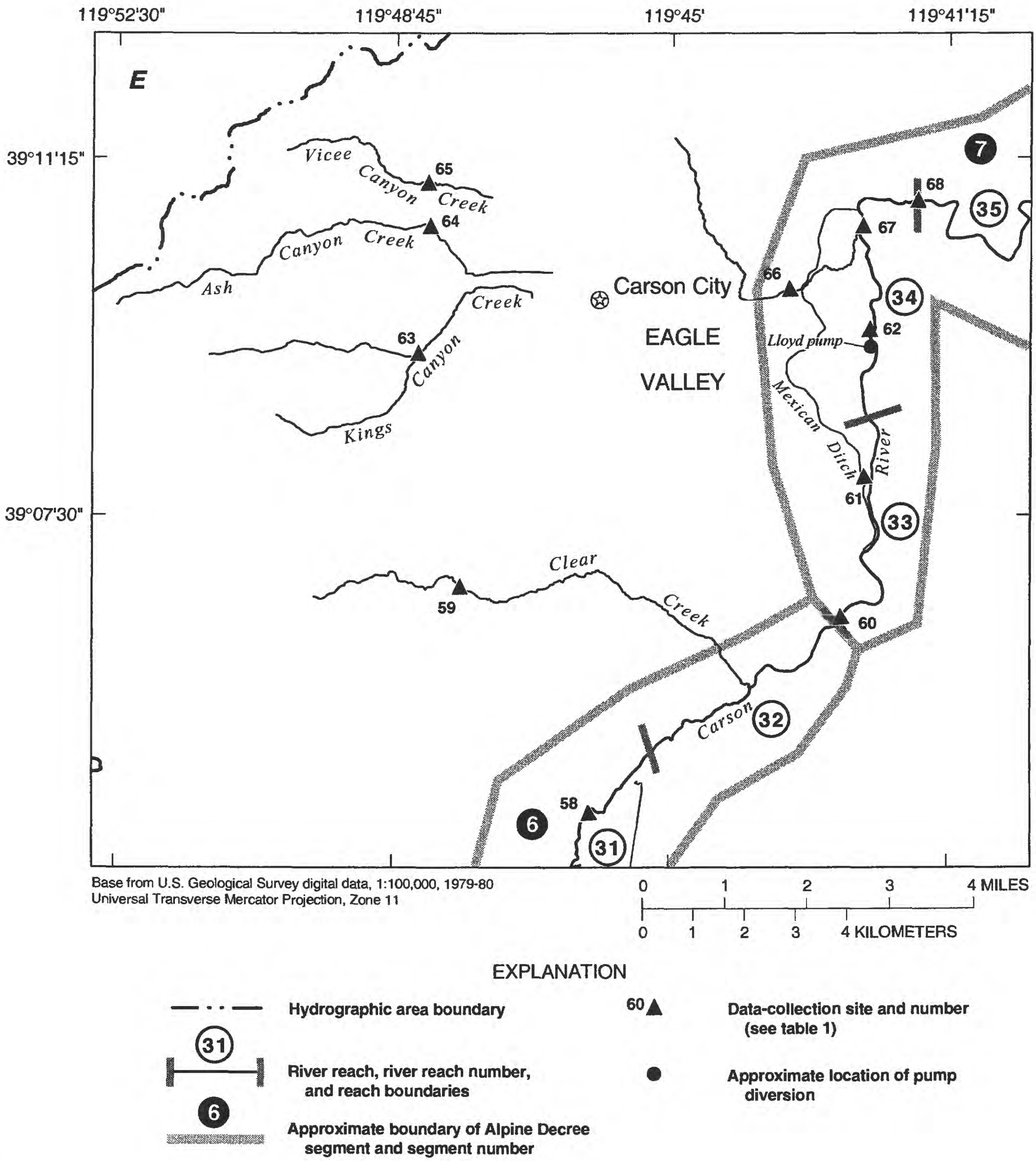


Figure 2. Continued.

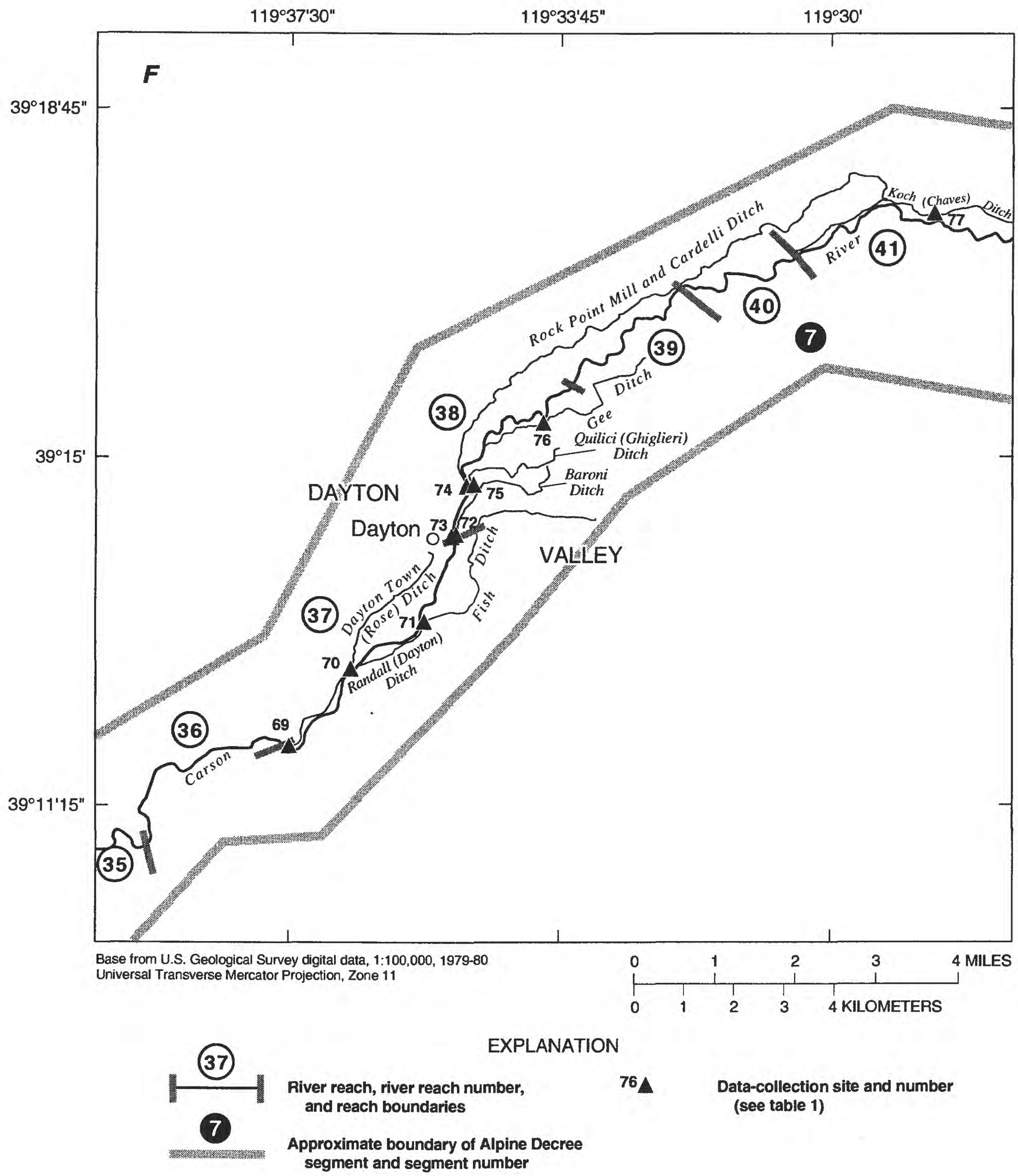


Figure 2. Continued.

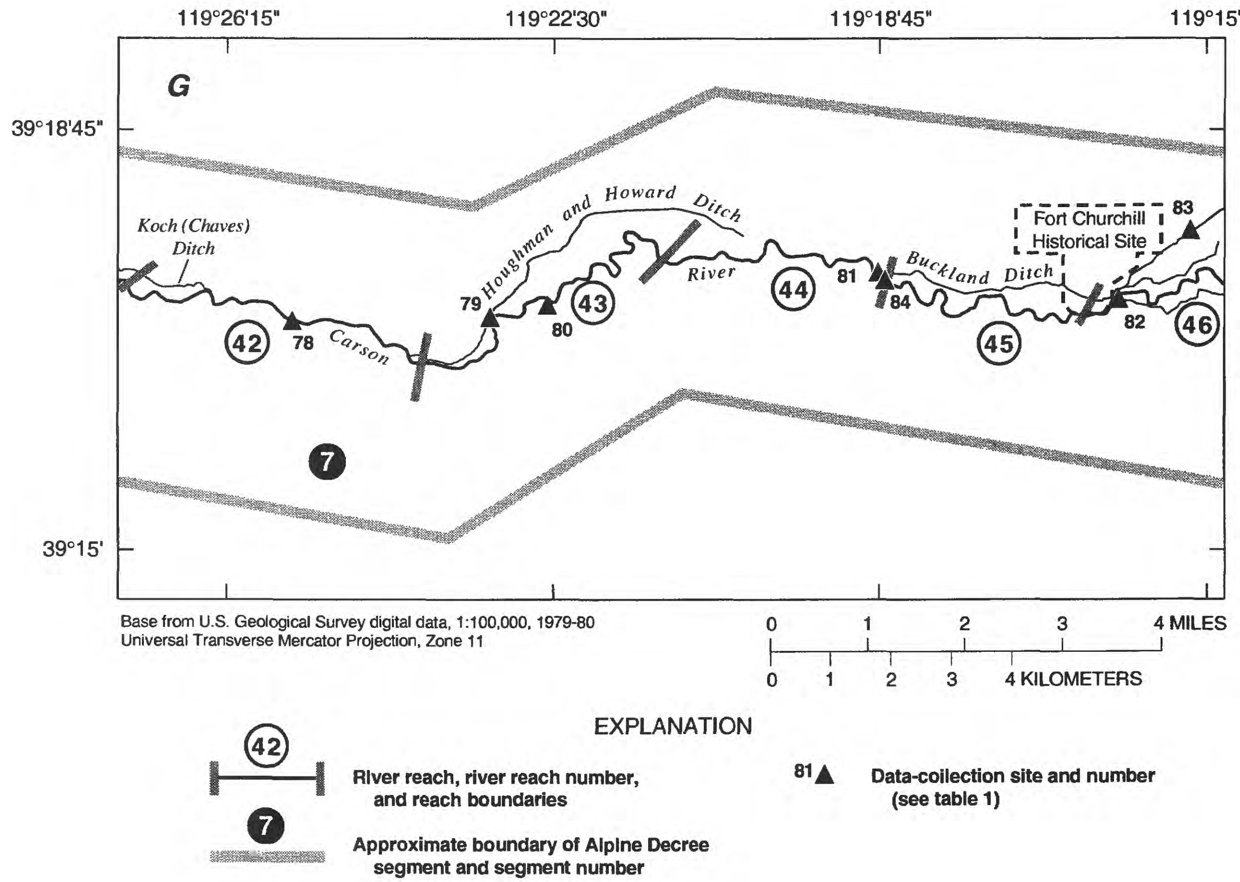


Figure 2. Continued.

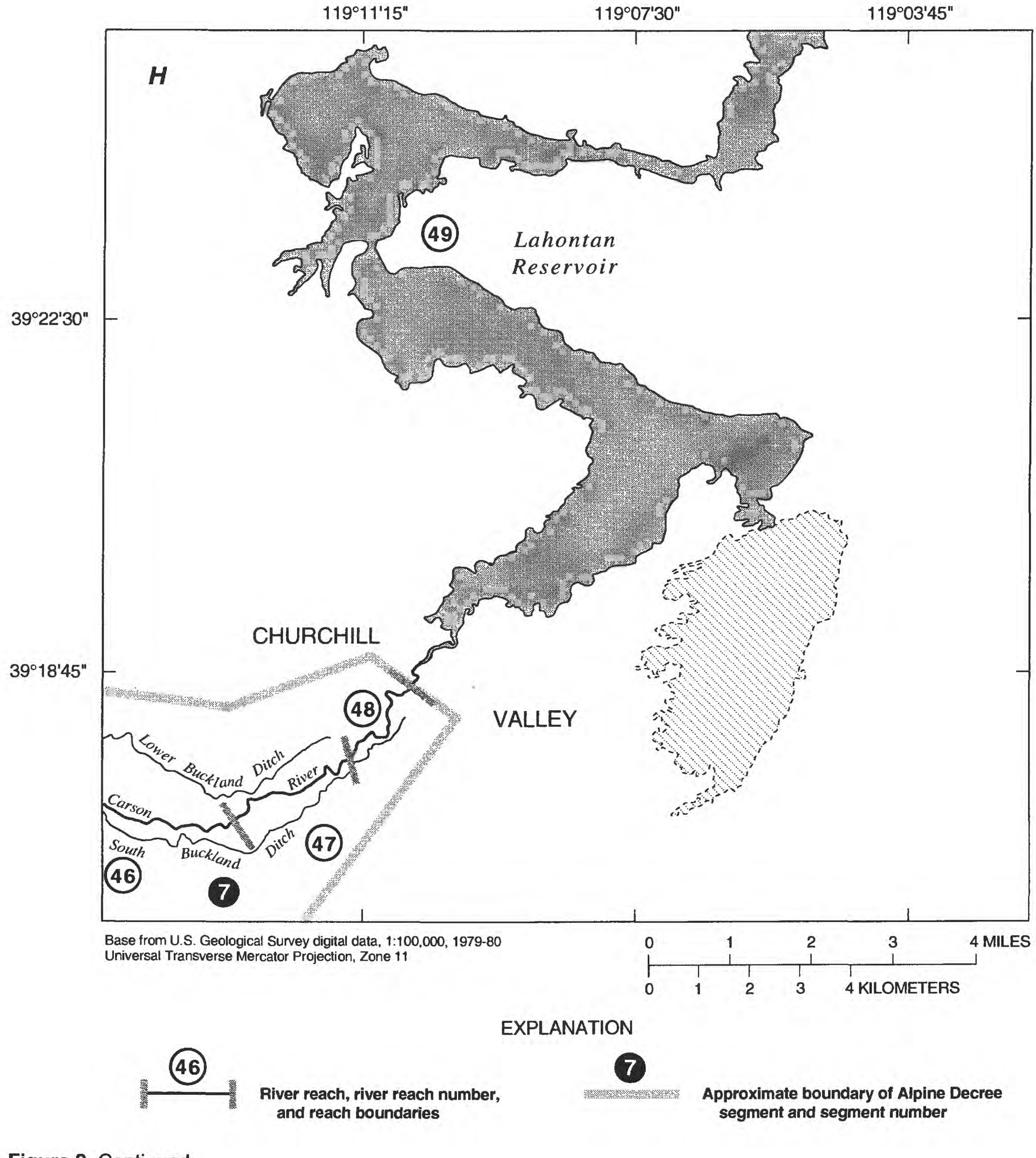


Figure 2. Continued.

