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Evaluation of Streamflow Losses Along the Gunnison River from Whitewater Downstream to the Redlands Canal Diversion Dam, near Grand Junction, Colorado, Water Years 1995–2003

Prepared in Cooperation with the
COLORADO WATER CONSERVATION BOARD,
UPPER COLORADO RIVER ENDANGERED FISH RECOVERY PROGRAM,
COLORADO RIVER WATER CONSERVATION DISTRICT,
COLORADO DIVISION OF WATER RESOURCES, and the
BUREAU OF RECLAMATION

Scientific Investigations Report 2004–5095

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

Front Cover:

Left photograph: Gunnison River about 2 miles downstream from Whitewater station (photograph by Paul Diaz, U.S. Geological Survey).

Right photograph: Gunnison River near midpoint of study reach photograph by Paul Diaz, U.S. Geological Survey).

Back Cover:

Gunnison River at Redlands Canal diversion dam: Redlands Canal is to the right of the dam, and the fish ladder is to the left and immediately downstream from dam (photograph by Cory Williams, U.S. Geological Survey).

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U.S. Geological Survey, Reston, Virginia: 2004
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Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch	25.4	millimeters

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

BOR Bureau of Reclamation
CDWR Colorado Division of Water Resources
IQR Interquartile range (between the 25th and 75th percentiles)
RPWA: Redlands Power and Water Authority
WY Water year—A continuous 12-month period representing an annual hydrologic cycle selected to present data relative to hydrologic or meteorological phenomena. The water year used by the U.S. Geological Survey runs from October 1 through September 30, and is designated by the year in which it ends.

Evaluation of Streamflow Losses Along the Gunnison River from Whitewater Downstream to the Redlands Canal Diversion Dam, near Grand Junction, Colorado, Water Years 1995–2003

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Abstract

In 2003, the U.S. Geological Survey, in cooperation with the Colorado Water Conservation Board, Upper Colorado River Endangered Fish Recovery Program, Colorado River Water Conservation District, Colorado Division of Water Resources, and Bureau of Reclamation, initiated a study to characterize streamflow losses along a reach of the Gunnison River from the town of Whitewater downstream to the Redlands Canal diversion dam. This report describes the methods and results of the study that include: (1) a detailed mass-balance analysis of historical discharge records that were available for the three streamflow-gaging stations along the study reach; and (2) two sets of discharge measurements that were made at the three stations and at four additional locations.

Data for these existing streamflow-gaging stations were compiled and analyzed: (1) Gunnison River near Grand Junction (Whitewater station); (2) Gunnison River below Redlands Canal diversion dam (below-Redlands-dam station); and (3) Redlands Canal near Grand Junction (Redlands-Canal station). Data for water years 1995–2003 were used for the mass-balance analysis. Four intermediate sites (M1, M2, M3, and M4) were selected for discharge measurements in addition to the existing stations. The study reach is the approximate 12-mile reach of the Gunnison River from the Whitewater station downstream to the Redlands Canal diversion dam, which is about 3 miles upstream from the confluence with the Colorado River.

For the mass-balance analysis, differences between the sum of the annual cumulative daily mean discharge at the two downstream stations and the annual cumulative daily mean discharges at the upstream station ranged from about –28,700 to –69,800 acre-feet (about –1.1 to –5.8 percent), indicating that the downstream discharges generally were less than the upstream discharges. Moving 3-day daily mean discharge averages also were computed for each of the three stations to smooth out some of the abrupt differences between the downstream and upstream daily mean discharges. During water years 1995–2002, differences between the downstream and upstream moving 3-day daily mean discharges ranged from about –200 to +100 cubic feet per second (ft^3/s) (about –10 to 1 percent) during one-half of each year, but the differences had absolute values as large as about 500 to 1,000 ft^3/s (about –60 to +50 percent) during the other one-half of the year.

Two sets of discharge measurements were obtained during water year 2003. For measurement set 1 (February 5–6), discharge was measured 5–8 times over a 24-hour period at sites M1–M4, where measured discharges ranged from 527 to 608 ft^3/s. Discharge was measured once each day at the Whitewater and below-Redlands-dam stations to verify discharge rating shifts; the Redlands Canal was not in operation at this time, so measurements were not needed at the Redlands-Canal station. Recorded 15-minute (unit) discharges ranged from about 575 to 615 ft^3/s at the Whitewater station and from about 560 to 600 ft^3/s at the below-Redlands-dam station during the February 5–6 period. Because of the inherent error in discharge measurements (5 percent for measurements rated good), and because the mean discharge at the below-Redlands-dam station, about 580 ft^3/s, was only about 2.5 percent smaller than the mean discharge at the Whitewater station, about 595 ft^3/s, it is concluded that there was no measurable streamflow loss along the study reach during measurement set 1.

For measurement set 2 (May 14–15), discharge in the Gunnison River was about 2,000 ft^3/s and increasing because of high-elevation snowmelt. Five discharge measurements were made at site M2, and discharge ranged from 1,668 to 2,117 ft^3/s. Measured discharges at the gaging stations were 2,730 ft^3/s at the Whitewater station, 1,268 ft^3/s at the below-Redlands-dam station, and 819 ft^3/s at the Redlands-Canal station. In a hydrographic analysis of unit discharges during May 14–15, and using an estimated traveltime of about 1.5 hours, the discharge measurements made at site M2 correlated closely with the unit discharges recorded about 1.5 hours earlier at the Whitewater station. Also, by using an estimated traveltime of about 3.5 hours, the sum of the unit discharges at the below-Redlands-dam and Redlands-Canal stations also correlated closely to the unit discharges recorded about 3.5 hours earlier at the Whitewater station. Based on these results, it is concluded that there also was no measurable streamflow loss in the study reach during measurement set 2.

Introduction

The Gunnison River is a major tributary of the Colorado River and provides about 42 percent of the streamflow of the Colorado River at the Colorado–Utah State line (Kuhn and Parker, 1992). Administration and management of water resources in the Gunnison River basin are shared by many water-resource agencies, including the Colorado Division of Water Resources (CDWR) and the Bureau of Reclamation (BOR). A responsibility of the CDWR is administration of water-use rights for agricultural, industrial, and municipal users. A responsibility of the BOR is management of the Aspinall Storage Unit, which consists of Blue Mesa, Morrow Point, and Crystal Reservoirs.

Since the mid-1990s, the use of web-based, real-time discharge data has become increasingly important for the administration of water-use rights and management of water resources in the Gunnison River basin. One particular reach along the Gunnison River where these data are used is from the town of Whitewater downstream to the Redlands Canal diversion dam (fig. 1). Three streamflow-gaging stations (fig. 1) (hereinafter referred to as station or gaging station) that provide real-time

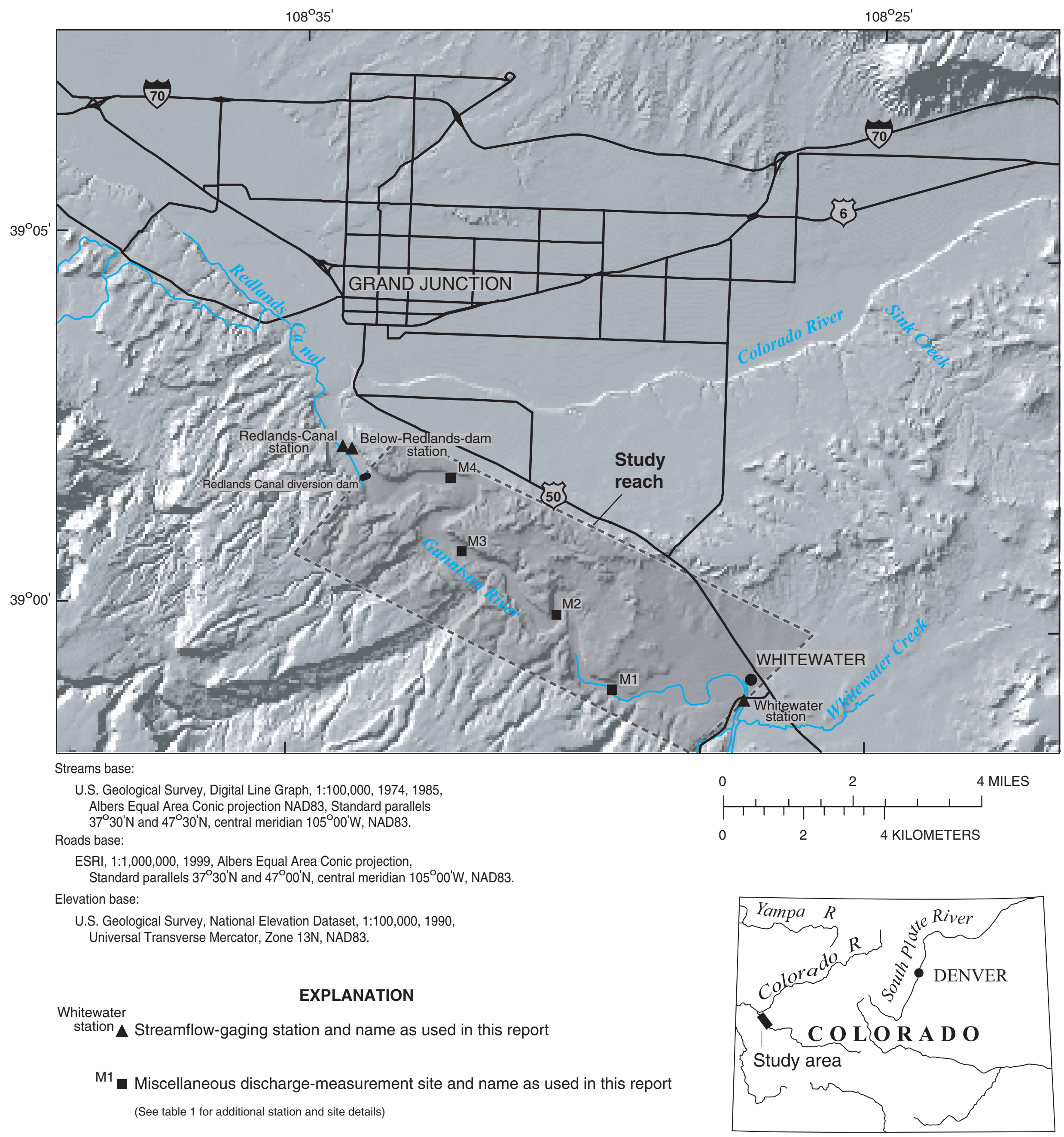

Figure 1. Location of streamflow-gaging stations and miscellaneous discharge-measurement sites along the Gunnison River study reach.

discharge data are in operation (as of 2003) in the reach. During 1995–2002, use of real-time discharge data for these three stations seemed to indicate that the sum of the discharges at the two downstream stations (a main channel and a canal station) usually was less than the discharge at the upstream station (only a main-channel station), indicating a general loss of streamflow in the reach (Coll Stanton, Bureau of Reclamation, and Jerry Thrush, Colorado Division of Water Resources, oral commun., 2002).