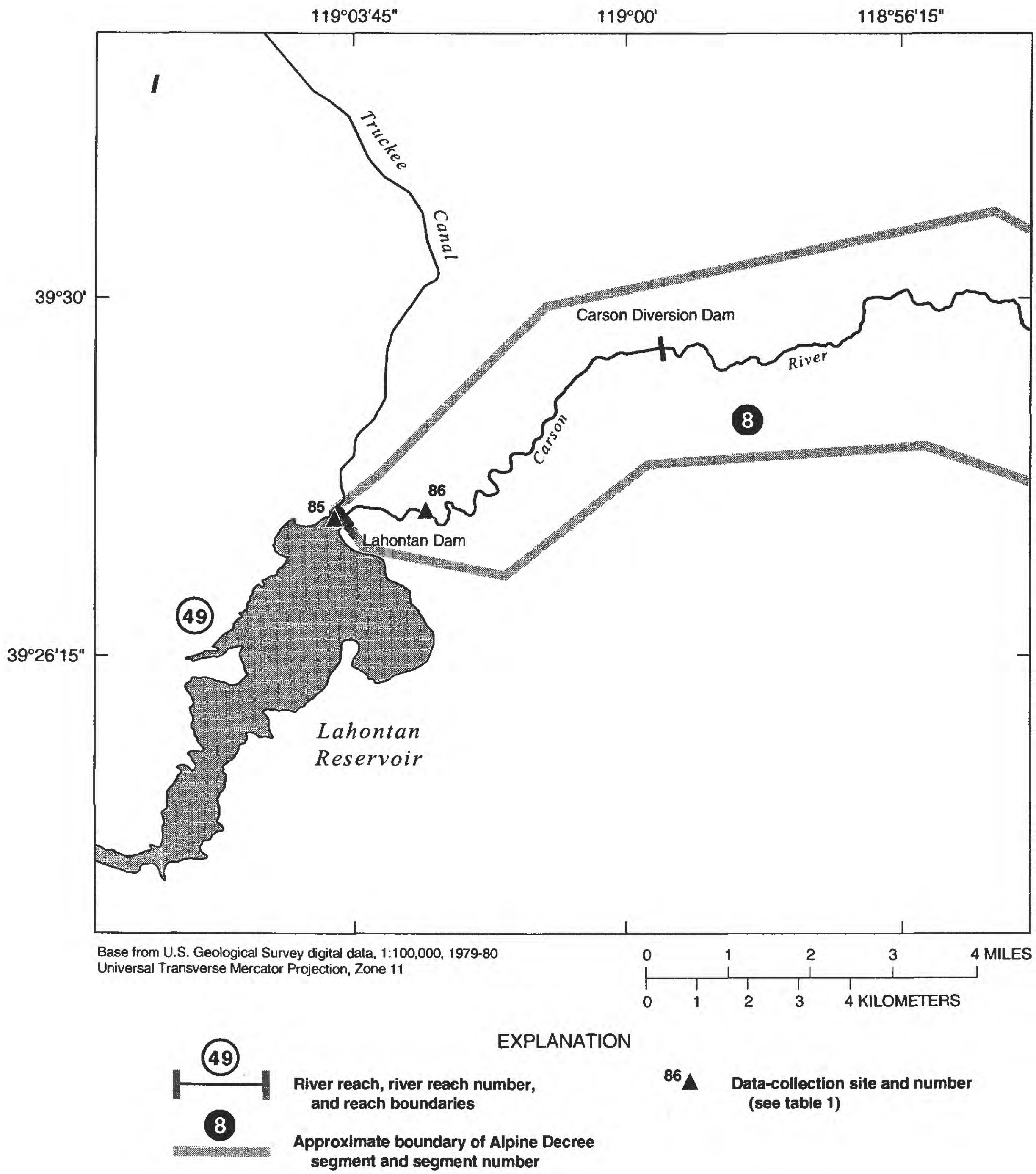


Figure 2. Continued.

the Negotiations Models were not intended to simulate historical streamflow, but used long-term (1901–80) data containing observed and simulated streamflows to make relative comparisons of the effects of alternative management practices on flows and allocations. A classic calibration comparing simulated and observed streamflow was impossible with these models and data bases. The Negotiations Model is currently being used to examine the effects of operation and allocation policies proposed in P.L. 101-618. The two models focused on the Truckee River system and, to a lesser degree, the Truckee Canal and the Carson River from Churchill Valley to Lahontan Reservoir (fig. 1). Model results were compared for several scenarios of alternative management practices of water demands and depletions to determine what shortages might result in the Newlands Project area. Small increases in water shortages in the Newlands Project area were a model result in a simulation by Cobb and others (1990). Simulated increased water use in the Reno area resulted in reduced downstream supplies in the same scenario.

Kennedy/Jenks Consultants (1991) used the MODSIM river model to simulate monthly streamflow along Nevada segments of the upper Carson River, which are defined in the Alpine Decree and Alpine Decree Opinion (U.S. District Court, 1980a,b). MODSIM is a water-management model that simulates the decreed water-rights priority system. Observed streamflow at gaging stations at the downstream segment boundaries was compared to simulated streamflow. Differences between modeled and observed streamflows were attributed to undefined irrigation practices, reservoir operations, ground-water influences, and irrigation return flows. Reservoir operations, ground-water interactions, and model results are not included in their analysis (Kennedy/Jenks Consultants, 1991).

A numerical model of the Carson River below Lahontan Reservoir was developed by Yardas (1996) to simulate streamflows in the Newlands Project area. The model can be used to understand the effects of water acquisitions and other policy actions on interbasin and intrabasin water demands and supplies.

A numerical model used to simulate the ground-water reservoir in Carson Valley was used by Maurer (1986). Geologic components of the ground-water reservoir were defined and estimates were made of the distribution of hydraulic properties of aquifer materials and water-budget components throughout the valley.

Hess (1997) summarized some of the capabilities of the upper Carson River operations model. Examples of operations described in Hess (1997) include diversions to meet agricultural and M&I demands, and diversions to fill reservoirs. Hess (1996) described other investigations of the Carson River Basin.

Acknowledgments

The authors gratefully acknowledge the support of many people and agencies who provided data used in this report. Dorothy Timian-Palmer of the Carson City Utilities Department and several people in the office of the U.S. District Court Water Master, also called the Federal Water Master, notably Garry Stone, Jeff Boyer, Julian Larrouy, Chad Blanchard, and Matthew Setty, provided insight into the complexities and operation of the Carson River.

DESCRIPTION OF STUDY AREA

The Carson River in Alpine County, Calif., flows to the northeast through Carson Valley, and parts of Eagle, Dayton, and Churchill Valleys into Lahontan Reservoir, Nev. From Lahontan Reservoir, the regulated lower river continues northeastward through the Newlands Project area and ultimately terminates in the Carson Sink (fig. 1). The waters of the Carson River and its tributaries support a variety of uses—agricultural irrigation, M&I demands, fish and wildlife habitats, hydroelectric power, and river and reservoir recreation.

The upper watershed of the Carson River is in Alpine County, Calif., and is divided into two parts—the West Fork Carson River and East Fork Carson River (hereinafter referred to as West Fork and East Fork)—both of which begin in the Sierra Nevada. Highest headwater altitudes are at about 9,000 ft above sea level on the West Fork and about 11,000 ft above sea level on the East Fork (Jones and others, 1991, p. 5). Both forks of the river at the higher altitudes have steep channel slopes. Most runoff in the watershed originates from the eastern slopes of the Sierra Nevada where precipitation is mostly snowfall. Also, both forks contain several small natural lakes at higher altitudes. Some of the lakes have been converted to reservoirs by constructing small dams at the outlets. The capacity of water in these reservoirs is typically less than 3,000 acre-ft.

West Fork streamflow upstream from the town of Woodfords, Calif., is slightly regulated by reservoirs (total capacity about 2,000 acre-ft), and the amount of diversion upstream from Woodfords is negligible (Jones and others, 1991, p. 5). The only agricultural area in the vicinity of Woodfords is Diamond Valley directly downstream from Woodfords, where a canal-and-ditch system distributes irrigation water. Between the West Fork and East Fork is Mud Lake (fig. 2*B*), which can be used to store municipal water for Carson City and agricultural irrigation water for Carson Valley (fig. 2*D*). Mud Lake has a capacity of about 3,100 acre-ft fed mostly by diversions from West Fork and Indian Creek. The West Fork continues northeastward before entering Carson Valley.

East Fork streamflow upstream from Markleeville, Calif., also is slightly regulated by several small reservoirs (total capacity about 5,000 acre-ft; Jones and others, 1991, p. 7). This fork veers to the northeast at the town of Markleeville and crosses into Nevada just upstream from its confluence with Bryant Creek (fig. 2*B*). The East Fork continues through a narrow canyon and enters into the Carson Valley near Gardnerville.

The West and East Forks of the Carson River join in the Carson Valley in Nevada, where the average altitude of the valley floor is about 4,700 ft above sea level. The Carson Valley is the major agricultural area of the upper Carson River and is characterized by a complex system of canals, small reservoirs, diversions, and return flows. Although Carson Valley historically has been largely agricultural, suburban development is increasing in and near the towns of Minden and Gardnerville. The intricate ditch systems that begin in the Diamond Valley area in California also serve water users in Carson Valley and are responsible for the lush green fields in an otherwise high-desert terrain.

From the 1850's through the early 1900's, ranching interests developed a series of small upstream reservoirs to store water and a canal system to distribute it across the Carson Valley (Dangberg, 1975, p. 11). This system exists today, virtually unchanged, in an area of about 43,000 acres of decreed farmland (U.S. District Court, 1980a,b). Most of the discharge of the East Fork on entering the Carson Valley is diverted for irrigation. Irrigation diversions on the western side of the East Fork flow toward the West Fork, leaving little discharge in the East Fork during dry years. Near Dresslerville, most discharge in the West Fork flows into the Brockliss Slough; discharge in the West Fork downstream from Brockliss Slough is derived primarily from irrigation return flows from the western side of the East Fork. The East Fork and West Fork converge near Genoa, Nev., to form the mainstem of the Carson River; Brockliss Slough flows back into the Carson River about 1 mi farther downstream (fig. 2*D*).

The Carson River flows along the eastern edge of Eagle Valley through parts of Carson City before passing through a deep canyon to the east. The Carson River then enters a small valley near the town of Dayton. Downstream from Dayton, the river passes through another agricultural area in Churchill Valley and another short canyon before flowing east toward Fort Churchill and into Lahontan Reservoir, the only large reservoir on the Carson River. Lahontan Reservoir has a design capacity of 314,000 acre-ft with flashboards (Tom Scott, Bureau of Reclamation, oral commun., 1997) and 295,000 acre-ft without flashboards (U.S. Geological Survey, 1994, p. 197).

Lahontan Reservoir stores the flow of the Carson River and water imported from the Truckee River via the Truckee Canal. Inflow to Lahontan Reservoir from the Truckee Canal consists of water diverted at Derby Dam, minus spills, seepage, evaporative losses, and deliveries to the Truckee Division ditches along the Truckee Canal. Water released from Lahontan Reservoir into the Carson River either flows through or bypasses Lahontan Power Plant at the base of Lahontan Dam.

DESCRIPTION OF OPERATIONAL PRACTICES FOR UPPER CARSON RIVER BASIN

In the Nevada part of the Carson River Basin, water rights are based on appropriative doctrine, which is often stated as "first in time, first in right." The appropriative doctrine states that the first person to put a quantity of water to beneficial use has a higher priority, or right, to the water than a subsequent water user. A water user is assigned a priority year (date of establishment of a water right) that is significant in relation to the dates assigned to other water users. The priority year is important when the quantity of available water is insufficient to meet all the needs of legal users. Under drought conditions, users with later appropriative dates may suffer water shortages.

In the California part of the Carson River Basin, water rights are based on riparian water-rights doctrine. The riparian doctrine states that all persons who own the land adjacent to a stream have an equal right to make reasonable use of the natural streamflow. Riparian users of a stream share the flow among themselves and the concept of priority of use is not applicable. Under drought conditions, users share shortages.

The irrigation season is usually the 7-month period from April 1 through October 31 of any given year. In practice, the beginning and ending of the irrigation season are determined by the amount of recent precipitation, the type of crop grown, or the amount of water available in the river.

Supplemental water is available to help meet irrigation demands. The use of this supplemental water is limited to not exceed the water duties described in the Alpine Decree. The sources of this water may include (1) storage in high-alpine reservoirs, (2) storage in off-river reservoirs, and (3) treated effluent. The high-alpine reservoir releases typically are used to supplement irrigation water during the August-September part of the irrigation season when natural flows are not enough to satisfy all rights. The off-river reservoirs and treated effluent are used throughout the irrigation season.

Anderson-Bassman Decree

Carson River water within segments 4 and 5 of the West Fork (figs. 2*B,D;* see later section titled "Description of Alpine Decree Segments") was allocated to specific acreages according to the Anderson-Bassman Decree (U.S. District Court, California, 1905). The decree also created a rule of rotation whereby the use of West Fork water for irrigation purposes is alternated between California and Nevada weekly. Rotation begins on the first Monday in June, if West Fork flow is not sufficient (less than about 180 ft^3/s) to satisfy all rights. When flow is greater than 180 ft^3/s, no rotation is necessary.

Price Decree

According to the Price Decree (California Superior Court, Alpine County, 1921) water rights in California and served by the West Fork (segment 4, fig. 2*B*) are determined according to a fixed schedule of allotments based on priority year. The schedule lists the name of the water user, name of ditch, quantity of water available for each right, order of priority, and the cumulative quantity of water available based on streamflow of the West Fork at Woodfords.

Alpine Decree

The Alpine Decree (U.S. District Court, 1980a) adjudicates most of the appropriative and riparian surface-water rights on the upper Carson River. The decree incorporates previous legal decisions (Price Decree and Anderson-Bassman Decree) to determine operations along the Carson River. The decree likewise established the rights to store water in the high-alpine reservoirs of the Sierra Nevada. The impact of irrigation of water-righted land by return flow from other lands also is discussed in the Alpine Decree Opinion (U.S. District Court, 1980b). Evidence presented prior to the Alpine Decree showed that large parts of the irrigated lands are irrigated by return flows. This practice occurs when water is used to cover a field (flood irrigation). Runoff water collected downhill from the first appropriator's land is used on the second appropriator's land and so on until the water is depleted or returns to the river or another diversion canal. Because of this historical practice, the Alpine Decree (U.S. District Court, 1980a) does not differentiate between water-righted land irrigated by direct diversions and water-righted land irrigated by return flows.

The Alpine Decree separates the Carson River Basin into eight segments (fig. 2*A*). Each segment is operated autonomously once regulation becomes effective with respect to diversions. As a result, appropriations with junior priority years in an upstream segment will be satisfied before a senior right in a downstream segment. Users in downstream segments are left to use only return flows if any. For segment 1 on the East Fork and segment 3 on the West Fork (fig. 2*B*) most rights are riparian with little supervision by the Federal Water Master (FWM).

The Alpine Decree also defines the filling of several small lateral reservoirs along the Carson River and its Forks, although the river is only slightly regulated by these reservoirs. The water from these small reservoirs is used to satisfy agricultural and M&I demands. For example, Mud Lake is filled during the nonirrigation season according to decreed storage rights. Similar rights are used in the filling of Dangberg Ponds and Ambrosetti Pond. A more descriptive table of all Carson River reservoirs is listed by Jones and others (1991, p. 18).