The Gunnison River also is important in the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) (U.S. Fish and Wildlife Service, 2002a). The Recovery Program, established in 1988, was implemented to conduct a long-term recovery program for four endangered upper Colorado River basin fish species—the Colorado pikeminnow, razorback sucker, bonytail, and humpback chub—that are protected under the Federal Endangered Species Act of 1973. These endangered fish species once thrived in the Colorado River system, but water-resource development, including the building of numerous diversion dams and several large reservoirs, and the introduction of nonnative fish resulted in large reductions in the numbers and range of the four species (U.S. Fish and Wildlife Service, 2002b).

In March 1994, the Department of the Interior designated 1,980 miles of the Colorado River as "critical habitat" for the Colorado pikeminnow, razorback sucker, bonytail, and humpback chub (U.S. Fish and Wildlife Service, 2002c). In the vicinity of Grand Junction, the designated critical habitat includes (1) the Gunnison River from Delta downstream to the confluence with the Colorado River at Grand Junction, (2) the Colorado River from the Gunnison River confluence upstream to the Grand Valley Canal diversion dam (the "15-mile reach"), and (3) the Colorado River from the Gunnison River confluence downstream to about Salt Creek (the "18-mile reach"). [Note: Delta, Grand Valley Canal, and Salt Creek are outside of the study area and are not shown in figure 1].

Movement of endangered fish from the 15- and 18-mile reaches on the Colorado River into the Gunnison River reach has not been possible since about 1917, when the existing Redlands Canal diversion dam (fig. 1) was completed. In 1996, a 350-foot fish ladder was built by the Recovery Program at the Redlands Canal diversion dam; the ladder provides upstream access to 57 miles of historical habitat that had been inaccessible for nearly a century (U.S. Fish and Wildlife Service, 2002d). However, during low-flow conditions [about 1,000 cubic feet per second (ft^3/s), or less] in the Gunnison River, diversion by the Redlands Canal, which has a decreed capacity of 850 ft^3/s, might decrease discharge flowing through the fish ladder to the point that fish cannot move upstream. The ladder requires 100 ft^3/s to operate and an additional 200 ft^3/s are needed to help the fish navigate through shallow areas downstream from the dam (U.S. Fish and Wildlife Service, 2004).

The Recovery Program has identified recommended flows for the Gunnison River. The BOR intends to prepare a draft Environmental Impact Statement to describe potential effects of operational changes to the Aspinall Unit and its authorized purposes that are related to compliance with the Endangered Species Act (Coll Stanton, Bureau of Reclamation, written commun., May 3, 2004). An important aspect of any operational change is the resulting change to the Gunnison River; therefore, it is necessary to understand the streamflow-loss characteristics of the Gunnison River, particularly along the reach from Whitewater downstream to the Redlands Canal diversion dam, which is thought to be a losing reach. To better understand the streamflow-loss characteristics of this reach, the U.S. Geological Survey (USGS) began a study in 2003, in cooperation with the Colorado Water Conservation Board, the Recovery Program, the Colorado River Water Conservation District, the CDWR, and the BOR, to characterize streamflow losses in the reach of the Gunnison River from Whitewater downstream to the Redlands Canal diversion dam. Results of the study could help in refining operational release rates from the Aspinall Storage Unit to support the Recovery Program, as well as release rates for other purposes.

Purpose and Scope

The purpose of this report is to describe the methods and results of a study of the streamflow-loss characteristics of the Gunnison River from Whitewater downstream to the Redlands Canal diversion dam. Specifically, this report describes the methods and results of the two principal components of the study that include (1) a detailed mass-balance analysis of historical discharge records that were available for the three gaging stations along the study reach, and (2) two sets of discharge measurements that were made at the three stations and at four additional sites.

For the mass-balance analysis of historical discharge records, data for these current (2003) gaging stations (fig. 1, table 1) were compiled and analyzed: (1) Station 09152500 Gunnison River near Grand Junction (hereinafter the "Whitewater" station), operated by the USGS; (2) Station GUNREDCO Gunnison River below Redlands Canal diversion dam (hereinafter the "below-Redlands-dam" station), operated by the CDWR; and (3) station RLCGRJCO Redlands Canal near Grand Junction (hereinafter the "Redlands-Canal" station), also operated by the CDWR. Data for water years (WY) 1995–2003 were used for the mass-balance analysis, because data for the below-Redlands-dam station were available only for this period (table 1). For WY 1995, data for the below-Redlands-dam station only are available for March 1–September 30, but in this report, the period is referred to as "WY 1995."

Although the below-Redlands-dam and Redlands-Canal stations are about 0.7 mile downstream from the Redlands Canal diversion dam (fig. 1, table 1), streamflow losses were investigated only for the reach from the Whitewater station downstream to the Redlands Canal diversion dam (fig. 1). It was assumed that the sum of the discharges at the below-Redlands-dam and Redlands-Canal stations, whether recorded or measured, was the same as the discharge in the Gunnison River just upstream from the diversion dam; hence, for purposes of the

Table 1. Streamflow-gaging stations and miscellaneous discharge-measurement sites along the Gunnison River study reach.

[--, not applicable; USGS, U.S. Geological Survey; ND, not determined; CDWR, Colorado Division of Water Resources; RPWA, Redlands Power and Water Authority]

Station or site name as used in this report (figure 1)	Complete station name	Distance downstream from White-water station (river miles)	Drainage area (square miles)	Operating agency	Period of discharge record (water year)
		Streamflow-gaging stations			
Whitewater station	Station 09152500 Gunnison River near Grand Junction	--	7,928	USGS	1897–98; 1902–06; 1916–2003
Below-Redlands-dam station	Station GUNREDCO Gunnison River below Redlands Canal diversion dam	12.64	ND	CDWR	1995–2003[1]
Redlands-Canal station	Station RLCGRJCO Redlands Canal near Grand Junction	12.52	--	CDWR	1975–2003
		Miscellaneous discharge-measurement sites			
M1	--	3.10	ND	--	--
M2	--	5.68	ND	--	--
M3	--	7.89	ND	--	--
M4	--	9.92	ND	--	--
		Other site			
--	Redlands Canal diversion dam	11.83	--	RPWA	--

[1]Station is operated only as a real-time station for purposes of water-rights administration and water-resources management—No historical daily mean discharge records are available.

study described in this report, it also was assumed that there were no streamflow losses from the diversion dam downstream to the two stations. Streamflow losses were investigated directly (by making discharge measurements) for discharges of about 600 and 2,000 ft^3/s, and indirectly (by analysis of historical discharge records) for the complete range of discharges recorded along the study reach.

Prior to making the discharge measurements along the study reach, two reconnaissance trips were made during January 2003 to evaluate the geologic, hydrologic, and physical characteristics of the study reach and to select intermediate measuring sites between the upstream and downstream gaging stations. Four intermediate sites (M1, M2, M3, and M4; fig. 1, table 1) were selected for discharge measurements in addition to the current stations. Originally, five sets of discharge measurements were proposed to be made, but because of the results of the first two sets (described later in this report), it was determined that the additional measurement sets were not needed.

Although streamflow transit losses along the Gunnison River for Recovery Program releases from the Aspinall Storage Unit eventually might require investigation from the release point downstream to the Redlands Canal diversion dam, the scope of the current study was limited to the reach from the Whitewater station downstream to the Redlands Canal diversion dam. Estimation of streamflow transit losses upstream from Whitewater will be more difficult because of extensive modification of streamflow by irrigated agriculture and the much longer distances involved.

Description of Study Area

The study area is the approximate 12-mile reach of the Gunnison River from the Whitewater station downstream to the Redlands Canal diversion dam, which is about 3 miles upstream from the confluence with the Colorado River (fig. 1). The Redlands Canal (properly named “Redlands Power Canal,” but commonly, and in this report, referred to as “Redlands Canal”) has operated since about 1906, but the existing dam was built in 1917. The primary purpose of the canal is for power generation, but some of the diverted water also is used for agricultural irrigation.

Elevations along the river range from about 4,560 feet at the below-Redlands-dam station to about 4,630 feet at the Whitewater station, but elevations are about 400–600 feet higher on top of the canyon walls that are along some parts of the study reach. Precipitation rates are typical of the arid to semiarid climate and average about 9 inches annually (Western Regional Climate Center, 2004). Rangeland (mixed, herbaceous, and shrub and brush) and forest (evergreen, mixed, and deciduous) predominate the high-desert landscape, accompanied by minor amounts of residential area and a few gravel pits (U.S. Geological Survey, 1992).

Snowmelt during late spring and early summer in the mountainous headwaters of the Gunnison River basin provides most of the streamflow to the study reach. With the exception of occasional monsoonal-thunderstorm events and minor, infrequent snowmelt, the surrounding highlands adjacent to the study reach contribute little streamflow to the main stem of the Gunnison River (Butler and Leib, 2002). Since major completion of the Aspinall Storage Unit (1967), the timing and quantity of streamflow have changed at the Whitewater station. Snowmelt peak flows during April–July are attenuated, and low flows during August–March are larger after completion of the Aspinall Storage Unit in comparison to the more natural flow conditions prior to completion of the unit (fig. 2). Nevertheless, mean annual discharge decreased only slightly from about 2,577 ft^3/s (1,867,000 acre-ft) during 1916–65 to about 2,538 ft^3/s (1,838,000 acre-ft) during 1967–2003. Discharge during the study period (WY 2003) generally was less than the 10th percentile discharge (for WYs 1967–2003) during the first half of the water year and generally was between the 10th and 25th percentiles, except for a few days of higher flow, during the second half of the water year (fig. 2).

The geology within and adjacent to the study reach predominantly consists of Mesozoic sedimentary rock formations and Quaternary alluvium (Bankey, 2004). The oldest formation in the area is the Brushy Basin Member of the Jurassic Morrison Formation, which is composed primarily of multicolored claystone and mudstone (bentonitic). The Brushy Basin Member outcrops along the western flanks of the area and often is overlain by Quaternary landslide deposits. The Cretaceous Burro Canyon Formation and the Cretaceous Dakota Sandstone Formation overlie the Brushy Basin Member throughout the area and form sandstone-topped cliffs along the banks of the river, especially between sites M3 and M4. Jointing in these sandstones seen during reconnaissance of measuring sites is consistent with the northwest trend of faults mapped by Scott and others (2002). Overlying the Dakota Sandstone, the Cretaceous Mancos Shale Formation outcrops along the riverbanks between the Whitewater station and site M1. Various gravels, alluvium, and colluvium of Quaternary age cover the valley floor, some of which are mined in gravel pits along the river between the Whitewater station and site M1, and between site M3 and the Redlands Canal diversion dam (Scott and others, 2002).

Acknowledgments

The authors extend a special thank you to Jerry Thrush of the CDWR in Montrose; his knowledge of the operation of the below-Redlands-dam and Redlands-Canal stations was very useful in completing the analysis of the historical discharge records, and this analysis could not have been completed without his assistance in providing the needed records for the analysis. In addition, his assistance during measurement set 2, especially in measuring discharge at the Redlands-Canal station is greatly appreciated. The assistance of Coll Stanton, BOR in Grand Junction also is appreciated, especially for providing a discharge database for water year 2003 to be included in the analysis of historical discharge. Technical reviews of the report made by George Smith (U.S. Fish and Wildlife Service), and Coll Stanton also are greatly appreciated.

Thanks also are extended to these USGS personnel who assisted in completion of the study and preparation of this report: Assistance during measurement sets 1 and 2, especially those who spent a cold night out along the river during February 5–6, 2003—Eric Adams, Rich Carver, Dan Chafin, Paul Diaz, Ben Glass, Dave Hartle, Ken Leib, Paul von Guerard, and Kirby Wynn; additional technical reviews—William H. Asquith and Jack Veenhuis; editorial review—Carol Anderson; preparation of figure 1—Jean Dupree; and preparation of final manuscript—Margo VanAlstine and Alene Brogan.

Analysis of Historical Discharge Records

As previously discussed, a cursory use of real-time discharge data for the three stations along the study reach (fig. 1, table 1) by water-resource managers indicates that the study reach generally is a losing reach. Therefore, a component of the study was a detailed mass-balance analysis of the historical discharge records available for the three stations along the study reach.

Overview of Discharge-Records Computation

Two types of discharge data usually are available for a gaging station. First, unit discharge data, which typically are data recorded at 15-minute intervals, and second, daily mean discharge data, which are computed from 24 hours (midnight to midnight) of unit-discharge data. A streamflow-gaging station is equipped to directly measure water-surface (stream) elevation (stage) relative to an arbitrary datum, and a recording device records the stage every 15 minutes. Discharge is indirectly measured using stage and a stage-discharge relation.

When a station is first established, a number of discharge measurements are made at the station at various stages, which are used to develop the stage-discharge relation (discharge rating) that relates a given stage to a specific discharge. The discharge rating then is used to determine a unit-discharge value for each of the unit-stage values that are recorded; the daily mean discharge is computed by applying the daily mean stage to the discharge rating or by computing the mean of the unit discharges. After a station has been established and the stage-discharge relation defined, periodic discharge measurements are needed because changes in the channel conditions, such as bed scour or fill during changes in the flow regime, commonly modify the original stage-discharge relation; this is especially relevant to natural stream channels. These additional measurements might define corrections, called shifts, that are applied to

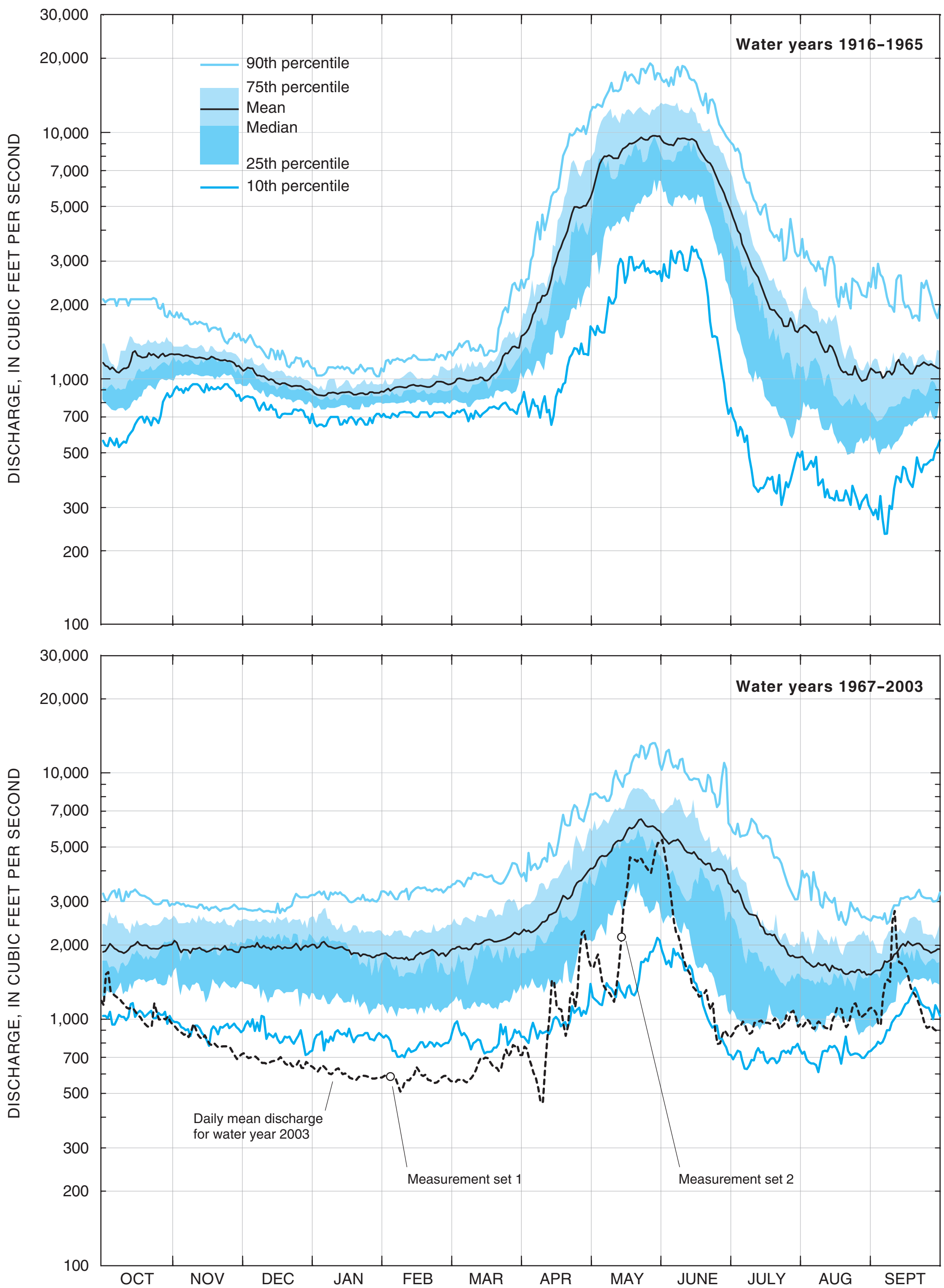

Figure 2. Selected statistics of daily mean discharge for the Whitewater station before (1916–65) and after (1967–2003) major completion of the Aspinall Storage Unit.

the discharge rating to ensure the accuracy of the discharge values. It is common practice in the USGS not to apply shifts if the percentage difference between the measured discharge and the discharge rating is within 5 percent. These methods are described in detail in Rantz and others (1982a, 1982b).

A large proportion of gaging stations currently (2003) operated, including the three stations along the study reach, are equipped with satellite telemetry devices, enabling access of real-time data using the internet. These real-time data are considered provisional (subject to revision) because (1) the recorded stage data might be in error due to equipment malfunctions or other factors; (2) the application of shifts may require modification as more information of gage operation is determined during the year; (3) or other reasons. In most cases, real-time discharge data are reasonably accurate because the technology, operation, and maintenance of real-time discharge stations are well established. During the course of, and at the end of a water year, the recorded unit-stage data undergo extensive quality assurance to ensure that the computed unit-discharge data and the computed daily mean discharges, have the best possible accuracy. During the quality assurance, the shifts that were applied previously to the real-time data may be modified. When all of the quality assurance is completed after the end of the water year, the daily mean discharges are finalized and published. Unit data are not published, but for USGS stations, the unit data are permanently stored in the National Water Information System.

Data computation for the Whitewater and Redlands-Canal stations follows the procedures just described, resulting in published daily mean discharges that are quality assured. The below-Redlands-dam station, however, is operated only for purposes of real-time water-rights administration and water-resource management, and no quality-assured daily mean discharges are available. The only available discharge data are the unit data. These data are subject to a larger degree of error than the quality-assured data for the Whitewater and Redlands-Canal stations. The CDWR makes discharge measurements at regular intervals at the below-Redlands-dam station to identify any discharge rating shifts; however, once applied to the real-time data, no retrospective shift adjustments (quality assurance) to the data are made.

Analysis of Shifts

Use of discharge rating shifts in computation of discharge records is a common and necessary practice and increases the accuracy of the record. In computation of a discharge record, use of percentage differences in discharge (difference between the measured discharge and the discharge rating) requires critical evaluation. Use of percentage differences that have either negative or positive tendencies can introduce some bias into a computed record. Discharge rating shift and percentage difference in discharge data were compiled for the three stations along the study reach and graphically analyzed in order to gain some understanding of the shift history.

Discharge measurements made at the Whitewater station during WYs 1995–2002 usually ranged from 1,000 to 5,000 ft^3/s, with some measurements outside of that range (fig. 3). Zero shifts, with a few exceptions, were used most of the time, and percentage differences in discharge for the shifts generally ranged from –4 to +4 percent (fig. 3). The USGS hydrologic technicians responsible for the station consider the use of mostly zero shifts with some percentage difference between the discharge and the discharge rating as a better approach to records computation than variable shifts with zero percentage difference because the stage-discharge relation at the station is quite stable and has not changed substantially during the past several years (J.R. Sullivan, U.S. Geological Survey, oral commun., 2004).