The Alpine Decree specifically defines the operations in segment 2 of the East Fork during the irrigation season. When the flow in the East Fork is less than 200 ft^3/s during irrigation season, Allerman Canal is allowed to divert one-third of the flow from the East Fork to meet agricultural demands.

Description of Alpine Decree Segments

The Carson River is operated in eight autonomous segments and operational practices in each differ slightly. Alpine Decree segment 1 is defined as the East Fork from the headwaters in the mountains downstream to the California-Nevada State line. Segment 1 is characterized by riparian-water rights and minor ground-water pumpage. No major diversions in the segment exist, but several high-alpine reservoirs are used to store small amounts of water.

Alpine Decree segment 2 (figs. *2B-D*) is defined as the East Fork from the California-Nevada State line downstream to the confluence of the East Fork and West Fork. Segment 2 is characterized by appropriative water rights, some of which are supplied by ground-water pumpage. The major diversions in segment 2 are Allerman Canal, Rocky Slough, Virginia Ditch, Company Ditch, Henningson Ditch, Edna Wilslef Ditch, Cottonwood Slough, St. Louis Straight Ditch, Home Slough, and Martin Slough. The Dangberg Ponds are filled through the Allerman Canal in segment 2. Minden-Gardnerville Sanitation District (MGSD) and Douglas County Sewer Improvement District (DCSID) effluents are used for agricultural purposes in segment 2. Since the autumn of 1986, a small amount of MGSD treated effluent has been stored in ponds in July and August. The effluent is then transported into a slough and used for irrigation. Since 1979, DCSID effluent has been applied by sprinkler during the winter months at a ranch in northwestern Carson Valley and released to irrigation ditches during the summer months. Irrigation return flows from the western side of segment 2 flow toward segments 5 and 6 (figs. *2B,E*).

Alpine Decree segment 3 is defined as the West Fork from the headwaters in the mountains downstream to the gaging station *West Fork Carson River at Woodfords, Calif.* (fig. *2B*). Segment 3 is characterized by riparian water rights and minor ground-water pumpage. No major diversions in the segment exist, but as in segment 1, several high-alpine reservoirs are used to store water.

Alpine Decree segment 4 (fig. *2B*) is defined as the West Fork from the gaging station *West Fork Carson River at Woodfords, Calif.*, to the California–Nevada State line. Segment 4 is characterized by mostly appropriative water rights according to the Price Decree and only minor ground-water pumpage. The major diversions in segment 4 are Snowshoe Thompson Ditch No. 2 and Fredericksburg Ditch. South Tahoe Public Utilities District (STPUD) treated effluent, from the Lake Tahoe Basin is stored in Stevens Lake and Harvey Place Reservoir and released for agricultural purposes in segments 4 and 5. In summer months, STPUD effluent is mixed with surface water and transported by irrigation ditch to four Alpine County ranches in Carson Valley. Although Mud Lake physically is in segment 5, the diversion of West Fork water typically is conveyed to Mud Lake through the Snowshoe Thompson Ditch No. 2 in segment 4. Although Indian Creek physically is in segments 4 and 5, it is considered to be in segment 4 according to the Alpine Decree.

Alpine Decree segment 5 is defined as the West Fork from the California-Nevada State line downstream to the confluence of the East Fork and West Fork. Segment 5 is characterized by appropriative water rights, some of which are satisfied by ground-water pumpage. No major diversions or reservoirs are in segment 5. Return flows from segment 2 flow through segment 5.

Alpine Decree segment 6 (figs. *2D,E*) is defined as the mainstem of the Carson River from the confluence of East Fork and West Fork to the gaging station *Carson River near Carson City, Nev.* Segment 6 is characterized by appropriative water rights and some ground-water pumpage. The major diversion in segment 6 is Heyburn Ditch. Incline Village General Improvement District (IVGID) treated effluent is used for agricultural purposes in segment 6. IVGID effluent is applied with sprinklers at a ranch in northwestern Carson Valley from April to October and is discharged to 770 acres of wetlands from November to March. Ambrosetti Pond is in segment 6 and is filled with return flows from irrigation upgradient. Some of the return flows from the east side of the river in segment 2 flow into segment 6.

Alpine Decree segment 7 (figs. *2E-H*) is defined as the Carson River from the gaging station *Carson River near Carson City, Nev.*, to Lahontan Reservoir. Segment 7 is characterized by appropriative water rights, many of which are satisfied by ground-water pumpage. Segment 7 is further subdivided for administration into five autonomous subsegments: (1) Mexican Ditch, Dayton Ditch, and reach between Dayton Town (Rose) Ditch, and Rock Point Mill and Cardelli Ditch; (2) Gee Ditch; (3) Koch (Chaves) Ditch; (4) Houghman and Howard Ditch; and (5) Buckland Ditch. The major diversions in segment 7 include those listed above, along with Baroni Ditch, Fish Ditch, and Quilici (Ghiglieri) Ditch. Carson City Water Treatment Plant (CCWTP) treated effluent is used for agricultural purposes in segment 7. Since September 1987, CCWTP effluent also has been used for irrigating several golf courses and farms in the Eagle Valley area. Lahontan Reservoir stores water from the Carson River just below the downstream end of segment 7.

Alpine Decree segment 8 (fig. 2*I*) is defined as the area below Lahontan Dam, which includes the areas irrigated in the Newlands Project area in Lahontan Valley and ultimately where the Carson River terminates in the Carson Sink.

CONSTRUCTION OF OPERATIONS MODEL FOR UPPER CARSON RIVER BASIN

A daily operations model was constructed to simulate streamflow and reservoir and river operations for the upper Carson River Basin. This model was constructed within a larger *modeling system* which includes a data base management program (ANNIE) (Lumb and others, 1990), a graphical user interface (GENSCN) (Kittle and others, 1998), and a program which simulates reservoir/river operations and a variety of hydrologic processes (Hydrological Simulation Program-FORTRAN (HSPF), Bicknell and others, 1997). This modeling system provides standard formats for data exchange and programs to enable statistical and graphical analysis (Bohman and others, 1995). The modeling system is described in the next three sections. The HSPF program is composed of a variety of *modules* which are used to simulate operations or physical processes. Some of these HSPF modules can be used by themselves, while others must be used with one or more other modules. The simulation of operations requires the use of a flow-routing module and an operations module. *Models* are unique applications of generic programs such as HSPF. Once data and parameters unique to a particular river or basin are input to the program, a model results which cannot be used for a different river or basin. The upper Carson River Basin operations *model* was constructed using the flow-routing and operations modules.

Data Management Program

Data requirements of the modeling system are managed by ANNIE, a time-series data-management program. ANNIE operates on binary direct-access principles. ANNIE is an interactive program that facilitates file creation, data-set management, data analysis, and data display. HSPF input and output is sent to time-series files that are formatted and managed by ANNIE.

Graphical User Interface

An interactive graphical-user interface called GENSCN (GENeration and analysis of model simulation SCeNarios), has been developed for use with the modeling system. GENSCN is a program which can be used to make changes to variables in HSPF, thereby creating different operational scenarios. Following simulation(s), GENSCN can then be used to analyze the results statistically or graphically.

Hydrological Simulation Program - FORTRAN

HSPF was used to define the hydrological processes in the upper Carson River operations model. This program contains several optional *modules* that can simulate operations and various hydrologic processes such as flow-routing, rainfall-runoff, and associated water-quality processes on land surface, in streams, and in well-mixed impoundments (Bicknell and others, 1997). The HSPF program was chosen for use in the upper Carson River operations model primarily because it can (1) simulate streamflows, including periods of storm runoff and low flows, continuously over time, and at a variety of time steps, including daily and hourly; (2) simulate the hydraulics of complex natural and manmade drainage networks; (3) account for both channel inflows and diversions along a stream reach; (4) simulate manmade operations through reservoir releases and river diversions; and (5) produce simulation results at many locations.

The user's control input (UCI) file contains information the user must provide to run functional modules within HSPF. Modules describe discrete physical processes that may be added to the UCI. The UCI provides instructions to HSPF by defining the required modules to simulate a particular modular objective, such as streamflow routing. Modules describing flow routing and operations were built in a logical stepwise fashion. HSPF modules simulating flow routing and operations are used to represent river and reservoir operations in the upper Carson River Basin operations model. The flow-routing module characterizes the movement of water into and through the reaches of the drainage network so the operations module can simulate the man-made regulation of water movement within and out of the drainage network. The operations module must be run in combination with the flow-routing module.

The modules in HSPF include one or more "blocks" which group the computations needed by each module. The streamflow-routing module uses only one block, the reach-reservoir (RCHRES) block. The operations module uses the RCHRES block and the special-actions (SPECL) block. The SPECL block contains the conditional-logic code that simulates river and reservoir operations. Both modules, and therefore both blocks, are required to fully simulate operations using HSPF.

The following sections describe the flow-routing and operations models used in HSPF to simulate hydrologic processes.

Flow-Routing Model

A flow-routing model, constructed for simulating streamflow in the Carson River at daily time intervals, was documented by Hess (1996). In that study, daily streamflow data for water years 1978-92 for the upper Carson River, for tributaries, and for irrigation ditches from the *East Fork near Markleeville, Calif.*, and *West Fork at Woodfords, Calif.*, downstream to the *Carson River near Fort Churchill, Nev.* (just upstream from Lahontan Reservoir), were obtained from several agencies and were compiled into a comprehensive data base. Where streamflow data were unavailable or incomplete, hydrologic techniques were used to estimate flows. For modeling purposes, the Carson River was divided into six individual models, each of which correspond to a segment established in the Alpine Decree (Alpine Decree segments 3 and 8 were not modeled). Cross-sectional data, obtained from previous studies and field surveys, were used to define hydraulic characteristics for 48 stream reaches throughout the study area. Testing the HSPF flow-routing models demonstrated that hydraulic characteristics of the Carson River were adequately represented for a range of flow regimes. Differences between observed and simulated streamflows result mostly from inadequate data on inflow to or outflow from the river.

For the operations model described in this report, the scope of the flow-routing model was expanded by adding additional input data to route streamflow along the upper Carson River. The data added since the previous study (Hess, 1996) include (1) tributary inflow, (2) ground-water gains or losses, (3) streamflow losses due to evapotranspiration from phreatophytes, and (4) precipitation and evaporation. The data are described in a companion report by Hess (1999). For reader convenience, data-collection sites in the upper Carson River used in the flow-routing model are listed in table 1 (figs. 2*B-I*).

Operations Model

In the upper Carson River Basin, ditch headgates along the East Fork Carson, West Fork Carson, and Carson Rivers are operated according to complex regulations and legal decrees that specify conditions for the use of water. HSPF uses conditional logic to simulate river diversion operations (Tom Jobes, Aqua Terra Consultants, written commun., 1995). Conditions that were evaluated in the upper Carson River Basin operations model include time of year; reservoir stage, reservoir storage, or volume of a given water category[2] (or ownership) in a reservoir; streamflow magnitude at a given location; and fulfillment of water demands. HSPF simulates operations by evaluating these conditions and simulating the resultant operations. Conditional-logic code, which controls inflows to and outflows from any particular river reach, is in the SPECL block and is required for each operations simulation. To develop this code, specific information was needed, such as (1) the data necessary for simulation of operations, (2) the logic governing river diversions, and (3) the assumptions made for simulating diversions. The following sections describe this information.

---

[2]A category of water is any block of water that is individually accounted for in an observed or simulated water budget. A single river, reservoir, lake, or diversion ditch may contain several categories. Water within a category may have specific ownership, such as "high-alpine reservoir water," or have a designated use.

Table 1. Data collection sites in the upper Carson River Basin, California and Nevada

[Agency source: CCWUD, Carson City Water Utility Division; DCSID, Douglas County Sewer Improvement District; FWM, U.S. District Court Water Master or Federal Water Master; IVGID, Incline Village General Improvement District; MGSD, Minden–Gardnerville Sanitation District; STPUD, South Tahoe Public Utilities District; USGS, U.S. Geological Survey. Symbol: --, no station no.]

Site no. [1]	Site no. [2]	Agency source	Station no.	Station name	Period of record used for streamflow simulation (water year [3])
1	--	FWM	--	East Fork Carson River Alpine Reservoir releases, near Markleeville, Calif.	1994-95
2	1	USGS	10308200	East Fork Carson River below Markleeville Creek, near Markleeville, Calif.	1978-95
3	2	USGS	10308800	Bryant Creek near Gardnerville, Nev.	1978-82
4	3	USGS	10309000	East Fork Carson River near Gardnerville, Nev.	1994-95
5	4	FWM	C82	Allerman Canal near Dresslerville, Nev.	1978-95
6	5	USGS	10309025	Indian Creek near Woodfords, Calif.	1987-89
7	6	USGS	10309030	Indian Creek near Paynesville, Calif.	1987-89
8	--	USGS	10309035	Indian Creek above mouth near Gardnerville, Nev.	1994-95
9	7	FWM	C84	Rocky Slough at Dresslerville, Nev.	1982-95
10	8	FWM	C85	Edna Wilslef Ditch near Dresslerville, Nev.	1982-95
11	9	FWM	C83	Virginia Ditch at Dresslerville, Nev.	1983-95
12	10	USGS	10309050	Pine Nut Creek near Gardnerville, Nev.	1980-95
13	11	FWM	C86	Company Ditch near Gardnerville, Nev.	1984-95
14	12	FWM	C88	Henningson Ditch near Gardnerville, Nev.	1983-95
15	13	FWM	C87	Cottonwood Slough near Gardnerville, Nev.	1983-95
16	14	MGSD	385814119475101	Minden–Gardnerville Sanitation District effluent near Gardnerville, Nev.	1978-86
17	15	USGS	10309070	Buckeye Creek near Minden, Nev.	1980-95
18	16	USGS	10309100	East Fork Carson River at Minden, Nev.	1978-84, 1994-95
19	17	DCSID	385815119475401	Douglas County Sewer Improvement District effluent discharge near Minden, Nev.	1978-79
20	18	FWM	C89	Heyburn Ditch near Minden, Nev.	1983-95
21	19	USGS	10310000	West Fork Carson River at Woodfords, Calif.	1978-95
22	20	FWM	C76	Snowshoe Thompson Ditch No. 2 near Woodfords, Calif.	1984-95
23	--	FWM	--	West Fork Carson River Alpine Reservoir releases near Woodfords, Calif.	1994-95
24	21	FWM	C77	West Fork Carson River at Paynesville, Calif.	1982-94
25	22	STPUD	38450811946280	South Tahoe Public Utility District effluent discharge near Paynesville, Calif.	1982-95
26	23	FWM	C78	Fredericksburg Ditch near Paynesville, Calif.	1982-95
27	24	USGS	10310300	Fredericksburg Canyon Creek near Fredericksburg, Calif.	1981-83, 1988-95
28	25	FWM	C79	West Fork Carson River at Dressler Lane near Fredericksburg, Calif.	1982-95
29	26	FWM	C80	Brockliss Slough at Ruhenstroth Dam near Gardnerville, Nev.	1982-95
30	27	FWM	C81	Brockliss Slough at Scossa Box near Gardnerville, Nev.	1982-95
31	--	USGS	1030909020	Cottonwood Slough at State Highway 88 near Minden, Nev.	1994-95
32	--	USGS	1030909042	Martin Slough at U.S. Highway 395 near Minden, Nev.	1994-95
33	--	USGS	1030909046	Middle Ditch at Muller Lane near Minden, Nev.	1994-95
34	--	USGS	1030909048	East Ditch at Muller Lane near Minden, Nev.	1994-95
35	--	USGS	1030909055	Martin Slough-Heyburn Ditch Return at U.S. Highway 395 near Minden, Nev.	1994-95
36	--	USGS	1030909060	Heyburn Ditch Return at Slash Bar H Ranch Road and U.S. Highway 395 near Minden, Nev.	1994-95
37	--	USGS	1030909065	Heyburn Ditch Return at U.S. Highway 395 near Minden, Nev.	1994-95
38	--	USGS	1030909070	Heyburn Ditch Return near Dangberg Well at U.S. Highway 395 near Minden, Nev.	1994-95
39	--	USGS	1030909075	Heyburn Ditch Return at Airport Road and U.S. Highway 395 near Minden, Nev.	1994-95
40	--	USGS	1030909080	Heyburn Ditch Return 0.75 mile south of Johnson Lane at U.S. Highway 395 near Minden, Nev.	1994-95