Discharge measurements made at the below-Redlands-dam station during WYs 1995–2002 usually ranged from 200 to 1,800 ft^3/s, with a few measurements made at discharges less than 200 ft^3/s (fig. 4). Shifts were variable throughout the period and always were negative; reasons for the large decrease in shifts during 1999–2000 are not known, but could be attributable to channel changes resulting from construction of the fish ladder at the Redlands Canal diversion dam or changes in operation of the sand trap at the Redlands Canal diversion dam. Percentage differences in discharge, when applying the indicated shifts, were zero, with a few exceptions (fig. 4).

Discharge measurements made at the Redlands-Canal station during WYs 1995–2002 usually ranged from 700 to 900 ft^3/s, with a few measurements made at discharges less than 700 ft^3/s (fig. 5). Shifts were variable throughout the period and ranged from –0.18 to +0.11 feet. Percentage differences, when applying the indicated shifts, frequently were zero, but about one-third of the measurements had a percentage difference other than zero (fig. 5).

Although the percentage differences for the three stations (figs. 3–5) generally do not appear to be particularly one-sided, box plots were prepared to further evaluate the percentage differences (fig. 6). Based on the results shown in figures 3–6, it was concluded that application of percentage differences in discharge did not result in any discernible bias in the computation of the discharge records for the three stations along the study reach.

Characteristics of the box plots (fig. 6, and others to follow) are as follows (paraphrased from Helsel and Hirsch, 2002, p. 25): The median (50th percentile) is the midpoint of the data values. The end points of the box, the 25th and 75th percentiles, define the interquartile range (IQR). The whiskers extend to the furthest data point that is within one step beyond either end of the box (adjacent values); one step is equal to 1.5 times the IQR. Data points that are between one and two steps from the box in either direction are plotted with an “x” (outliers). Data points that are farther than two steps beyond the box are plotted with an “o” (far outliers).

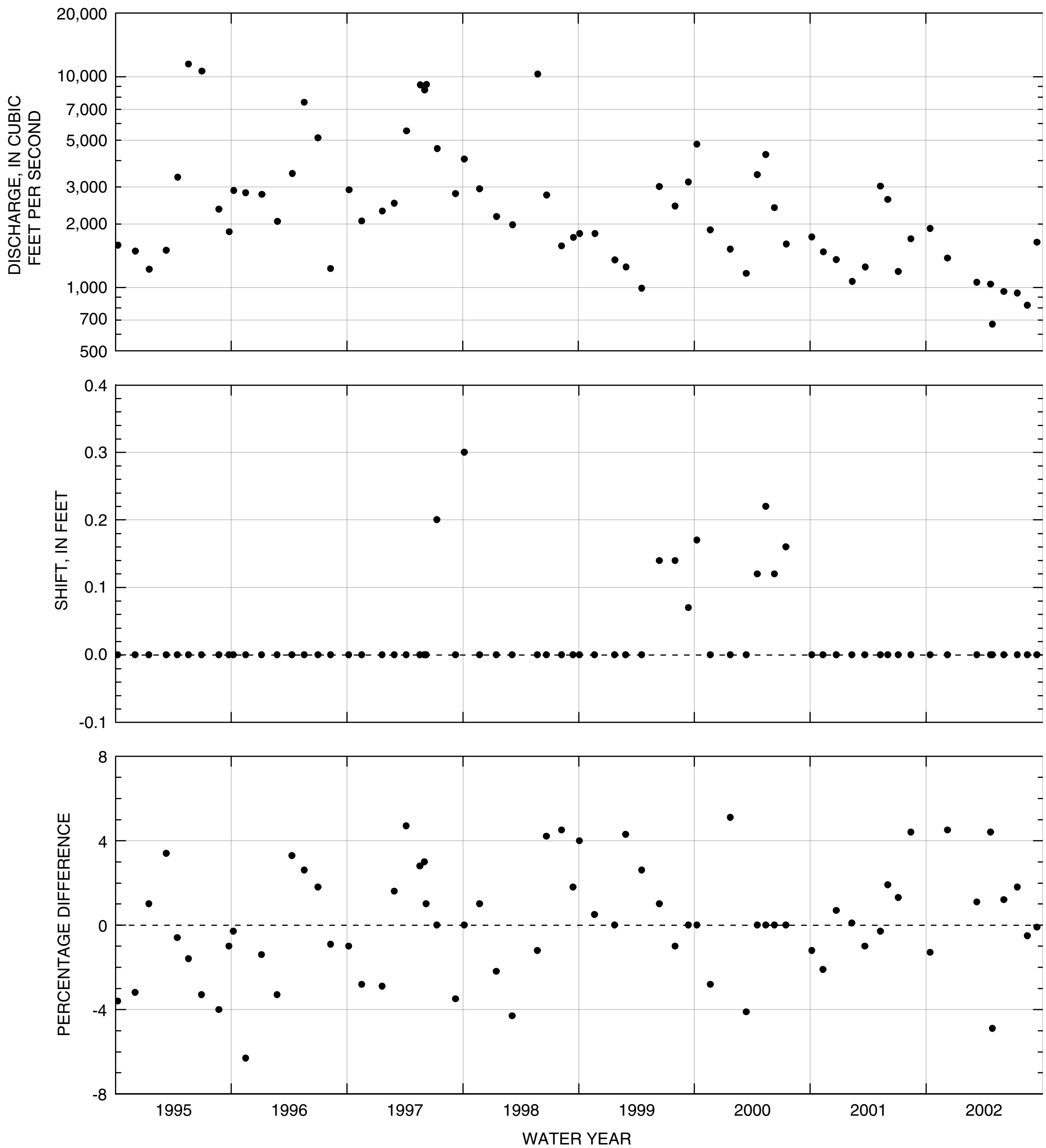

Figure 3. Discharge, shift, and percentage difference between discharge and discharge rating for measurements made at the Whitewater station, water years 1995–2002.

Results for Water Years 1995–2002

When the discharge mass-balance analysis was made, data for WY 2003 were not completed, so the analysis was made only for WYs 1995–2002. Because final, published daily mean discharge data were not available for the below-Redlands-dam station, the archived, real-time unit (15-minute) data were obtained (Jerry Thrush, Colorado Division of Water Resources, written commun., 2003) and daily mean discharges for the below-Redlands-dam station were computed from these data. Some of the unit-discharge values were missing because the unit-stage values were not recorded for a variety of reasons. For days with missing unit data, the mean of the available data was used provided that no more than about 25 percent of the unit values were missing. For days that the number of missing data exceeded 25-percent, the daily mean discharge was estimated (sometimes for more than 1 day) by linear interpolation between the daily mean discharges on the adjacent days that had a computed daily mean discharge. The interpolated values also were compared to the difference between daily mean discharge

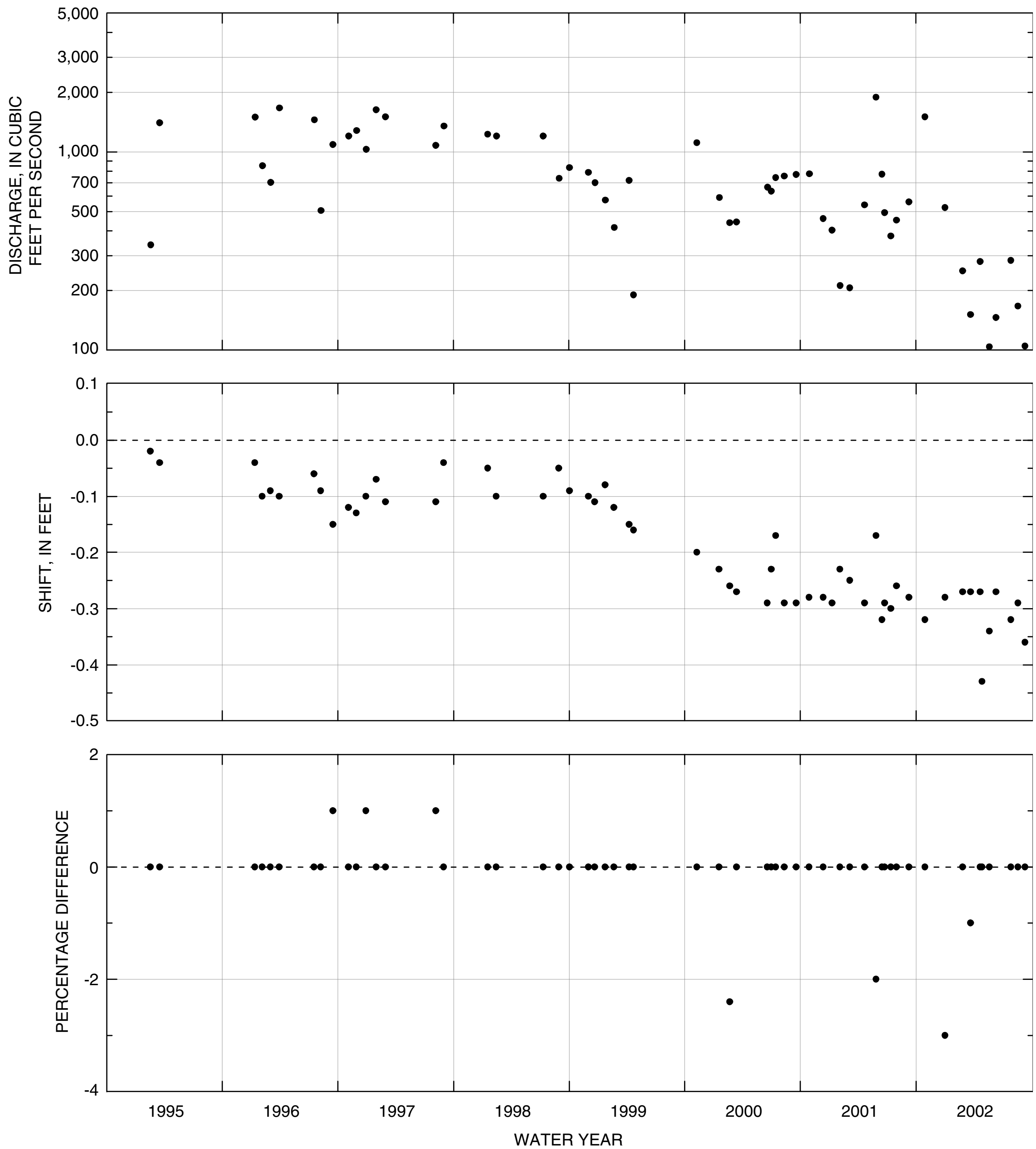

Figure 4. Discharge, shift, and percentage difference between discharge and discharge rating for measurements made at the below-Redlands-dam station, water years 1995–2002.

for the Whitewater and Redlands-Canal stations. For WYs 1995–2002, daily mean discharge was estimated for 85 days (out of 2,771) for the below-Redlands-dam station.