Table 1. Data collection sites in the upper Carson River Basin, California and Nevada—Continued

Site no. [1]	Site no. [2]	Agency source	Station no.	Station name	Period of record used for streamflow simulation (water year [3])
41	--	USGS	1030909085	Heyburn Ditch Return 0.25 mile south of Johnson Lane at U.S. Highway 395 near Minden, Nev.	1994-95
42	--	USGS	1030909090	Heyburn Ditch Return at Johnson Lane and U.S. Highway 395 near Minden, Nev.	1994-95
43	--	USGS	1030909095	Heyburn Ditch Return at Stephanie Lane near Minden, Nev.	1994-95
44	--	USGS	1030909710	St. Louis Straight Ditch at State Highway 88 near Minden, Nev.	1994-95
45	--	USGS	10309110	Home Slough at State Highway 88 near Minden, Nev.	1994-95
46	--	USGS	10309113	Home Slough at Muller Lane near Minden, Nev.	1994-95
47	--	USGS	10309117	Home Slough Return at Muller Lane near Minden, Nev.	1994-95
48	--	USGS	10309118	West Ditch at Muller Lane near Minden, Nev.	1994-95
49	--	USGS	103103576	West Fork Carson West Ditch at Muller Lane near Minden, Nev.	1994-95
50	--	USGS	103103577	West Fork Carson East Ditch at Muller Lane near Minden, Nev.	1994-95
51	--	USGS	10310358	West Fork Carson River at Muller Lane near Minden, Nev.	1994-95
52	28	USGS	10310400	Daggett Creek near Genoa, Nev.	1978-83, 1989-95
53	--	USGS	10310402	East Branch Brockliss Slough at Muller Lane near Minden, Nev.	1994-95
54	--	USGS	10310403	West Branch Brockliss Slough at Muller Lane near Minden, Nev.	1994-95
55	29	USGS	10310405	Carson River at Genoa, Nev.	1978-81
56	--	USGS	10310447	Ambrosetti Pond near Genoa, Nev.	1992-95
57	--	USGS	10310448	Ambrosetti Pond Outlet near Genoa, Nev.	1992-95
58	30	IVGID	390426119460401	Incline Village General Improvement District treatment plant effluent discharge near Carson City, Nev.	1978-85
59	31	USGS	10310500	Clear Creek near Carson City, Nev.	1989-95
60	32	USGS	10311000	Carson River near Carson City, Nev.	1978-95
61	33	FWM	C61	Mexican Ditch near Carson City, Nev.	1978-95
62	--	CCWUD	--	Carson River municipal diversion at Carson City, Nev.	1991-95
63	34	USGS	10311100	Kings Canyon Creek near Carson City, Nev.	1978-95
64	35	USGS	10311200	Ash Canyon Creek near Carson City, Nev.	1978-95
65	36	USGS	10311260	Vicee Canyon Creek near Sagebrush Ranch near Carson City, Nev.	1983-85, 1989-95
66	37	CCWUD	391036119422401	Carson City Wastewater Treatment Plant effluent discharge at Carson City Nev.	1978-86
67	38	USGS	10311300	Eagle Valley Creek at Carson City, Nev.	1985-95
68	39	USGS	10311400	Carson River at Deer Run Road near Carson City, Nev.	1979-85, 1990-95
69	40	FWM	C62	Dayton Town (Rose) Ditch near Dayton, Nev.	1978-95
70	41	FWM	C63	Randall (Dayton) Ditch near Dayton, Nev.	1978-95
71	42	FWM	C64	Fish Ditch near Dayton, Nev.	1978-95
72	43	FWM	C65	Baroni Ditch near Dayton, Nev.	1978-95
73	--	USGS	10311700	Carson River at Dayton, Nev.	1994-95
74	44	FWM	C66	Rock Point Mill and Cardelli Ditch near Dayton, Nev.	1978-95
75	45	FWM	C67	Quilici (Ghiglieri) Ditch near Dayton, Nev.	1978-95
76	46	FWM	C68	Gee Ditch near Dayton, Nev.	1978-95
77	47	FWM	C69	Koch (Chaves) Ditch near Dayton, Nev.	1978-95
78	--	USGS	10311875	Carson River near Clifton, Nev.	1992-95
79	48	FWM	C70A	Houghman and Howard Ditch No. 1 near Fort Churchill, Nev.	1978-95
80	--	FWM	C70B	Houghman and Howard Ditch No. 2 near Fort Churchill, Nev.	1978-95

Table 1. Data collection sites in the upper Carson River Basin, California and Nevada—Continued

Site no.[1]	Site no.[2]	Agency source	Station no.	Station name	Period of record used for streamflow simulation (water year[3])
81	49	USGS	10311900	Buckland Ditch near Fort Churchill, Nev.	1978-95
		FWM	C71		
82	--	FWM	C71A	South Buckland Ditch near Fort Churchill, Nev.	1978-95
83	--	FWM	C72	Lower Buckland Ditch near Fort Churchill, Nev.	1978-95
84	50	USGS	10312000	Carson River near Fort Churchill, Nev.	1978-95
85	51	USGS	10312100	Lahontan Reservoir near Fallon, Nev.	1978-95
86	52	USGS	10312150	Carson River below Lahontan Dam near Fallon, Nev.	1978-95

[1] Site numbers are used in figure 2 of this report.

[2] Site numbers are used on plate 1 of Hess (1996).

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

Due to the autonomous nature of each of the Alpine Decree segments, individual segment models must be run in a particular sequence for a complete operations model run. Certain diversion and return flows may be required as input into downstream segments to properly simulate upper Carson River operations. Therefore, segment models are run in the following sequence; segments 1 (flow routing only), 2, 4 and 5, 6, and 7. This run sequence ensures that junior water rights in the upstream segments are satisfied before senior water rights in downstream segments and that return flows from upstream segments are transferred downstream. As stated previously, segments 3 and 8 were not modeled as part of this study.

Data Necessary for Construction of Operations Model

Conditional logic and certain quantifiable data were necessary to simulate allocation and diversion operations on the upper Carson River. The data are from forecasts, Alpine Decree water duties and irrigated acreage, Price Decree water rights, and off-river storage rights.

Forecast Data

Forecasts of flows at the gaging stations, *West Fork Carson River at Woodfords, Calif.; East Fork Carson River near Gardnerville, Nev.;* and *Carson River near Fort Churchill, Nev.,* were provided by the Natural Resources Conservation Service (Becky Wray, written commun., 1995). These forecasts were used to determine conditions that may govern the simulation of various reservoir and river operations.

Alpine Decree Water Duties and Irrigated Acreages

The water duty[3] specified as 4.5, 6.0, or 9.0 acre-ft/acre for agricultural demands and the net water duty specified as 2.5 acre-ft/acre for agricultural and M&I demands used in this study were determined using information from the FWM, the Alpine Decree and Alpine Decree Opinion (U.S. District Court, 1980a,b) and soil-type analysis. The FWM provided general trends in water duties throughout the Alpine Decree segments (Garry Stone, oral commun., 1993). The Alpine Decree lists water duties for only several parcels; however, the available duties can be used for determining duties for other nearby parcels of land.

Analyses defining the primary soil type for lands near major irrigation areas were used to establish approximate water duties for irrigated lands along each ditch. Using geographic-information-system (GIS) technology, the soil coverages defined in soil surveys for Carson City (Candland, 1979), Douglas County (Candland, 1984), and Lyon County (Archer, 1984) from 1:24,000 scale maps were digitized and used to determine permeability characteristics. By comparing

[3] The water duty for agriculture is the total volume of irrigation water per unit area required to mature a particular type of crop. The duty is the amount of water supplied to the land with transmission losses, not the volume of water actually consumed by the plants. The water duty for M&I has no transmission losses.

these primary soil types and associated permeability characteristics with known water duties provided by FWM, and the Alpine Decree and Alpine Decree Opinion (U.S. District Court, 1980a,b), the unknown water duties were estimated.

Water-righted acreages in Alpine Decree segments 2, 5, 6, and 7 were determined from the most recent (1995) water-rights compilation for agricultural and M&I (Garry Stone, U.S. District Court Watermaster, written commun., 1995). To simplify the complexity of many individual water rights for each segment, water rights were divided into 10 groups. Water-right groups were determined by priority year, or year when water right was granted within each segment so that each of the 10 groups contained approximately equal irrigated acreages (tables 2-5).

Price Decree Water Rights

The water rights in segment 4 are regulated according to the Price Decree (California Superior Court, Alpine County, 1921). These water rights are satisfied using a fixed schedule of allotments based on priority year and the amount of water available in West Fork, Alpine County, Calif. The schedule of water rights for segment 4 used in the operations model lists, by priority, the available streamflow in the West Fork at Woodfords, the name of the ditch, and incremental and cumulative allowable diversion to each named ditch (table 6).

Off-River Storage Water Rights

The water rights for off-river storage were modeled for Carson Valley including Mud Lake, Dangberg Ponds, and Ambrosetti Pond (table 7). Capacity curves for Mud Lake were provided by Thiel and others (1993). Capacity for Dangberg Ponds was determined from the Alpine Decree. Capacity curves and use characteristics for Ambrosetti Pond were provided by Dorothy Timian-Palmer (Carson City Utilities, written commun., 1993).

Description of Logic Governing River Diversions

The operations model for the upper Carson River used conditional logic to simulate river diversions (Tom Jobes, Aqua Terra Consultants, written commun., 1995). These diversions were determined from agricultural, M&I, and off-river reservoir demands that were defined by the Alpine, Price, and Anderson-Bassman Decrees. The conditional logic used to determine the amount and timing of simulated diversions along the upper Carson River is shown in figure 3.

The conditional logic used in the operations model compares the flow at the upstream boundary of each segment to the total demand (water rights) that could be satisfied based on priority-year groups. In segment 7, the flow at each subsegment is compared. For lands within a segment, demand (total water right) was determined using (1) the water duty and (2) the water-righted acreage in each priority-year group. Demands, stated in terms of flow per day, are determined by multiplying the irrigated acreage by the duty and dividing the product by the length of the irrigation season, in days. For example during the irrigation season, agricultural or M&I demands capable of being satisfied under 1985 flow conditions were diverted from the Carson River to the appropriate ditch.

The use of conditional logic in the operations model to satisfy existing agricultural demands for the period April through October 1985 for the Buckland Ditch in segment 7 is shown in figure 4. For the period April to mid-July, flows of 23 ft^3/s or greater were available to satisfy all water rights for Buckland Ditch. Thereafter, flow in the river declined to less than 23 ft^3/s, ditch diversion was reduced, and fewer senior rights were satisfied. In late September, no rights were served because of the prevailing low flow in the river.

Valid water-right diversions along the West Fork in segment 4 are simulated in the operations model for the Carson River according to the Price Decree (California Superior Court, Alpine County, 1921) schedule. For example, when simulated West Fork flows are greater than or equal to 113.2 ft^3/s (table 3), all Alpine County West Fork rights are satisfied. Thereafter, as simulated flow in the river continues to decline, individual diversions within segment 4 are reduced according to the Price Decree schedule.

The Alpine Decree specifically defines the operations of the East Fork in segment 2 during the irrigation season when flows are less than 200 ft^3/s. Under these conditions one-third of the flow is directed to the Allerman Canal and two-thirds of the flow must remain in the river. Conditional logic within the model diverts flow to the Allerman Canal according to these rules. Daily diversions on the Allerman Canal simulated by the operations model are shown in figure 5. For the period from April 1 to late July 1984, Allerman Canal diversions were determined from operations based on

Table 2. Decreed and supplemental irrigated acreage from Alpine Decree segment 2 grouped according to priority year and ditch or reach

[Abbreviations: M&I, municipal and industrial; DCSID, Douglas County Sewer Improvement District]

Priority-date group	Priority year(s)	Decreed irrigated acreage from non-Allerman Canal	Decreed irrigated acreage from appropriated non-Allerman Canal											Decreed-irrigated acreage	Supplemental-irrigated acreage		
			Reach 6	Reach 7	Virginia Ditch	Company Ditch	Henningson Ditch	Cottonwood Slough	Home Slough	St. Louis Straight Ditch	Rocky Slough	Williams Slough	Edna Wilslef Ditch	Allerman Canal[1]	Cottonwood M&I rights by Minden Purchase	Williams Slough DCSID rights	Home Slough DCSID rights
0	1857-58	3,309.9	0.0	95.0	0.0	0.0	10.0	1,009.0	1,684.0	511.9	0.0	0.0	0.0		0.0	0.0	0.0
1	1859-60	1,464.1	162.0	90.0	.0	.0	258.0	387.0	131.0	182.5	.0	253.6	.0		.0	233.6	123.5
2	1861-62	1,387.9	.0	72.0	.0	15.0	284.0	343.0	.0	.0	.0	457.9	216.0		.0	384.9	.0
3	1863	1,118.6	.0	.0	157.0	145.0	.0	236.6	.0	.0	20.0	375.0	185.0		.0	375.0	.0
4	1864	846.0	.0	.0	.0	.0	654.0	.0	.0	160.0	32.0	.0	.0		.0	.0	.0
														[7,543.1]			
5	1865-69	1,260.2	.0	100.0	.0	243.7	605.4	203.1	.0	.0	108.0	.0	.0		.0	.0	.0
6	1870-77	1,730.5	.0	9.4	158.0	267.0	329.3	614.8	.0	.0	252.0	.0	100.0		10.0	.0	.0
7	1878-86	1,855.2	8.0	166.3	89.3	237.5	.0	796.6	.0	120.0	153.5	143.0	141.0		51.8	.0	.0
8	1887-98	1,380.9	137.0	.0	.0	25.0	10.0	820.2	.0	.0	257.0	122.7	9.0		41.2	22.4	.0
9	1899-1900	1,328.1	112.0	.0	9.0	.0	.0	112.0	.0	.0	199.2	181.8	714.1		.0	.0	.0
Total acres		15,681.4	419.0	532.7	413.3	933.2	2,150.7	4,522.3	1,815.0	974.4	1,021.7	1,534.0	1,365.1	7,543.1	103.0	1,015.9	123.5

[1] The Alpine Decree specifically defines the diversion of the Allerman Canal during the irrigation season. Modeled Allerman Canal diversions are not based on priority-date groups.