Daily mean discharges at the two downstream stations (below-Redlands-dam and Redlands-Canal) were summed to produce an estimate of the downstream streamflow; this sum was subtracted from the daily mean discharge at the Whitewater station (the upstream streamflow). This difference provides an estimate of the difference between downstream and upstream streamflow along the study reach. These data were compiled for each day of WYs 1995–2002, and the values were summed by water year (table 2). Excluding the partial data for WY 1995, the differences between the annual sums of daily mean discharge at the two downstream stations and the annual sums of daily mean discharges at the upstream station ranged from about –28,700 to –69,800 acre-ft. The difference, as a percentage of the upstream discharge, ranged from about –1.1 to –5.8 percent (table 2). These results indicate that the downstream discharges generally were less than the upstream discharges.

Moving 3-day daily mean discharges also were computed for each of the three stations and the differences between the

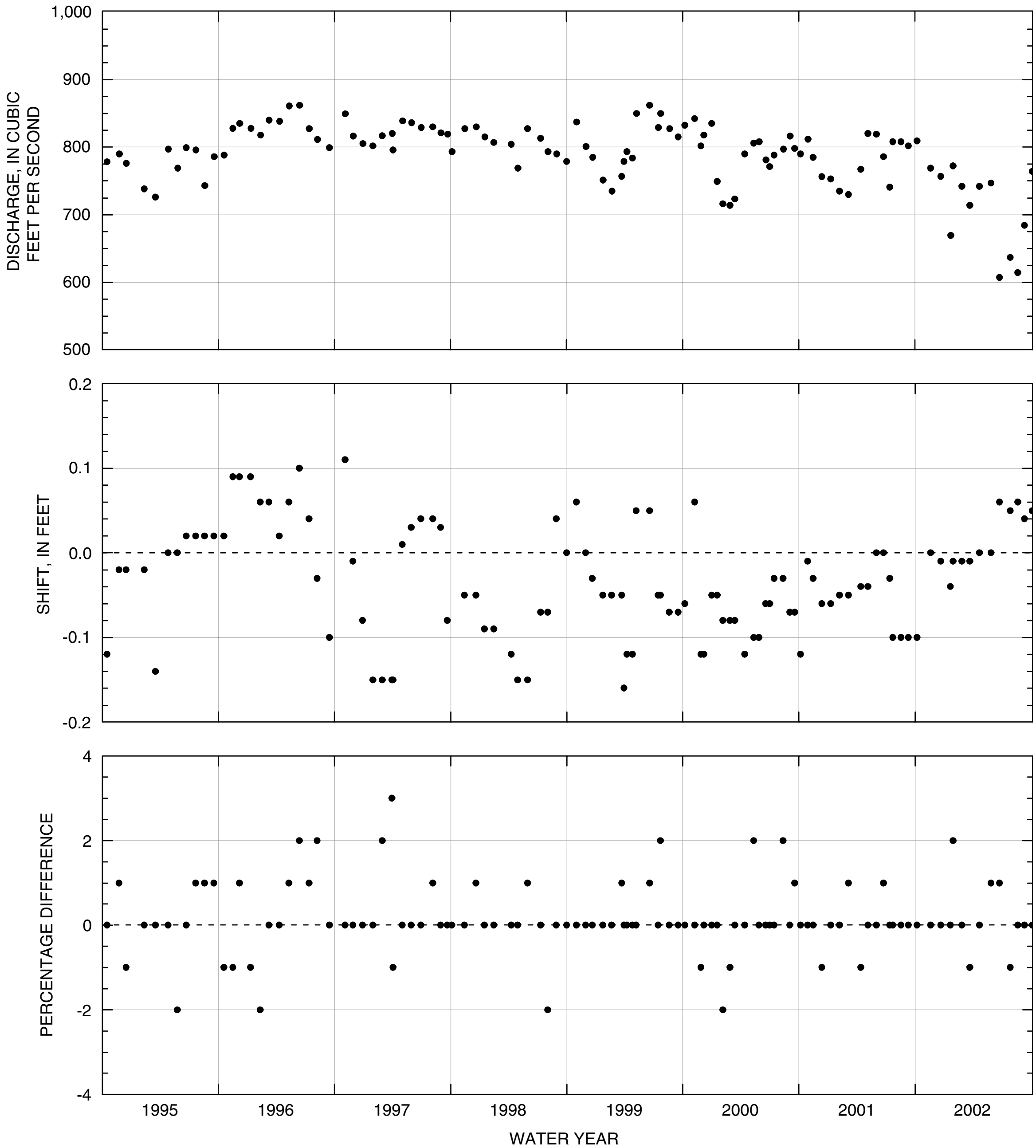

Figure 5. Discharge, shift, and percentage difference between discharge and discharge rating for measurements made at the Redlands-Canal station, water years 1995–2002.

sum of the 3-day daily mean discharges at the two downstream stations and the 3-day daily mean discharge at the upstream station, for additional analyses. The moving 3-day daily mean was used because the sum of the daily mean discharge at the downstream stations almost never is the same as the daily mean discharge at the upstream station because of traveltime effects, even with no loss or gain in the reach; a moving 3-day daily mean could smooth out some of the abrupt differences between the daily mean discharges attributed to traveltime. More complex analytical methods, such as those involving computerized streamflow routing programs, were beyond the scope of this study.

An example of the moving 3-day daily mean discharges at the three stations along the study reach, the sum of the 3-day daily mean discharges at the two downstream stations, and the differences between the downstream and upstream discharges for WY 1996 are shown in figure 7. The characteristics of the data for the other WYs (excluding WY 2003) were similar. Most of the discharge differences are between –200 and +100 ft^3/s and most of the percentage differences are between –10 and 0 percent (fig. 7). The differences between the 3-day daily mean discharge sum at the two downstream stations and the 3-day daily mean discharge at the upstream station seem to be smaller in figure 7*A* in comparison to figure 7*B*; this prima

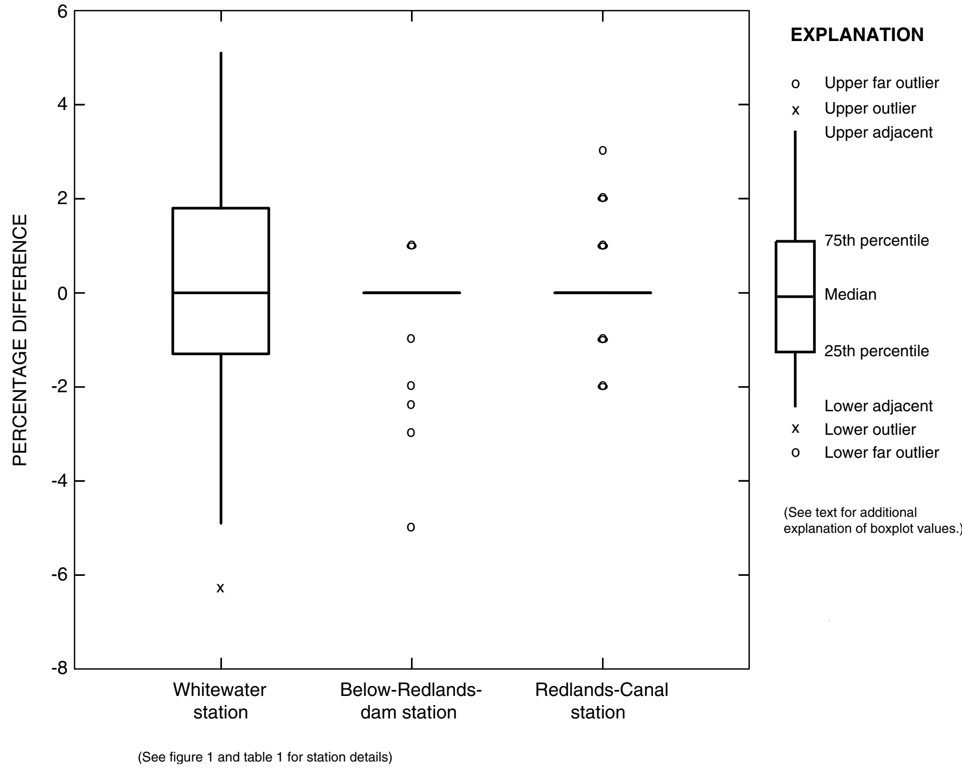

Figure 6. Distribution of percentage differences for applied shifts for measurements made at stations along the Gunnison River study reach, water years 1995–2002.

rily is due to the different types of y-axes—Logarithmic in figure 7*A* and arithmetic in figure 7*B*.

Distributions of daily differences between the moving 3-day daily mean discharge sum at the two downstream stations and the moving 3-day daily mean discharge at the upstream station and the percentage differences during WYs 1995–2002 are shown in figure 8. Excluding WY 2003, differences between the downstream and upstream 3-day daily mean discharges ranged from about –200 to +100 ft^3/s during one-half of each year (the values within the IQR), but the differences had absolute values as large as about 500 to 1,000 ft^3/s during the other one-half of the year (the values outside the IQR). Daily percentage differences each year (1995–2002) almost always ranged from 0 to –10 percent within the IQR and were as small or large as about –60 to +50 percent outside the IQR.

The below-Redlands-dam station does not have a bridge or cableway nearby from which high-discharge measurements can be made, and the highest wading discharge measurement made at the station during WYs 1995–2002 was about 1,800 ft^3/s (fig. 4). Consequently, discharge rating shifts might have considerable error when discharge is larger than about 1,800 ft^3/s. Therefore, a subset of the moving 3-day daily mean discharge data was analyzed that only included those data for which the 3-day daily mean discharges at the below-Redlands-dam station were less than 2,000 ft^3/s. For the subsetted data, the height of the IQR box (between 25th and 75th percentiles) for both the discharge differences and the percentage differences (fig. 9) is somewhat smaller than for all the data (fig. 8). The range of the discharge and percentages differences outside the IQR is nearly as large for the subsetted data (fig. 8), as for all the data (fig. 9), although the number of values each year is smaller for the subsetted data. Overall, differences between the subsetted data and all the data are not large, indicating that the differences can be large even during times of smaller discharge.