Table 3. Decreed and supplemental or transferred irrigated acreage from Alpine Decree segments 4 and 5 grouped according to priority year and ditch or reach

[Abbreviation: STPUD, South Tahoe Public Utilities District]

Priority-date group	Priority year(s)	Decreed irrigated acreage	Appropriated-decreed-irrigated acreage													Supplemental acreage	Transferred acreage		
			Falke and Tillman Ditch	Reach 16	Reach 17	Reach 18	Reach 19	Reach 20	Reach 23	Reach 24	Reach 25	Reach 26	Reach 27	Reach 28	Fredericks-burg Ditch	Fredericksburg Ditch STPUD right	Segment 4 Mud Lake rights	Falke and Tillman Ditch Mud Lake rights	Reach 16 Mud Lake rights
0	1852-56	1,300.4	0.0	0.0	0.0	0.0	0.0	0.0	74.0	621.0	207.0	308.0	90.4	0.0	0.0	0.0	0.0	0.0	0.0
1	1857	1,372.3	.0	13.3	.0	.0	477.2	344.3	68.5	67.0	308.0	.0	94.0	.0	.0	.0	0.0	.0	.0
2	1858	1,012.7	.0	21.3	.0	175.4	374.0	.0	226.0	20.0	.0	196.0	.0	.0	.0	.0	0.0	.0	.0
3	1859-60	818.0	.0	190.0	.0	.0	.0	.0	331.0	75.0	222.0	.0	.0	.0	.0	.0	99.8	.0	.0
4	1861-63	676.5	.0	210.0	74.5	.0	.0	.0	212.0	.0	.0	100.0	.0	.0	80.0	.0	12.7	.0	75.0
5	1864	1,529.0	.0	.0	.0	362.0	.0	.0	376.0	.0	.0	.0	.0	.0	363.0	428.0	.0	.0	.0
6	1865	988.0	.0	839.0	.0	.0	.0	.0	.0	.0	81.0	.0	.0	.0	68.0	0.0	122.3	.0	.0
7	1866-79	892.0	113.0	85.0	.0	43.0	.0	.0	.0	504.0	37.0	.0	.0	.0	.0	110.0	131.2	113.0	.0
8	1880-97	935.7	416.7	313.0	.0	.0	88.0	40.0	.0	.0	28.0	.0	50.0	.0	.0	.0	159.1	144.0	150.0
9	1897-1914	1,022.1	525.8	261.4	.0	.0	.0	.0	12.5	.0	.0	158.6	.0	63.8	.0	.0	49.7	.0	.0
Total acres		10,546.7	1,055.5	1,933.0	74.5	580.4	939.2	384.3	1,300.0	1,287.0	883.0	762.6	234.4	63.8	511.0	538.0	574.8	257.0	225.0

Table 4. Decreed irrigated acreage from Alpine Decree segment 6 grouped according to priority year and ditch or reach

Priority-date group	Priority year(s)	Decreed irrigated acreage	Appropriated-decreed-irrigated acreage	
			Adams pump	Cook pump
0	1852-57	211.9	211.9	0.0
1	1858-59	27.8	27.8	.0
2	1860-61	409.3	119.3	290.0
3	1862	490.0	360.0	130.0
4	1863	115.0	.0	115.0
5	1864	.0	.0	.0
6	1865	135.0	.0	135.0
7	1866-74	297.5	78.7	218.8
8	1875-82	.0	.0	.0
9	1883-1921	19.8	19.8	.0
Total acres		1,706.3	817.5	888.8

Table 5. Decreed irrigated acreage from Alpine Decree segment 7 grouped according to priority year and ditch or reach

[Abbreviation: M&I, municipal and industrial]

Priority-date group	Priority year(s)	Decreed irrigated acreage	Appropriated-decreed-irrigated acreage												
			Mexican Ditch agricultural rights	Mexican Ditch M&I rights	Lloyd pump	Dayton Town (Rose) Ditch	Randall (Dayton) Ditch	Fish Ditch	Rock Point Mill and Cardelli Ditch	Baroni Ditch	Quilici (Ghiglieri) Ditch	Gee Ditch	Koch (Chaves) Ditch	Houghman and Howard Ditch	Buckland Ditch
0	1849-61	588.8	94.6	243.7	0.0	45.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	122.0	81.0
1	1862-70	1,817.2	74.0	9.2	.0	4.0	.0	122.0	151.0	75.0	87.0	101.0	160.0	75.0	959.0
2	1871-77	666.5	15.0	.0	.0	36.0	216.0	.0	171.0	13.0	3.0	23.5	.0	.0	189.0
3	1878-85	772.7	70.8	.0	.0	.0	.0	.0	218.0	.0	.0	.0	29.0	454.9	.0
4	1886-94	242.0	0	.0	.0	.0	140.0	.0	55.0	.0	32.0	.0	15.0	.0	.0
5	1895-99	261.3	5.0	76.0	50.0	3.0	.0	.0	25.0	8.0	.0	94.3	.0	.0	.0
6	1900-05	510.5	22.4	103.1	5.1	.0	36.4	10.5	161.7	5.0	116.1	.0	30.0	20.2	.0
7	1906-10	107.0	50.0	.0	.0	57.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
8	1911-13	525.4	492.3	33.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
9	1914-21	114.1	14.2	.0	26.1	14.0	.0	.0	.0	59.8	.0	.0	.0	.0	.0
Total acres		5,605.5	838.3	465.1	81.2	159.0	392.4	132.5	784.2	160.8	238.1	218.8	234.0	672.1	1,229.0

Table 6. Schedule for Alpine Decree segment 4 priorities of water rights based on the Price Decree

[Abbreviations: ft^3/s, cubic feet per second; Inc., incremental change in allowable diversion; Cum., cumulative amount of allowable diversion]

Available streamflow at West Fork Carson River at Woodfords, Calif. (ft^3/s)	Allowable diversion to ditch (ft^3/s)									
	Heismoth Ditch		Snowshoe Thompson Ditch No. 2		McCollum Ditch		Fredericksburg Ditch		Falke and Tillman Ditch	
	Inc.	Cum.	Inc.	Cum.	Inc.	Cum.	Inc.	Cum.	Inc.	Cum.
10.6	1.3	1.3	6.8	6.8	0.0	0.0	0.0	0.0	2.5	2.5
16.7	.0	1.3	6.1	12.9	.0	.0	.0	.0	.0	2.5
38.8	1.7	3.0	.0	12.9	.0	.0	20.4	20.4	.0	2.5
53.4	.0	3.0	14.3	27.2	.3	.3	.0	20.4	.0	2.5
60.7	.8	3.8	.0	27.2	.0	.3	4.7	25.1	1.8	4.3
66.1	.0	3.8	2.1	29.3	.9	1.2	2.4	27.5	.0	4.3
83.0	.0	3.8	16.9	46.2	.0	1.2	.0	27.5	.0	4.3
87.8	1.6	5.4	.6	46.8	.0	1.2	2.6	30.1	.0	4.3
94.9	1.8	7.2	.8	47.6	.0	1.2	4.5	34.6	.0	4.3
100.5	.3	7.5	2.9	50.5	1.3	2.5	1.1	35.7	.0	4.3
105.2	1.4	8.9	1.1	51.6	.0	2.5	2.2	37.9	.0	4.3
113.2	.0	8.9	8.0	59.6	.0	2.5	.0	37.9	.0	4.3

Table 7. Off-river reservoir rights used in simulating upper Carson River diversions

Reservoir name	Alpine Decree claim number	Alpine Decree rights (acre-feet)
Mud Lake	814, 814a	3,172.0
Dangberg Ponds	815-816	1,081.1
Ambrosetti Pond	817	200.0

agricultural demands. From late July to October 1, 1984, when simulated flow in the East Fork was less than 200 ft^3/s, one-third of the flow was diverted into the Allerman Canal.

Brockliss Slough flows are influenced by the Anderson-Bassman Decree (U.S. District Court, California, 1905) rule of rotation between West Fork segments 4 and 5 in California and Nevada. Daily flows on the Brockliss Slough in Nevada simulated by the operations model are shown in figure 6. For example, for the period, June 1 to mid-June 1986, sufficient water (more than 180 ft^3/s) was available to satisfy all rights and no rotation occurred. From mid-June to late October 1, 1986, when simulated flows in the West Fork were less than about 180 ft^3/s, weekly rotation between California and Nevada segments caused flows downstream in segment 5 to fluctuate.

Using conditional logic, the operations model for the upper Carson River also simulates operations to fill off-river reservoirs based on pond or reservoir rights. Pond or reservoir capacities varied in the model by two methods. The desired method may be selected by changing a variable flag that controls storage. For the first method, current (1995) storage capacities of Mud Lake, Dangberg Ponds, and Ambrosetti Pond are set within the operations model. As described in the section, Alpine Decree, the Alpine Decree allows the filling of Mud Lake in segment 4 during the nonirrigation season according to decreed storage rights (table 7). The operations model determines when and how much flow is needed to satisfy the Mud Lake rights. Similar logic based on legal decrees is used to fill Dangberg Ponds (segment 2) and Ambrosetti Pond (segment 6) in the Carson Valley. In the operations model, for the second method, proposed storage capacity for Mud Lake can be set by changing the variable flag and by changing the variable specifying the capacity allowed.

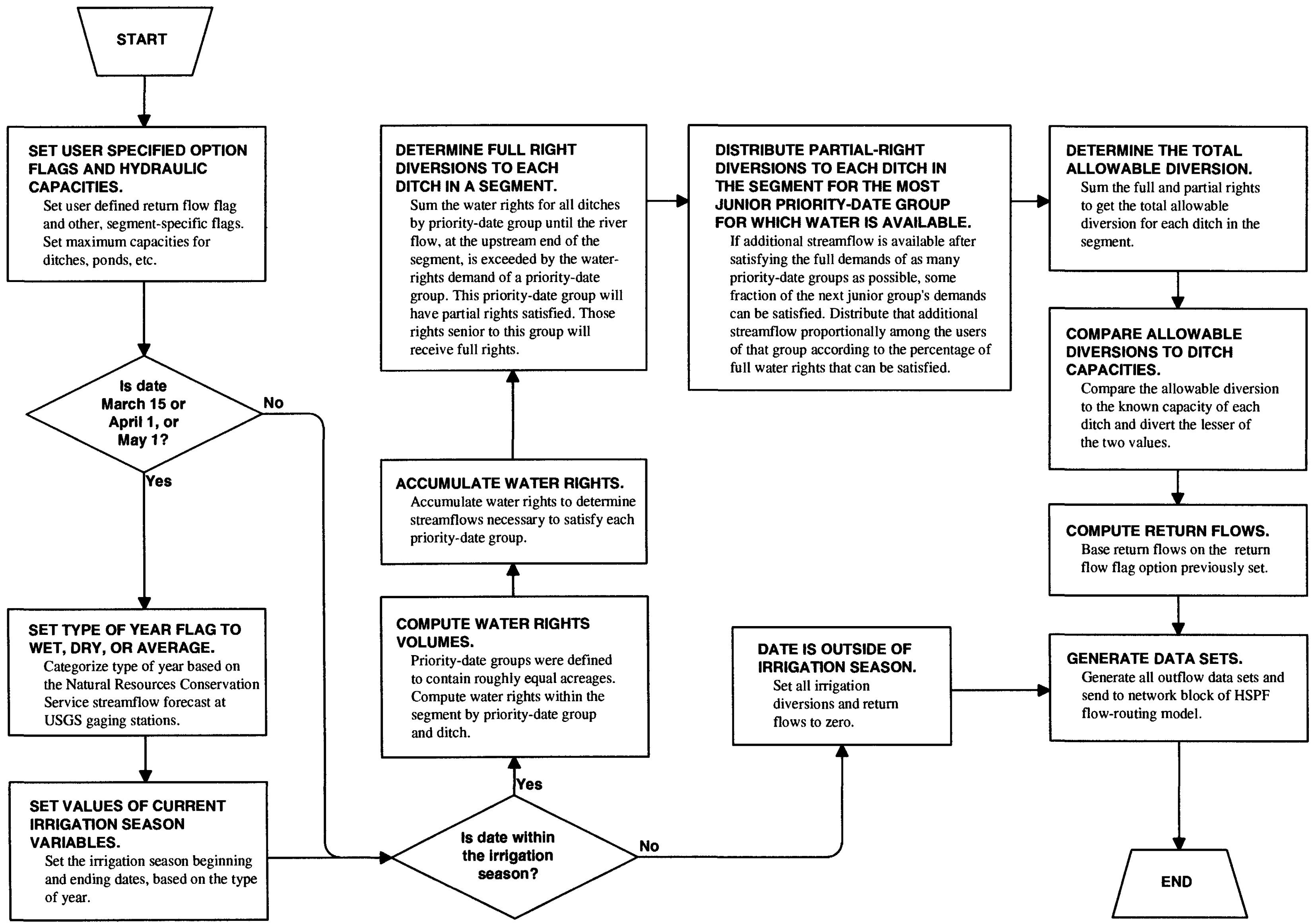


Figure 3. Flowchart of generalized logic used for upper Carson River diversion-operations simulation.

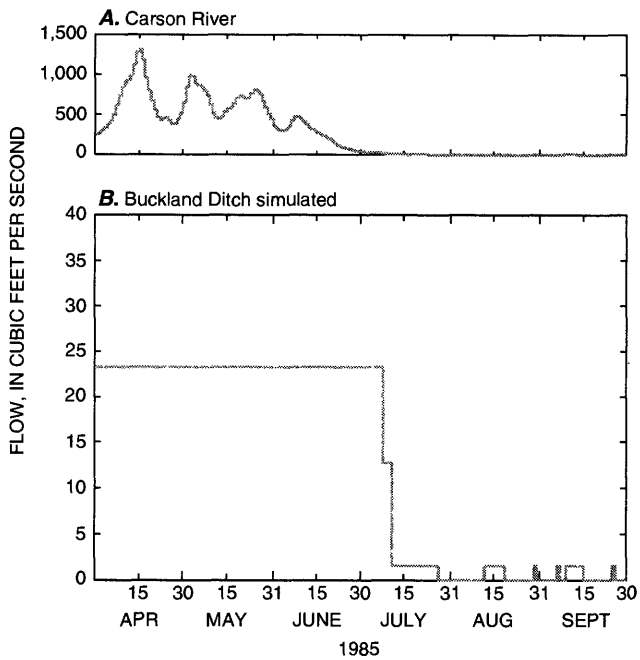


Figure 4. Carson River flow and diversion operations, Buckland Ditch. (*A*) Carson River flow above the ditch headgate and *(B)* HSPF river diversions using existing agricultural water rights to simulate flow in Buckland Ditch.