Results for Water Year 2003

Near the end of WY 2003, water-resource managers that used the real-time data at the three stations noticed that the general trend of decreased downstream discharge observed during the previous years seemed to have changed to an increase in downstream discharge (Coll Stanton, Bureau of Reclamation, oral commun., 2003). The reasons for the apparent change in downstream discharge were not known, but perhaps the change might be attributed to some changes in the equipment at the below-Redlands-dam station made earlier during WY 2003. At the station, the nitrogen bubbling system, the nitrogen line feeder tubing, and the orifice end cap were replaced on February 21, 2003; the new bubbling system automatically purges the nitrogen line to the stream every 15 minutes, decreasing the possibility of a plugged orifice (Jerry Thrush, Colorado Division of Water Resources, written commun.,

Table 2. Cumulative annual and annual mean discharges for streamflow-gaging stations at the upstream and downstream ends of the Gunnison River study reach and difference between these discharges, water years 1995–2003.

[acre-ft, acre-feet; ft^3/s, cubic feet per second; see figure 1 and table 1 for station details]

Water year	Units	Discharge, for indicated water year, in indicated units					[1]Percentage difference
		Whitewater station (upstream)	Below-Redlands-dam station	Redlands-Canal station	Sum of Below-Redlands-dam and Redlands-Canal stations (downstream)	Difference (down-stream - upstream)	
[2]1995	acre-ft	2,803,400	2,475,800	318,400	2,794,200	-9,200	-0.33
	ft^3/s	4,977	4,395	565	4,960	-16.3	
1996	acre-ft	2,007,600	1,400,000	546,300	1,946,300	-61,300	-3.05
	ft^3/s	2,773	1,934	752	2,681	-84.5	
1997	acre-ft	2,817,000	2,226,900	558,000	2,784,900	-32,100	-1.14
	ft^3/s	3,891	3,076	771	3,847	-44.3	
1998	acre-ft	2,093,000	1,505,600	542,200	2,047,800	-45,200	-2.16
	ft^3/s	2,891	2,080	749	2,829	-62.4	
1999	acre-ft	1,692,700	1,051,300	571,600	1,622,900	-69,800	-4.12
	ft^3/s	2,338	1,452	790	2,242	-96.3	
2000	acre-ft	1,466,400	863,000	542,000	1,405,000	-61,400	-4.19
	ft^3/s	2,020	1,192	747	1,939	-84.5	
2001	acre-ft	1,170,700	547,300	555,700	1,103,000	-68,000	-5.81
	ft^3/s	1,617	756	768	1,524	-93.5	
2002	acre-ft	805,100	296,900	479,500	776,400	-28,700	-3.56
	ft^3/s	1,112	410	662	1,072	-39.6	
2003	acre-ft	860,100	522,300	333,800	856,100	-4,000	-0.47
	ft^3/s	1,188	721	461	1,182	-5.43	

[1]Percentage difference = [(downstream discharge - upstream discharge) / upstream discharge] x 100.

[2]For the March 1–September 30, 1995, period.

2004). In order to evaluate the apparent change in downstream discharge, it was decided to expand the previously completed mass-balance analysis to include WY 2003. In addition to using the published daily mean discharge data for the Whitewater and Redlands-Canal stations for the mass-balance analysis, daily mean discharges for WY 2003 that received some quality assurance also were computed for the below-Redlands-dam station (Jerry Thrush, Colorado Division of Water Resources, written commun., 2003).

Methods for mass-balance analysis for WY 2003 were identical to those used for WYs 1995–2002, but the results were somewhat different. The difference between the sums of daily mean discharges at the two downstream stations and the daily mean discharge at the upstream station, about –4,000 acre-ft, and the percentage difference, about –0.5 percent, for WY 2003 are substantially smaller than for any other water year, excluding the 1995 partial year (table 2). Differences between the sum of the moving 3-day daily mean discharges at the two downstream stations and the moving 3-day daily mean discharge at the upstream station, as well as the percentage differences, for WY 2003 (fig. 10) are substantially smaller than those for WY 1996 (fig. 7), which is representative of WYs 1995–2002. In addition to a smaller annual difference for WY 2003 (table 2), the variability in the differences between downstream and upstream moving 3-day daily mean discharge also was much less during WY 2003 than during the previous years (figs. 8–9). Although the IQRs for discharge difference and percentage difference for WY 2003 are not the smallest, 2003 is the only water year for which the medians are near zero (figs. 8–9).

The near-zero annual difference (table 2) and near-zero medians for WY 2003 (figs. 8–9) resulted from generally negative differences during the first one-half of the year and

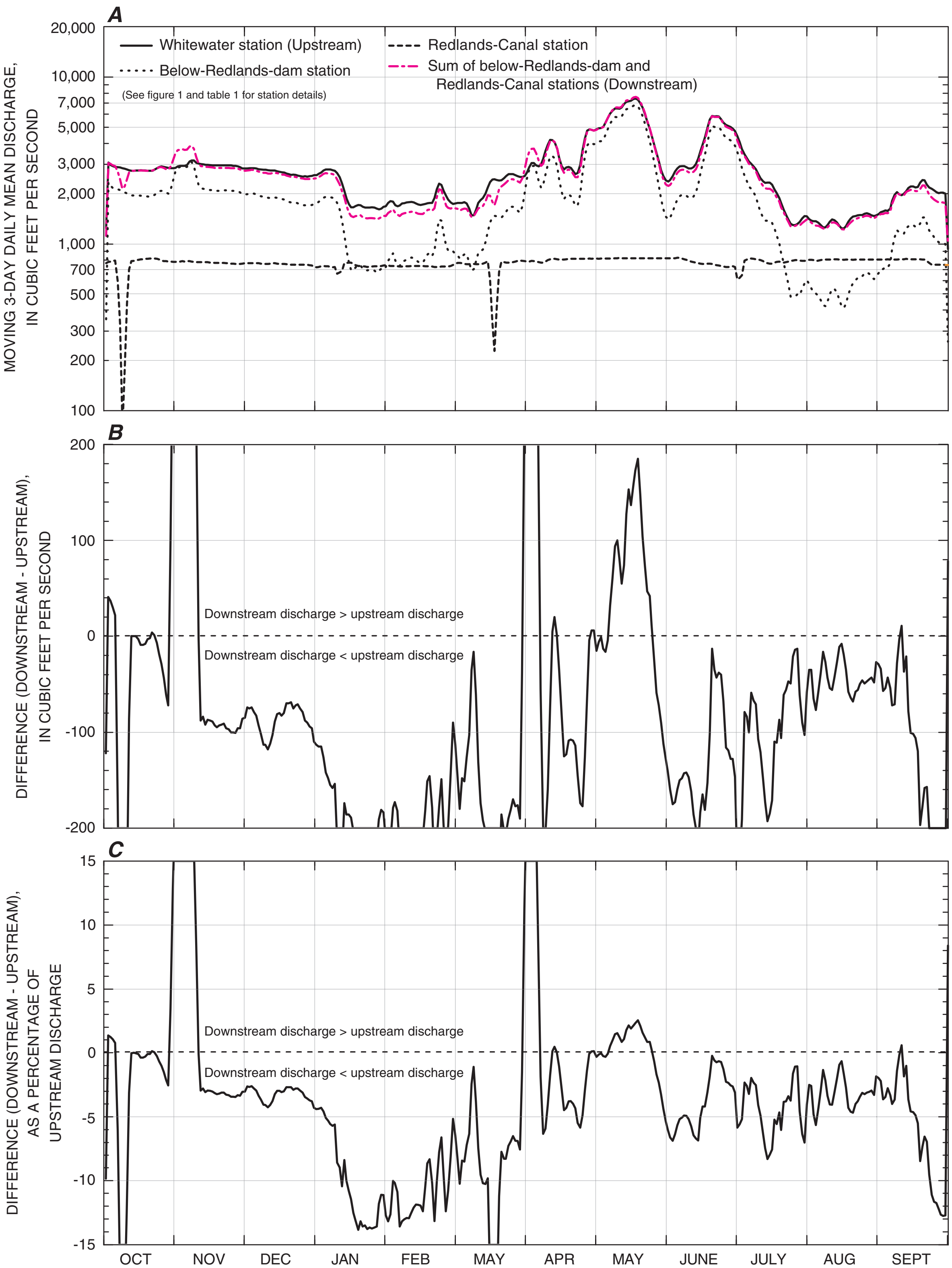

Figure 7. Moving 3-day daily mean discharge for stations at the upstream and downstream ends of the Gunnison River study reach and differences between the discharges, water year 1996.

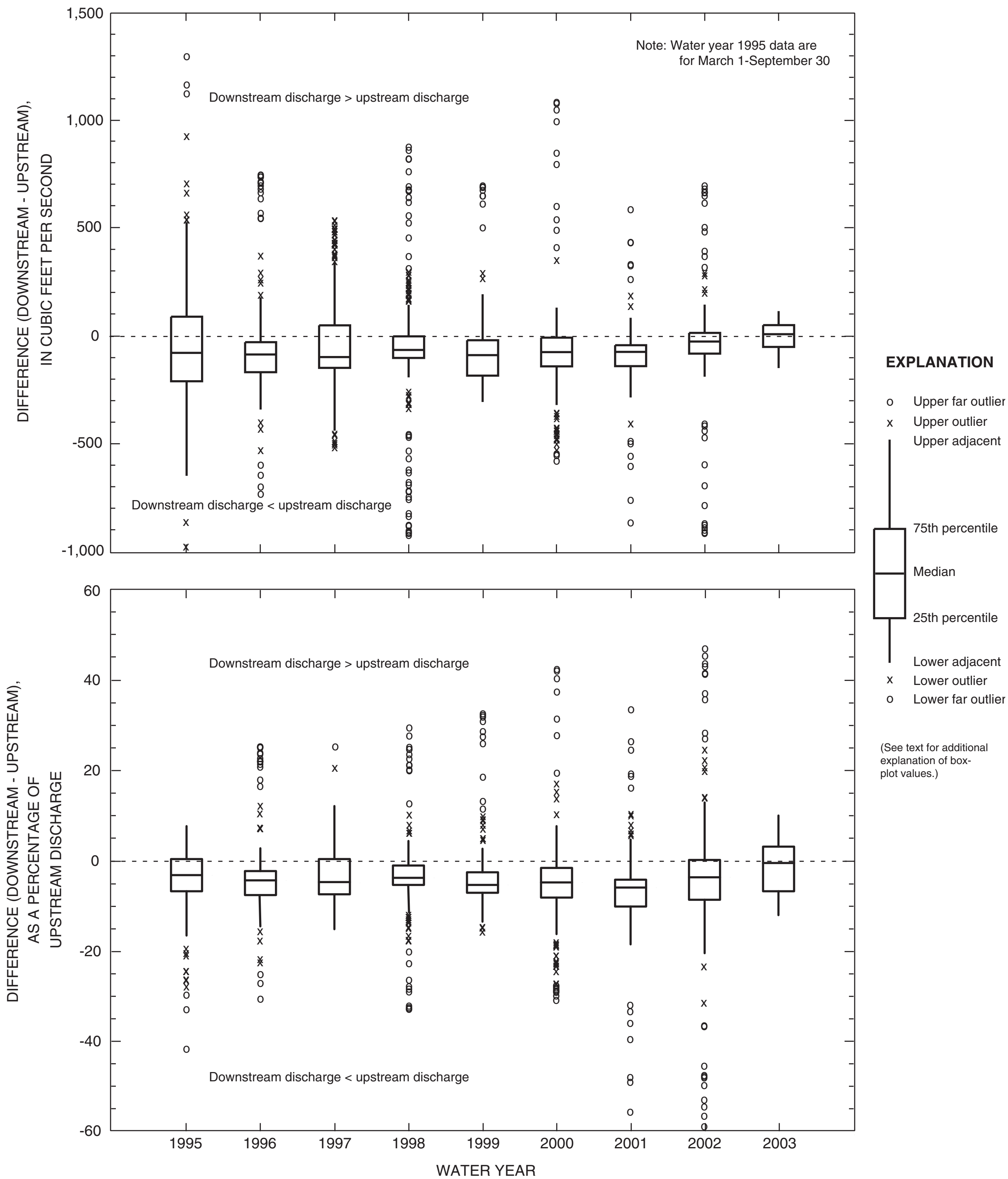

Figure 8. Distribution of differences between moving 3-day daily mean discharge at the upstream and downstream ends of the Gunnison River study reach, water years 1995–2003.

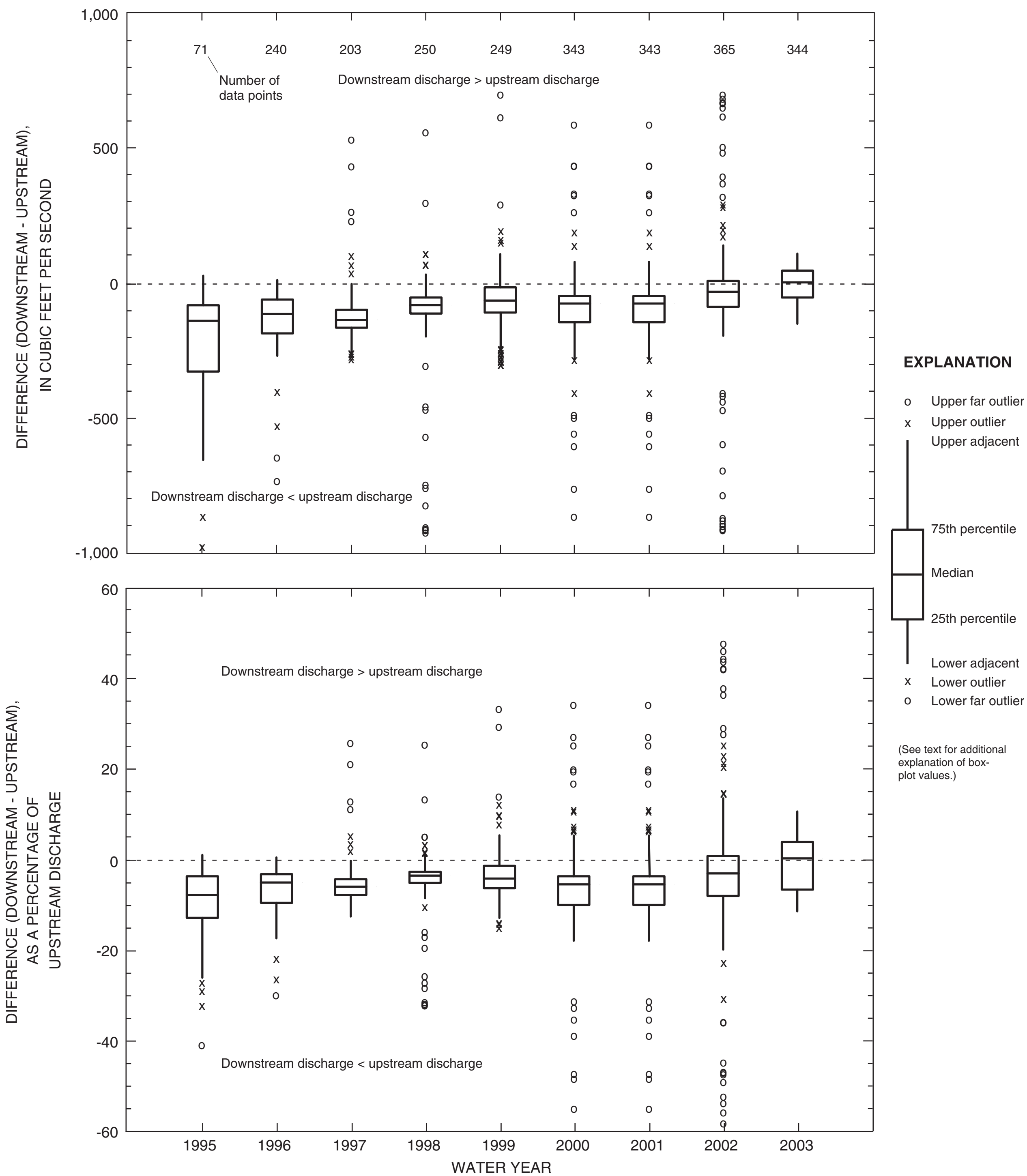

Figure 9. Distribution of differences between moving 3-day daily mean discharge at the upstream and downstream ends of the Gunnison River study reach when discharge at the below-Redlands-dam station is less than 2,000 cubic feet per second, water years 1995–2003.

generally positive differences during the second one-half of the year (fig.10*B*). The smaller overall difference (table 2) and the smaller 3-day daily mean differences (fig. 10) for WY 2003, however, partly could be the result of (1) the smaller than normal discharges during WY 2003 (fig. 2); (2) the period of no diversion by the Redlands Canal (fig. 10); and (3) the use of daily mean discharges for the below-Redlands-dam station that were partially quality assured.

Streamflow Measurements

A reconnaissance of the study reach was made during January 2003 to evaluate the geologic, hydrologic, and physical characteristics of the study reach. The location of geologic features, such as faults, or man-made features, such as gravel pits, that could affect streamflow loss along the study reach were noted for consideration in analysis of the study results; however, the effects of these on streamflow in the study reach were considered to be very minimal. Most of the study reach is inaccessible by vehicles, except in the vicinity of the upstream and downstream stations; therefore, the reconnaissance was made by canoes, traveling downstream from the Whitewater station. Four miscellaneous-measuring sites (M1–M4; fig.1, table 1) were selected during the reconnaissance for use in making the discharge measurement sets to aid in evaluating streamflow loss. Discharge measurements at the intermediate locations could help determine if the losses are uniformly distributed throughout the study reach or if the losses are just in a certain location or locations.

Two discharge measurement sets were obtained, one during February 2003, and one during May 2003 (fig. 2). All discharge measurements for measurement set 1 were made by wading and using standard current meters (Rantz and others, 1982a). Discharge measurements for measurement set 2 were made by wading (at the below-Redlands-dam station), long rod (at the Redlands-Canal station), and cableway (at the Whitewater station), all using standard current meters (Rantz and others, 1982a), and by using boat-mounted acoustic doppler current profiler equipment (Morlock, 1996; Simpson, 2001) at site M2.

Measurement Set 1

Discharge measurements for measurement set 1 were obtained during February 5–6, near the lowest discharge period during WY 2003 (fig. 2). Discharge was measured 5–8 times over a 24-hour period during the 2-day period at sites M1–M4, by teams who accessed the sites by canoe and remained onsite (from about mid-day on February 5 to about mid-day on February 6). Temporary staff gages also were installed at the four sites, and stage was observed about every hour and more frequently during each measurement. Maximum change in observed stage was small at the sites, ranging from 0.03 to 0.05 foot. Discharge was measured once each day at the Whitewater and below-Redlands-dam stations to verify discharge rating shifts; the Redlands Canal was not in operation, so measurements were not needed at the Redlands-Canal station.

Measured discharges at sites M1–M4 ranged from 527 to 608 ft^3/s; measured discharges at the Whitewater station were 628 and 588 ft^3/s; and measured discharges at the below-Redlands-dam station were 579 and 565 ft^3/s (fig. 11). All measurements were rated good (5-percent accuracy), except the measurement of 628 ft^3/s at the Whitewater station, which was rated fair (8-percent accuracy). Recorded unit discharges at the Whitewater station ranged from about 575 to 615 ft^3/s, and recorded unit discharges at the below-Redlands-dam station ranged from about 560 to 600 ft^3/s during the 2-day period (fig. 11).

Although the variation in mean or median discharge among the sites seems large (fig. 11), this partly results from the y-axis scale that has a large expansion of a relatively small discharge range. Generally, the range of the discharge measurements at each site is well within the 5-percent accuracy. For example, assuming a central discharge tendency of 580 ft^3/s, at a 5-percent accuracy, a measured discharge could range from 551 to 609 ft^3/s. The variation in discharge from one site or station to another (fig. 11) partly might be the result of differences in measurement technique, but probably is more attributable to local variations in channel conditions. For example, site M1 was just downstream from a pool and riffle sequence and site M4 was just downstream from a large bend where the channel began to broaden. At these sites, some discharge could have been flowing through the unconsolidated gravel adjacent to or under the streambed (underflow), only to be discharged back to the stream some distance downstream, indicated by the rises in discharge at site M2 and at the below-Redlands-dam station. Because of the inherent error in discharge measurements (5 percent for measurements rated good), and because the mean discharge (about 580 ft^3/s) at the below-Redlands-dam station was only about 2.5 percent smaller than the mean discharge (about 595 ft^3/s) at the Whitewater station it was concluded that there was no measurable streamflow loss along the study reach during measurement set 1.