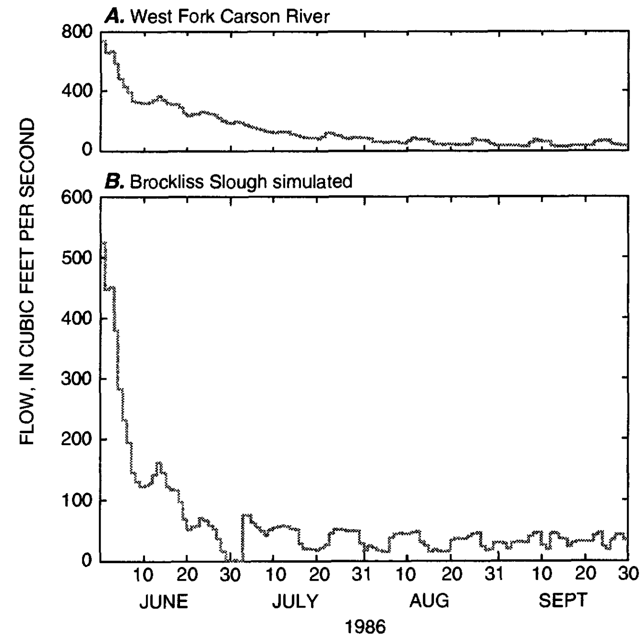


Figure 6. West Fork Carson River flow and diversion operations, Brockliss Slough. (*A*) West Fork Carson River flow and *(B)* HSPF river diversions using the Anderson-Bassman Decree rule of rotation to simulate flow in Brockliss Slough.

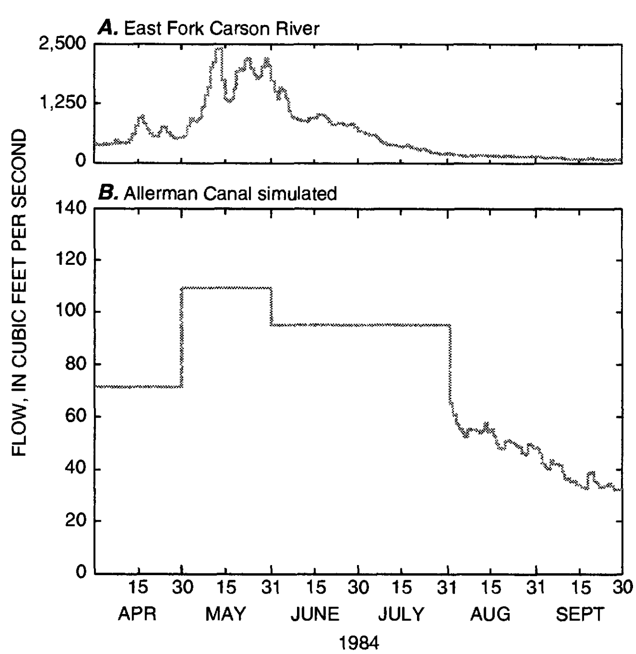


Figure 5. East Fork Carson River flow and diversion operations, Allerman Canal. (*A*) East Fork Carson River flow, and *(B)* HSPF river diversions using the Alpine Decree rules to simulate flow in Allerman Canal.

The irrigation season length and the beginning and ending dates within the model code are determined based on examination of FWM records and Natural Resources Conservation Service (NRCS) forecasted flow data. The forecasted flows are split into three climatic groupings—wet, average, or dry years. Climatic groupings are defined using NRCS forecasted flow data and long-term mean runoff at a site for this operation model. If the forecast is greater than the mean plus 0.5 times the standard deviation, the year is considered wet. If the forecast is less than the mean minus 0.5 times the standard deviation, the year is considered dry. All other years are considered average. The length, and beginning and ending dates of the irrigation season are determined once the climatic grouping is known.

The operations model for the upper Carson River determines the amount of agricultural return flows based on the amount of water diverted. M&I diversions are assumed to have no return flows. Simulated return flows can be varied in the model by two methods. The desired method may be selected by changing a variable flag controlling return flows. For the first method, the simulated return flows are assumed to be zero. This method can show the impact on the whole system if return flows are not available for diversion downstream. For the second method, the assumption is that return flows are conveyed to the next reach downstream. The simulated return flows may be a variable percentage of the diversions during each month of the irrigation season, or they may be a fixed percentage for all months of the irrigation season.

In the operations model, supplemental sources of water (treated effluent stored in reservoirs) are assumed to be used first. Any ditch that has a supplemental source of water will take water from the supplemental source before taking water from the river. The balance of water required to meet rights will then come from the river, if available. Only treated effluent from DCSID on segment 2 and STPUD on segments 4 and 5 is used to satisfy irrigation demands. The amount of treated effluent used, instead of river water, to satisfy irrigation demands on the Carson River can be varied in the model by three methods: (1) effluent is assumed to be used first to satisfy irrigation demands by setting a variable flag, or (2) effluent is not used to supplement irrigation demands, or (3) the amount of effluent available may be changed by multiplying by a percentage of the observed effluent.

Urban development frequently requires a conversion of land use from agricultural to residential or M&I. In the operations model, simulating the change from agricultural rights to M&I rights can be accomplished by reducing the acreage of agricultural rights and increasing the acreage of M&I rights by an equal amount. The operations logic includes the water duty for the agricultural and M&I demands. The water duty for each priority-year group along a ditch is defined by a model variable that can be changed by the user.

Daily patterns for release of water from high-alpine reservoirs for use in the model were determined after an examination of FWM records. In the model, the forecasted flows are split into two climatic groupings—wet years and dry or average years. The simulated high-alpine reservoir releases are determined once the climatic grouping is known. In the model logic, water releases from high-alpine reservoirs are made for irrigation demands based on historical release patterns.

Assumptions Made for Simulating Diversions

The following assumptions and comparison to actual practices, where applicable, were used to construct the operations model.

- The maximum flow capacity of gaged ditches was assumed to be the largest flow value recorded during the period of record.
- Eight hundred water rights, as defined in the Alpine Decree, were combined into 10 different priority-year groups for each segment that represent the individual rights. The rights corresponding to a particular priority-year group were summed for the major ditches in each segment. As a result, groups of rights were modeled for the major ditches rather than individual rights for individual parcels of land.
- The model simulates diversions to ditches as continuous or average amounts for each day throughout the irrigation season, so long as Carson River water is available and the priority years for the land being served are senior to those dates for land in the same segment not currently being served. Actual irrigation practices use water in a more cyclic manner. For example, fields might be flood-irrigated once a week with a daily amount greater than the constant amount simulated by the model. However, because neighboring farmers may stagger ditch withdrawals for lands served by the same ditch, the total volume diverted to any given ditch over a period of several days is assumed to be the same as that produced by the "average daily diversion" simulated by the model. Also, with ample supplies of water, the model will divert the full legal amount every year.
- Streamflow available, after satisfying the full demand of as many priority-year groups as possible, could be used to satisfy some fraction of the next junior group. This streamflow was distributed proportionally among the users of the next junior group according to the percentage of full water rights that could be satisfied.
- NRCS-forecasted flows at Woodfords and Gardnerville provide a reasonable index for estimating the beginning and ending dates of the irrigation season for operation simulations.
- Water duties for lands irrigated by each ditch were estimated in this report from information provided by FWM, the Alpine Decree and Alpine Decree Opinion (U.S. District Court, 1980a,b), and soil-type analyses, because geographically specific values have never been legally established.

- The simulated flow at the upstream boundary of a segment can be used to allocate water within that segment. In practice, the allocation of water also could be based on flow at interior points within the segment which might include "within-segment" return-flow amounts.
- For segment 1 on the East Fork and segment 3 on the West Fork (fig. 2*B*), most rights are riparian with little supervision by the FWM. Therefore, operations on these two segments were not modeled. However, the part of segment 1 from the Markleeville gage (upstream boundary for the flow-routing model) to the California-Nevada State line is modeled using only the flow-routing model.
- Agricultural flows return to the next model reach downstream, unless the return flows are defined otherwise on maps. In practice, agricultural return flows may be used on downgradient fields.
- M&I-diversion return flows are zero.
- Stockwater diversions were not simulated. These diversions were negligible when compared to the diversions for agricultural and M&I demands, and for filling reservoirs.

COMPARISON OF SIMULATED AND OBSERVED OPERATIONS

The upper Carson River Basin operations model was developed to provide water managers with a tool capable of simulating hydrologic processes and river/reservoir operations using a daily, rather than monthly, computation interval. A daily model is needed to examine policies that can be affected by the dynamic nature of streamflow and river/reservoir operations which exist in the day-to-day management of water resources in the upper Carson River Basin. Because the model is flexible, comprehensive, and documented, a common model can be used to examine individual interests which will allow investigation of alternative-management policies and verification of the results. The model documented in this report is not intended for use in simulating historical streamflows. Specifically, the model is designed to facilitate relative comparisons of the effects of alternative management practices or allocations on flows and storages within the system. Relative comparisons allow managers to make decisions based on whether a situation will improve under a proposed operating scenario. Exact water volumes attributable to changes in operations cannot be simulated and results should be considered reasonable estimates.

Traditional model development usually entails calibration and verification tasks in order to demonstrate the reliability of the model. The flow-routing processes embedded in the operations model were evaluated in a previous report by Hess (1996). Because observed streamflows are not meant to be reproduced by the operations model, a classic calibration comparing observed and simulated river operations is not considered appropriate with this model and data base for the four reasons explained in the paragraphs below.

First, the complexity of river and diversion operations in the upper Carson River Basin has been compounded by unique, one-time agreements which deviated from "normal" operations. The operations model does not simulate any of these one-time agreements. Dated operations could have been coded to account for known deviations, but, because the reason for deviation was not always documented nor the number of times the action took place, the decision was made to not account for these operations.

Second, many times nonroutine, minor operations were executed in the upper Carson River Basin. Although these operations were allowable, they were not documented in specific legal decrees or agreements. The operations model attempts to simulate only major, documented operations.

Third, considerable flexibility is used to manage the upper Carson River Basin and to meet the objectives of major decrees and agreements. This "human element" of judgement allows basin managers to implement documented decree and agreement operations differently each year. The operations model does not incorporate such an element of variable judgement. The course of action taken by the operations model will be the same each year under equal conditions.

Fourth, Hess (1996) concluded that data are unavailable to account for all surface- and groundwater inflows and outflows in the Carson River Basin. Errors in volume resulting from this lack of data may be either compensating or cumulative. Therefore, the magnitude of simulation differences resulting from these unavailable data are not fully known.

One, or a combination of, the above reasons make side-by-side comparisons of observed and simulated data difficult to reconcile. In view of these constraints, only limited testing of the upper Carson River Basin operations model can be accomplished. Simulations of upper Carson River streamflow were made using the operations model by applying historic inflow time-series and observed data for water years 1978-95, to conditional logic in the HSPF SPECL block. The period 1978-95 was chosen for comparison for three reasons: (1) those years most represented the current operating strategy coded in the model, (2) operations were more consistent over this period than during other years, and (3) better documentation of all operations in the basin began about 1978.

Many possible geographic locations and hydrologic characteristics could be compared. Streamflow in the main channel is an easily measurable and comparable response that integrates the many complex and interrelated operations in the basin. River and reservoir operations are reflected in downstream flows. To simplify possible lengthy and detailed comparisons, only graphs of observed and simulated streamflow, at three sites along the upper Carson River are provided: *East Fork near Gardnerville, Nev.* (fig. 7), *Carson River near Carson City, Nev.* (fig. 8), and *Carson River near Fort Churchill, Nev.* (fig. 9). These sites correspond to the downstream boundaries of Alpine Decree Segments 1, 6, and 7, where long-term observations of flow are available.

The following text describes qualitative comparisons of observed and simulated daily streamflows determined for monthly time periods and the probable reasons for differences between observed and simulated streamflows. Although the operations model is daily, plots of daily values would be difficult to evaluate for the long period of time and are unnecessary for the purpose of general comparison. Plots of observed and simulated monthly flow at all three sites (figs. 7-9) mostly are similar for water years 1978-95. However, some differences between observed and simulated streamflows can be noted during two time periods: (1) over-simulation of flows in the autumn and winter during low-flow periods, and (2) under-simulation of flows in spring during high-flow periods. Over-simulation of flows in the autumn and winter during low-flow periods is due to inadequate inflow and outflow data. The inadequate data results from unknowns associated with the complex and poorly defined interaction between the river and the ground-water system in the Carson Valley (fig. 2*D*) and from variable return flows from diversions used for agricultural purposes. Under-simulation of flows in spring during high-flow periods is due to inadequate data to account for all tributary inflows. The problem is particularly evident at the Carson River sites, just downstream of areas of substantial ungaged tributary inflows.

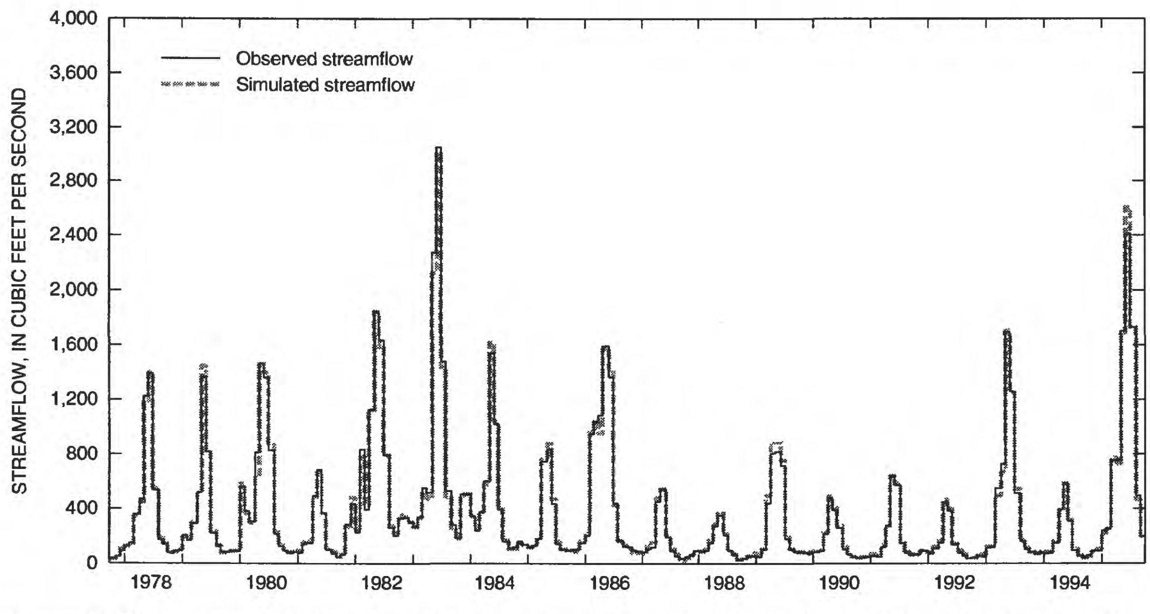


Figure 7. Observed and simulated monthly mean streamflow at East Fork Carson River near Gardnerville, Nev., water years 1978-95.

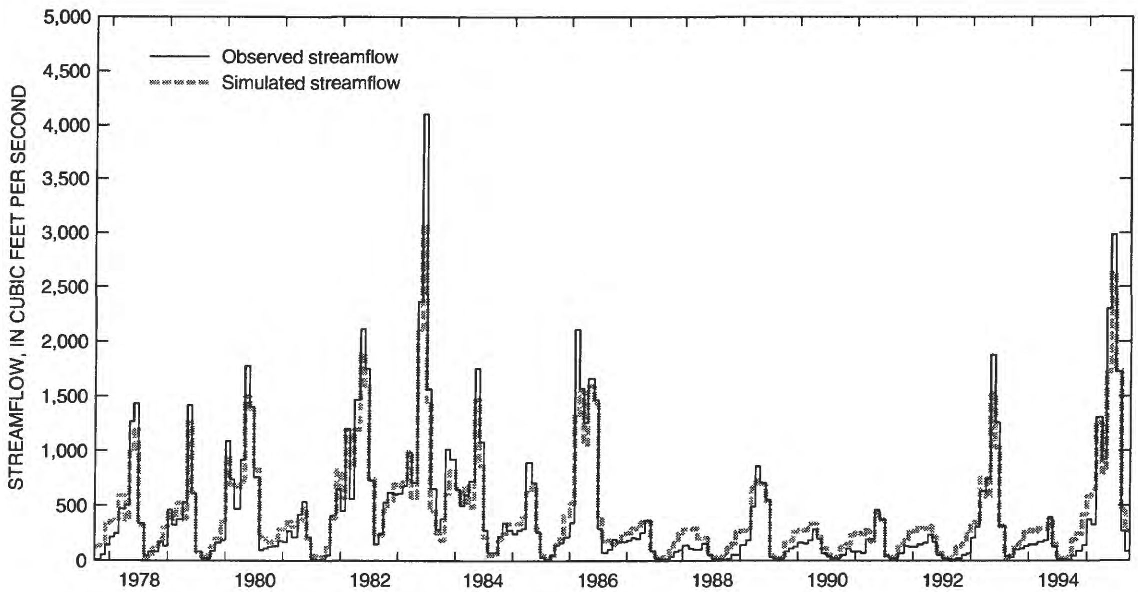


Figure 8. Observed and simulated monthly mean streamflow at Carson River near Carson City, Nev., water years 1978-95.

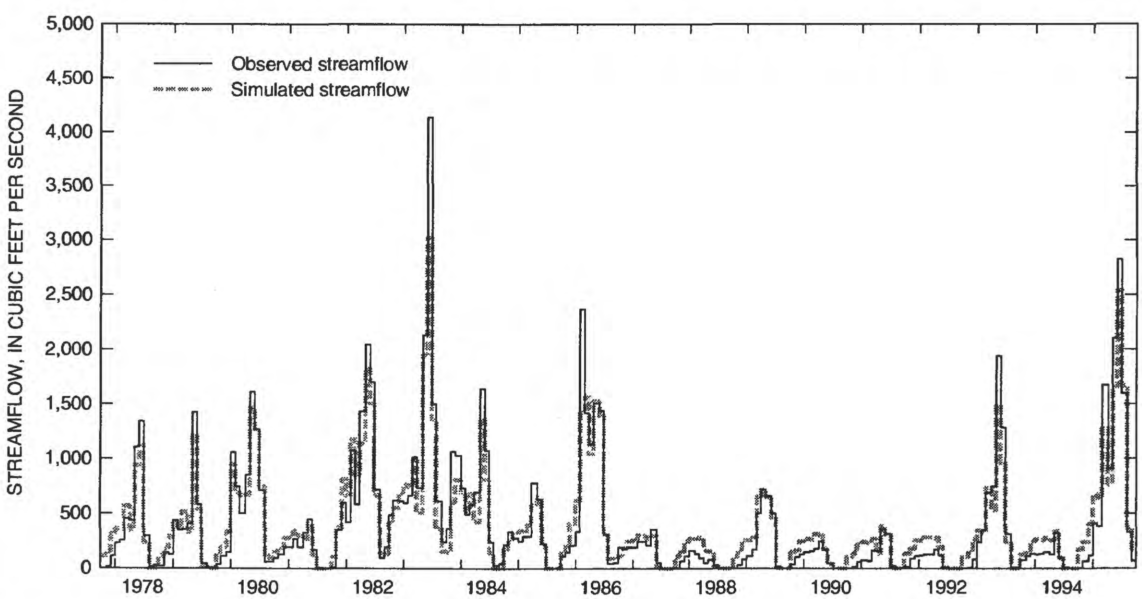


Figure 9. Observed and simulated monthly mean streamflow at Carson River near Fort Churchill, Nev., water years 1978-95.

Model Limitations

Model limitations were defined based on the construction of the operations model:

- Data are unavailable to account for all inflows and outflows in the Carson River Basin. Errors in volume resulting from this lack of data may be either compensating or cumulative. Therefore, the magnitude of simulation differences resulting from these unavailable data is not fully known.
- Various amounts and locations of ground-water pumping cannot be addressed using this model. An additional analysis using a ground-water model, similar to Maurer's (1986) model, might assess the impact of ground-water pumping.
- Some water rights could be satisfied with ground water. However, ground-water simulations for this application are not part of the capabilities of this model.
- In this model, flows are assumed to return to the next reach downstream. Reaches are about 2-3 mi in length (fig. 2*A*). In practice, return flows may be used on the next field downgradient from the first field irrigated. Fields typically are 0.5 mi in length.

Model Improvements

Possible improvements to the USGS upper Carson River Basin operations model are based on the results of the simulations:

- Data are unavailable to account for some inflows and outflows in the Carson River Basin. Additional inflow/outflow information would improve model simulations. Streamflow data from a gaging station at the outlet from Mud Lake could provide better insight into the management of water stored in Mud Lake. Stage data at Mud Lake or inflows are needed to define storage patterns. Flow capacity of ditches used to fill and distribute water from Mud Lake needs to be defined to better simulate inflows to and releases from Mud Lake.
- Significant improvements would be realized if a ground-water model similar to Maurer's (1986) could be integrated into the operations model. This ground-water/surface-water interaction would provide better estimates of the annual or monthly contributions from or losses to the ground-water system of Carson Valley. Similarly, various amounts and locations of ground-water pumping cannot be addressed using the operations model for the upper Carson River.
- Expanding the ability for return flows to serve the next field downgradient would provide more realistic use of return flows in satisfying junior irrigation rights in the same reach.
- Data from additional gaged tributaries would help to better estimate the contributions of ungaged tributaries in Carson and Eagle Valleys, especially during periods of high-spring runoff.
- The USGS Precipitation–Runoff Modeling System (PRMS) simulated daily runoff in the East Fork and West Fork for water years 1969-90. The model also was used to develop twenty-five 100-year, climate-change scenarios (Jeton and others, 1996). Simulated streamflows created by Jeton and others could be used as upstream boundary inflows to show the effect of varying the hypothetical time series of inflows in response to differing climate-change scenarios. The operations model, in conjunction with PRMS models, could be used to help forecast near-term flows into Lahontan Reservoir.

SELECTED MODEL APPLICATIONS

The following sections of the report describe uses of the operations model to simulate complex river diversions in the upper Carson River Basin in eastern California and western Nevada. These applications use selected data for water years 1978-95. Model applications discussed: (1) vary the type of land use by changing agricultural rights to M&I rights, (2) vary the amount of treated effluent for agricultural rights, (3) vary the volume of storage rights, and (4) vary the amount of return flows.

Varying the Type of Land Use

Population growth in the upper Carson River Basin may cause a change in land use from agricultural to urban. During this change, water rights are converted from agricultural use to M&I use. This conversion of water rights can cause changes in streamflows in the upper Carson River by changing the amount of water diverted for agricultural use. In the operations model, varying land use and therefore changing agricultural rights to M&I rights is accomplished by reducing the acreage of agricultural rights and increasing the acreage of M&I rights by an equal amount. The operations logic includes the duty for the agricultural and M&I demands. The water duty for each group of rights along a ditch is defined by a single model variable that can be changed by the user. The following example compares changes in water use in segment 7 (figs. 2*E-H*), caused by changes in land use for Mexican Ditch, and resultant changes in water volume flowing past Fort Churchill, Nev.

Mexican Ditch serves the agricultural water rights for 838.3 acres. In this example, 492.3 acres, all of the agricultural acreage in the eighth priority-year group, were converted to M&I rights. For Mexican Ditch the agricultural duty is 6.0 acre-ft/acre and the M&I duty is 2.5 acre-ft/acre, a decrease in water use of 3.5 acre-ft/acre. However, the model accounts for return flow from agricultural land, which causes the difference in water use to be less than 3.5 acre-ft/acre depending on the amount of return flow assumed. In fact, a large return flow would cause water use to be higher when water rights are converted from agricultural to M&I use because in the model no water is returned from M&I diversions. For this example, an average return flow of 30 percent was assumed for Mexican Ditch agricultural acreage. The model was run for a period of 18 water years, October 1, 1977, through September 30, 1995, with and without the transfer of water rights from agricultural to M&I use. For the 18-year period, the average daily flow in the Carson River below the Mexican Ditch subsegment before the transfer was 415.8 ft^3/s and after the transfer was 417.2 ft^3/s. Downstream at Fort Churchill, the average daily flow before the transfer was 399.4 ft^3/s and after the transfer was 400.5 ft^3/s. Therefore, an increase of flow below the Mexican Ditch subsegment was 18,300 acre-ft and an increase of flow at Fort Churchill was 14,300 acre-ft over the 18-year period due to the transfer. Not all of the increase in flow below the Mexican Ditch subsegment gets to Fort Churchill. Some of the "extra water" is available to satisfy previously unfulfilled water-rights users between Mexican Ditch and Fort Churchill.

Three conditions affect the outcome of this example. These conditions are (1) the assumed amount of return flow, (2) the priority-year group of the rights that are transferred, and (3) the amount of flow available in the river. Under some combinations of these three conditions, water use can be greater when agricultural rights are transferred to M&I rights.

Varying the Amount of Treated Effluent

Population growth in the Lake Tahoe Basin may cause treated-effluent supplies from the Lake Tahoe Basin to the Carson River Basin to increase from Alpine Decree segments 4 and 5. That treated effluent from STPUD (table 3) on segments 4 and 5 is used instead of Carson River water to satisfy agricultural rights in some parts of Carson Valley. As the treated-effluent supply increases, less irrigation water will be diverted from the river and more Carson River water will be available for diversion downstream.

In the operations model, Fredericksburg Ditch in segment 4 has water rights using supplemental treated effluent in addition to Alpine Decree water rights. The observed treated-effluent supply from STPUD in segment 4 is about 3,780 acre-ft/yr for 1978-95. In this example application, the available treated effluent on average is 7,560 acre-ft/yr—two times the supply for 1978-95. A comparison of simulations of streamflow at *Carson River near Fort Churchill, Nev.,* was made between conditions with the observed treated-effluent supply and with double the observed treated-effluent supply. Differences in streamflow simulated in the model at *Carson River near Fort Churchill, Nev.,* indicate that no additional water reaches that point. Doubling the amount of STPUD water available for irrigation did not result in increased flow at Fort Churchill because water rights that were not satisfied when only 3,780 acre-ft/yr of treated effluent were available, were satisfied by diverting the extra 3,780 acre-ft/yr included in the second simulation. Therefore, increasing the amount of STPUD water available for irrigation can increase the number of water rights that are satisfied or partially satisfied, but will not necessarily increase flows at Fort Churchill. The amount of West Fork water diverted to the Fredericksburg Ditch decreased 589 acre-ft/yr on average for 1978-95, because twice the observed amount (7,560 acre-ft/yr) of treated effluent was available to substitute for Carson River withdrawals. The difference, 6,971 acre-ft/yr, was not used for irrigation on Fredericksburg Ditch due to the additional effluent being available for diversion, but was used by previously unsatisfied water rights holders between Fredericksburg Ditch and Fort Churchill.

Varying the Volume of Storage Rights

The volume of storage rights in a reservoir can change due to transfer of water rights as specified under the Alpine Decree. The operations model was used to simulate these changes of water rights and volumes of storage.

The existing Mud Lake storage (segment 4) for October 15, 1983, through September 30, 1984, is shown in figure 10. About November 20, storage in Mud Lake reached the legal limit of 3,172 acre-ft. From November 20 to April 15, Mud Lake storage remained constant except for a slight increase due to localized precipitation on the lake. From April 15 to September 10, the lake storage decreased to zero due to withdrawals for agricultural demands. From September 10–30, 1984, the lake remained empty until filling began in October 1984.

Expanding the storage capacity of reservoirs can be simulated using the operations model. By changing the variable that specifies reservoir capacity as stated in the Alpine Decree, Mud Lake could be simulated to store more water than presently allowed. For example, simulations show that Mud Lake storage increased from 3,172 to 5,104 acre-ft (fig. 10) for October 15, 1983, through September 30, 1984. From April 15 through September 30, the lake storage decreased to about 1,200 acre-ft due to withdrawals for agricultural demands.

Varying the Amount of Return Flow

Irrigation return flow is the excess irrigation water not used that returns to the mainstem (or a collection ditch) from surface runoff, subsurface underflow, or ground-water inflows. These return flows from diversions to the Carson River can be used to satisfy water rights downstream. However, most of these return flows are ungaged. For the operations model as described in the section, Description of Logic Governing River Diversions, return flows are estimated by two

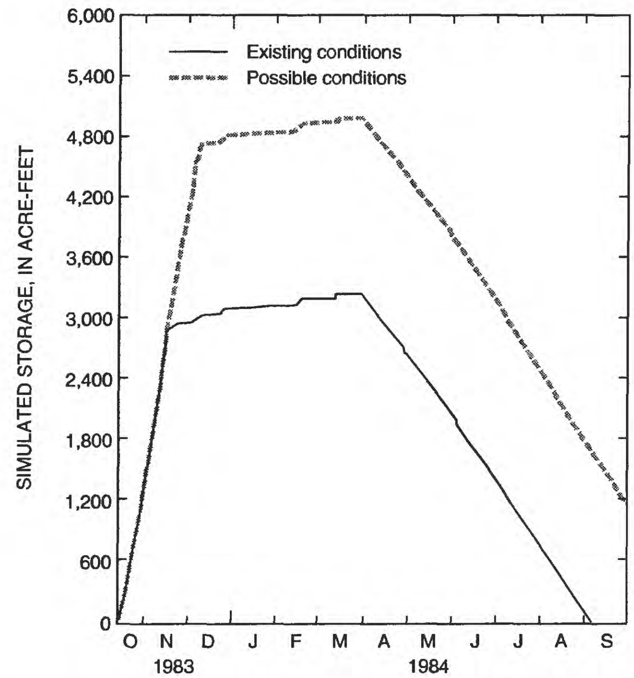


Figure 10. HSPF simulation of water storage in Mud Lake for existing and possible conditions.

methods based on the amount of water diverted. In this application, a comparison was made between model simulations using the two return-flow estimates to analyze downstream effects on the upper Carson River. For one simulation return flows for all segments were set equal to zero. In other words, 100 percent of the water diverted from the river was used for agricultural demands and no return flows were available for downstream use. For the second simulation, return flows were a variable percentage of the diversions during each month. A comparison of the two model simulations for the period 1978-95 at *Carson River near Fort Churchill, Nev.*, indicated that flow at the Churchill gage would be reduced by, on average, 19,100 acre-ft/yr if return flows for all segments were set to zero for the period. This comparison indicates return flows provide on average 19,100 acre ft/yr additional water that can be used to satisfy water rights upstream of Fort Churchill.

SUMMARY

After decades of litigation and negotiation, the Truckee–Carson–Pyramid Lake Water Rights Settlement Act (Public Law 101-618) was passed in 1990. The law provides a foundation for developing operating criteria for interstate allocations of water to meet demands for municipal, irrigation, fisheries and wildlife, and recreational uses. Also water-quality standards are developed for the approximately 7,000-mi^2 Truckee and Carson River Basins of eastern California and western Nevada. The Truckee–Carson Program of the USGS is assisting the U.S. Department of Interior in implementing Public Law 101-618 in part by developing and supporting a modeling system that is physically based for the Truckee River, Carson River, and Truckee Canal. This report discusses the development and application of an operations model to simulate daily streamflow and diversions of the Carson River under current or proposed management constraints.

A daily operations model was constructed to simulate streamflow and reservoir and river operations for the upper Carson River Basin. This model was constructed within a larger *modeling system* which includes a data base management program, a graphical user interface, and a program which simulates reservoir/river operations and a variety of hydrologic processes (Hydrological Simulation Program-FORTRAN (HSPF), Bicknell and others, 1997). This modeling system provides standard formats for data exchange, and programs to enable statistical and graphical analysis (Bohman and others, 1995). The HSPF program is composed of a variety of *modules* which are used to simulate operations or physical processes. Some of these HSPF modules can be used by themselves, while others must be used in tandem with one or more other modules. The simulation of operations requires the use of a flow-routing module and an operations module. *Models* are unique applications of generic programs such as HSPF. Once data and parameters unique to a particular basin are specified or input to the program, a model results which cannot be used in another river or basin. The upper Carson River Basin operations *model* was constructed using the flow-routing module and the operations module.

This report briefly describes the operational practices of the Carson River; describes the modeling system; documents construction of the daily operations model, including a flow-routing model, the data used to simulate operations, and the operational logic and assumptions; and presents selected applications of the operations model. The simulations describe effects of diversions within the Carson River Basin from the gaging stations *East Fork Carson River near Markleeville, Calif.*, and *West Fork Carson River at Woodfords, Calif.*, to the gaging station *Carson River near Fort Churchill, Nev.*

A general overview of daily operations and how they were simulated is provided in this report. In addition to this report, supplemental information that documents the extremely complex operating rules is available. The supplemental information consists of detailed flowcharts, original model code, and a listing of variable names and definitions found in the flowcharts and code.

A physically based operations model using Hydrological Simulation Program - FORTRAN was constructed for simulating streamflow and diversions along the upper Carson River at daily time intervals. An overview of the operational practices in the upper Carson River is given to provide an insight into how the Carson River is operated. The Alpine Decree, which adjudicates the surface-water rights of the Carson River, separates the Carson River Basin into eight segments. Each segment is operated autonomously with respect to diversions. The construction of the model included modules with flow-routing and operational functions.

The flow-routing module characterizes the movement of water into and through the reaches of the drainage network so the operations module can simulate the manmade regulation of water movement within and out of the network. The flow-routing module uses hydraulic characteristics of upper Carson River for 48 stream reaches. This requires the operations module for the Carson River to be run with the flow-routing module that was previously developed.

Much of the data used to simulate operations of Carson River was based on Alpine Decree irrigated acreage and water duties, Price Decree Water Rights, and off-river storage rights. The logic governing river diversions along the Carson River is discussed. Many simplifying assumptions were required and are provided to guide user-application of the model and interpretation of the results. These assumptions are listed in the report.

The operations model documented in this report is not intended for use in simulating historical streamflows. It was specifically designed to facilitate relative comparisons of the effects of alternative management practices or alternative allocations on streamflows and alternative reservoir storages within the system. Relative comparisons allow managers to make decisions based on whether a situation will improve or worsen under a proposed operating scenario. Exact water volumes attributable to changes in operations cannot be simulated and results should not be considered to be anything other than reasonable estimates.

Traditional model development usually entails calibration and verification tasks in order to demonstrate the reliability of the model. However, in the upper Carson River Basin operations model, testing is not considered appropriate for several reasons. In view of these reasons, only limited testing of the USGS upper Carson River Basin operations model can be accomplished. Therefore, current operations were simulated and streamflows at the *East Fork near Gardnerville*, Nev.; *Carson River near Carson City*, Nev.; and *Carson River near Fort Churchill*, Nev., gaging stations were compared to observed values. The time period 1978-95 was chosen because this time period is the most representative of operations coded in the model. Graphs comparing observed and simulated streamflows indicated that differences were mostly due to inadequate inflow and outflow data associated with the flow-routing model used by the operations model.

Suggested model improvements include (1) additional information describing various hydrologic components such as ground-water/surface-water interactions and additional tributary streamflow data, and (2) refining our knowledge of return flows throughout the system as well as our ability to simulate the spatially varied aspects of these components in the model.

Example applications illustrate use of the operations model to simulate diversion operations in the upper Carson River Basin. Selected model applications included varying the type of land-use changes, varying the amount of treated effluent, varying the volume of storage rights, and varying the amount of return flows.

REFERENCES CITED

Archer, W.M., 1984, Soil survey of Lyon County area, Nevada: U.S. Department of Agriculture, Soil Conservation Service, 513 p., 41 plates.

Berris, S.N., 1996, Daily-flow routing simulations for the Truckee River, California and Nevada: U.S. Geological Survey Water-Resources Investigations Report 96–4097, 83 p.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Donigan, A.S., and Johanson, R.C., 1997, Hydrological simulation program–FORTRAN: User's manual for Version 11: U.S. Environmental Protection Agency, National Exposure Research Laboratory, publication EPA/600/R-97/080, 660 p.

Bohman, L.R., Berris, S.N., and Hess, G.W., 1995, Interactive computer program to simulate and analyze streamflow, Truckee and Carson River Basins, Nevada and California: U.S. Geological Survey Fact Sheet FS-165-95, 4 p.

Brown, W.M., III, Nowlin, J.O., Smith, L.H., and Flint, M.R., 1986, River-quality assessment of the Truckee and Carson River system, California and Nevada—Hydrologic characteristics: U.S. Geological Survey Open-File Report 84-576, 201 p.

California Superior Court, Alpine County, 1921, In the matter of the determination of the rights, based upon prior appropriation, of the various claimants of the waters of the West Fork of Carson River and its tributaries, in California: Markleeville, Calif., no docket number; Decree dated Nov. 21, 1921 [known as the Price Decree].

Candland, D.M., 1979, Soil survey of Carson City area, Nevada: U.S. Department of Agriculture, Soil Conservation Service, 169 p.

———1984, Soil survey of Douglas County area, Nevada: U.S. Department of Agriculture, Soil Conservation Service, 575 p., 16 plates.

Cobb, E.D., Olson, A.F., Moosburner, Otto, and Pupacko, Alex, 1990, Review of selected water-management models and results of simulations for the Truckee–Carson Rivers system, California and Nevada: U.S. Geological Survey Open-File Report 90-393, 40 p.

Dangberg, Grace, 1975, Conflict on the Carson—A study of water litigation in western Nevada: Minden, Nev., Carson Valley Historical Society, 467 p.

Hess, G.W., 1996, Progress report on daily flow-routing simulation for the Carson River, California and Nevada: U.S. Geological Survey Open-File Report 96-211, 41 p.

———1997, Simulation of selected river diversion operations in the upper Carson River Basin, Nevada and California: U.S. Geological Survey Fact Sheet FS-240-96, 4 p.

———1999, Hydrologic data for water years 1978-97 used in daily flow-routing and river-operations models for the upper Carson River Basin, California and Nevada: U.S. Geological Survey Open-File Report 99-256, 16 p.

Horton, Gary, 1996a, Carson River chronology - a chronological history of the Carson River and related water issues - pre-Twentieth Century: Nevada Division of Water Planning, Nevada Water Basin Information and Chronology Series, unpaginated.

———1996b, Carson River chronology - a chronological history of the Carson River and related water issues - Twentieth Century: Nevada Division of Water Planning, Nevada Water Basin Information and Chronology Series, unpaginated.

Jeton, A.E., Dettinger, M.D., and Smith, J.L., 1996, Potential effects of climate change on streamflow eastern and western slopes of the Sierra Nevada, California and Nevada: U.S. Geological Survey Water-Resources Investigations Report 95-4260, 44 p.

Jones, J., Maxwell, S.R., and Wieking, J., 1991, Carson River atlas: California Department of Water Resources, 133 p.

Kennedy/Jenks Consultants, 1991, Upper Carson River MODSIM river model: Reno, Carson Water Subconservancy District, Report 877029.07, 354 p.

Kittle, J.L., Jr., Lumb, A.M., Hummel, P.R., Duda, P.B., and Gray, M.H., 1998, A tool for the generation and analysis of model simulation scenarios for watersheds (GenScn): U.S. Geological Survey Water Resources Investigations Report 98-4134, 152 p.

Langbein, W.B., and Iseri, K.T., 1960, General introduction and hydrologic definitions: U.S. Geological Survey Water-Supply Paper 1541-A, 29 p.

Lumb, A.M., Kittle, J.L., and Flynn, K.M., 1990, Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p.

Maurer, D.K., 1986, Geohydrology and simulated response to ground-water pumpage in Carson Valley, a river-dominated basin in Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 86-4328, 109 p.

Taylor, R.L., 1998, Simulation of hourly stream temperature and daily dissolved solids for the Truckee river, California and Nevada: U.S. Geological Survey Water-Resources Investigations Report 98-4328, 69 p.

Thiel, Winchell and Associates, 1993, Investigation of the Mud Lake Reservoir and conveyance methodology: Dayton, Nev., 66 p.

U.S. Congress, 1990, Truckee-Carson-Pyramid Lake Water Rights Settlement Act: Title II of Public Law 101-618, 104, Stat. 3289, 19 p.

U.S. District Court, California, 1905, *Anderson* v. *Bassman*: Final Decree, Equity No. 140-14, 23 p.

U.S. District Court, Nevada, 1944, *The United States of America* v. *Orr Water Ditch Company, et al.*: Final Decree, Equity No. A-3, 88 p.

———1980a, *The United States of America* v. *Alpine Land and Reservoir Co., et al.*, findings of fact, conclusions of law, tabulation and administrative provisions: Final Decree, Civil No. D-183 BRT, 18 p.

———1980b, *The United States of America* v. *Alpine Land and Reservoir Co., et al.*, Alpine Decree Opinion: Civil No. D-183 BRT, p. 877-894 [known as the Alpine Decree Opinion].

U.S. Geological Survey, 1994, Water resources data, Nevada, water year 1993: U.S. Geological Survey Water-Data Report NV-93-1, 596 p.

Yardas, D.E., 1996, Below Lahontan Reservoir model: Reno, Nev., U.S. Fish and Wildlife Service, Documentation and User Guide, version 3,49, 63 p.

GLOSSARY

The technical terms and acronyms used in this report are defined for convenience of the reader. See Langbein and Iseri (1960) for additional information regarding hydrologic terminology.

ANNIE. The time-series, data-management system that includes file creation, data management, analysis, and display.

BOR. Bureau of Reclamation.

CCWTP. Carson City Water Treatment Plant.

CCWUD. Carson City Water Utility Division.

Daily mean streamflow. The mean streamflow for a given day.

DCSID. Douglas County Sewer Improvement District.

Decreed acreage. Irrigated acreage defined by case law.

East Fork. East Fork Carson River.

FWM. U.S. District Court Water Master or Federal Water Master.

GENSCN. Interactive computer program describing GENeration and analysis of model SCENarios (Bohman and others, 1995).

HSPF. Hydrological Simulation Program - FORTRAN.

Hydrographic comparison. A plotted comparison of two or more sets of time-series data showing flow with respect to time.

Individual components of the hydrologic system. The different parts of the water balance of the river such as tributary inflows, irrigation-ditch diversions, irrigation return flows, and ground-water inflows.

Irrigation return flow. Excess irrigation water not used that returns to the mainstem (or a collection ditch) from surface runoff, subsurface underflow, or ground-water inflows.

Irrigation season. Usually the 7-month period April 1 through October 31.

IVGID. Incline Village General Improvement District.

Low-flow investigations. Serial, nearly concurrent, streamflow measurements along the length of the river to determine areas or points of gain or loss.

MGSD. Minden–Gardnerville Sanitation District.

M&I. Municipal and industrial.

NRCS. Natural Resources Conservation Service.

Observed data. A water data base generated from continuous or intermittent gaging-station data.

P.L. Public Law.

PRMS. Precipitation-Rainfall Modeling System.

RCHRES. HSPF block called reach reservoir that simulates processes within a single reach.

Reach. Single zone between two points along the river having uniform hydraulic properties and used within HSPF to simulate the movement of water in a river-channel system.

SPECL. HSPF block called SPECiaL actions that permits the user to simulate operations using conditional logic.

Stockwater diversions. Irrigation diversion outside the irrigation season to provide water for livestock.

STPUD. South Tahoe Public Utilities District.

Streamflow station. A gaging station where a continuous record of discharge is obtained. Within the U.S. Geological Survey, the term is used only for stations where a continuous record of discharge is obtained.

TCID. Truckee-Carson Irrigation District.

UCI. User's Control Input.

USGS. U.S. Geological Survey.

Water balance. An accounting of the inflow to, outflow from, and storage in a hydrologic unit.

Water year. The 12-month period beginning October 1 and ending September 30, and designated by the calendar year in which it ends.

West Fork. West Fork Carson River.

Appendix. Name, size, and description of input files used in hydrologic simulation program for upper Carson River operations model, California and Nevada [1]

File name	Size (bytes)	Description
hspf12.0	5,859,268	Binary file containing source code for HSPF model version 12.0.
annie2.0	3,425,836	Binary file containing source code for data-management system ANNIE.
mast.carson.wdm	15,564,800	Binary file created by ANNIE which contains input and output data sets.
carson1.4.uci	11,026	ASCII-format file containing UCI file for segment 1, operations model.
carson2.4.uci	161,235	ASCII-format file containing UCI file for segment 2, operations model.
carson45.4.uci	192,365	ASCII-format file containing UCI file for segments 4 and 5, operations model.
carson6.4.uci	72,990	ASCII-format file containing UCI file for segment 6, operations model.
carson7.4.uci	178,133	ASCII-format file containing UCI file for segment 7, operations model.
carson.flowchart [2]	175,000	Portable document format (pdf) file containing flowcharts which depict logical decisions coded with the UCI file.
carson.variable.list [3]	15,100	ASCII-format file containing variables used in the UCI and flowcharts along with brief definitions.

[1] To obtain the supplemental documentation on diskette or electronic transfer, please contact the U.S. Geological Survey, Water Resources Division, Nevada District at (702) 887-7649 or email request to <usgsinfo_nv@usgs.gov>.

[2] The flowchart file contains a detailed representation of the logic coded within the SPECL block of the UCI. THis file would be useful to those individuals who would like to know the details of particular operations, but are not familiar with the organization or syntax used in the UCI file.

[3] The variable listing contains all of the variables found in the UCI file and the flowcharts. Brief definitions are provided to assist the user when examining the flowcharts or examining, revising, or correcting conditional logic in the UCI file.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1999-785-517/19154