Measurement Set 2

Discharge in the Gunnison River during measurement set 2 (May 14–15, fig. 2) was about 2,000 ft^3/s and increasing because of high-elevation snowmelt. Because of the high discharge, wading measurements were not possible at any of the sites or stations, except at the below-Redlands-dam station, where discharge was lower due to the upstream diversion into the Redlands Canal. In addition, besides making discharge measurements at the three stations to verify discharge rating shifts, discharge was measured only at site M2 for the following reasons: (1) The changes in discharge observed from one site or station to another during measurement set 1 (fig. 11), likely would not be observed during measurement set 2 because of the

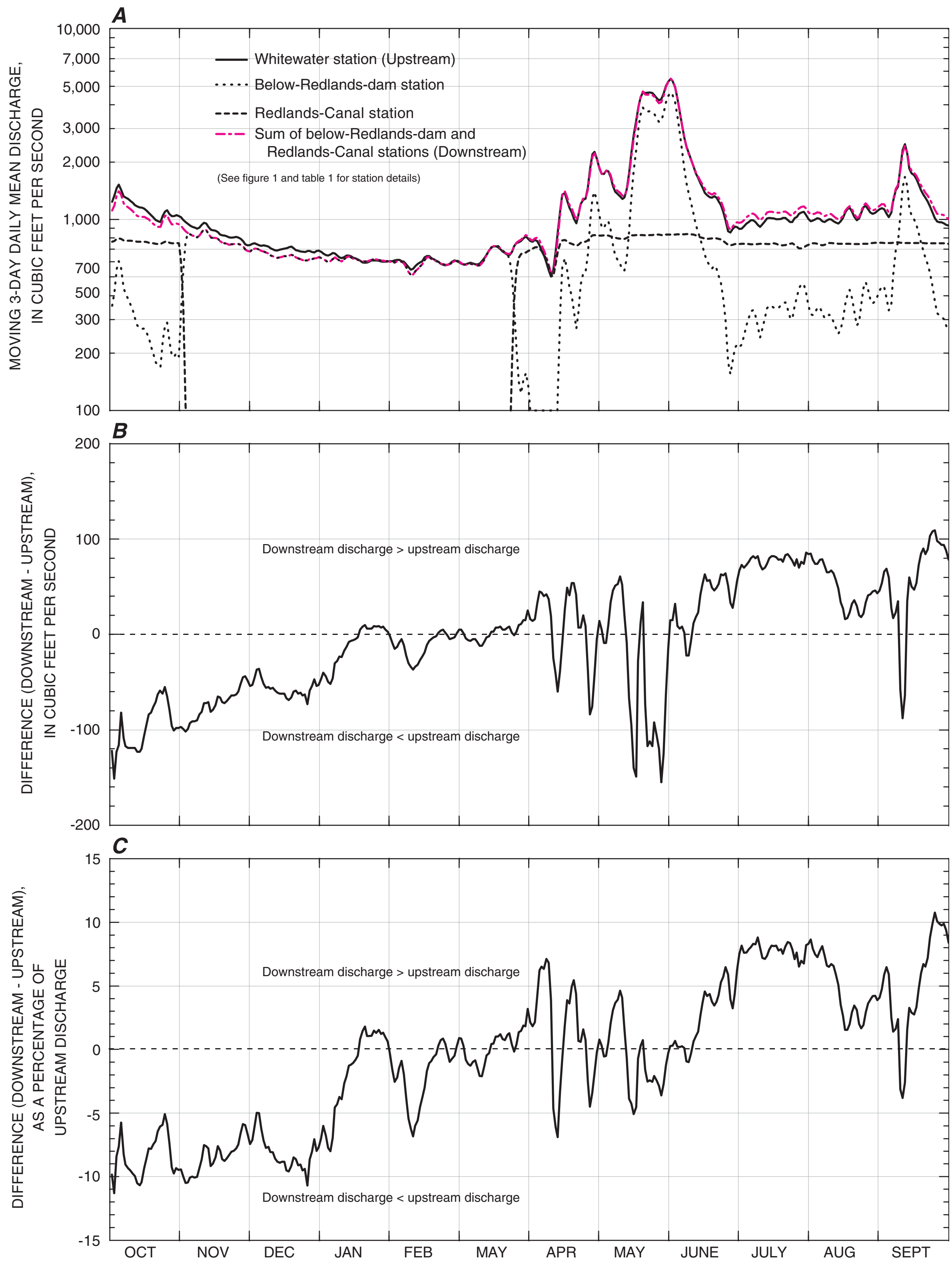

Figure 10. Moving 3-day daily mean discharge for stations at the upstream and downstream ends of the Gunnison River study reach and differences between the discharges, water year 2003.

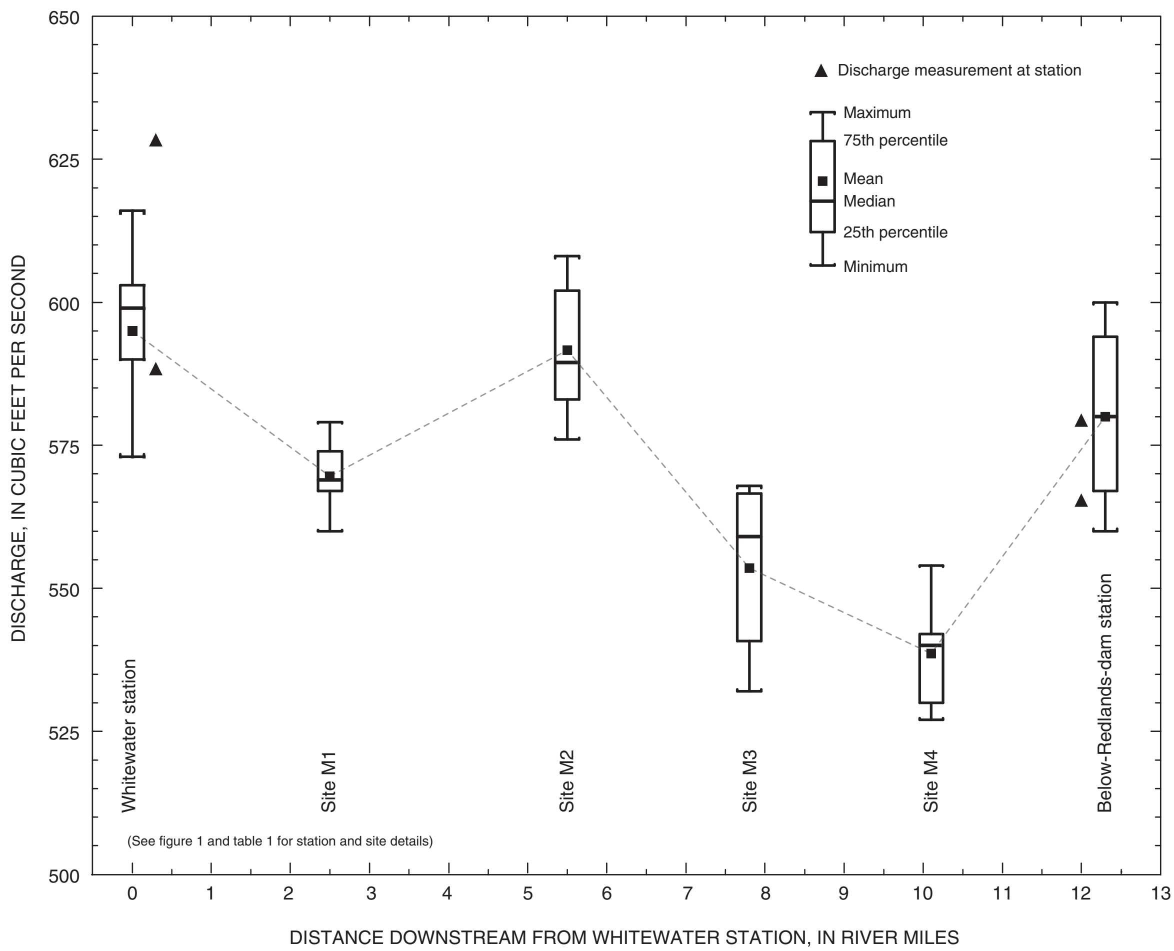

Figure 11. Distribution of unit discharges for stations at the upstream and downstream ends of the Gunnison River study reach and distribution of discharge measurements made at miscellaneous discharge-measurement sites along the reach during measurement set 1, February 5–6, 2003.

much larger discharge; and (2) the changes likely would not be proportionally larger because the much smaller traveltime during the higher flow would minimize any localized changes in discharge. Therefore, site M2, being nearest to the midpoint of the study reach, was the only miscellaneous site at which discharge measurements were made. A temporary staff gage was not installed at site M2 for measurement set 2.

Five discharge measurements made at site M2 ranged from 1,668 to 2,117 ft^3/s, and all but one were rated good; one measurement was made May 14 and four measurements were made May 15 (fig. 12). One measurement, 2,730 ft^3/s (rated good), was made at the Whitewater station, but the measurement was not made until May 16 (not shown in fig. 12) because of equipment problems. One measurement, 1,268 ft^3/s (rated good), was made at the below-Redlands-dam station; and one measurement, 819 ft^3/s (rated good), was made at the Redlands-Canal station (not shown in fig. 12).

Because of the change in discharge during measurement set 2 (fig. 12), consideration of traveltime is of critical importance in evaluating any streamflow losses. Traveltimes through the study reach were estimated by comparing the unit-discharge hydrographs at the Whitewater and below-Redlands-dam stations; the estimated traveltimes then were used to lag the recorded unit discharges at the Whitewater station through the study reach. Using an estimated traveltime of about 1.5 hours, the discharge measurements made at site M2 correlated closely with the discharges recorded about 1.5 hours earlier at the Whitewater station (fig. 12). Using an estimated traveltime of about 3.5 hours, the sum of the unit discharges at the below-Redlands-dam and Redlands-Canal stations, correlated closely to the unit discharges recorded about 3.5 hours earlier at the Whitewater station (fig. 12). The use of constant traveltimes likely resulted in some error in the lagging of the unit discharges because the traveltime most certainly varied with changes in discharge. Results of measurement set 2 also indicate no substantial streamflow loss along the study reach. Based on the results of the mass-balance analyses and the two measurement sets, and discussion of the results with the cooperators, the additional measurement sets that were planned were not made.

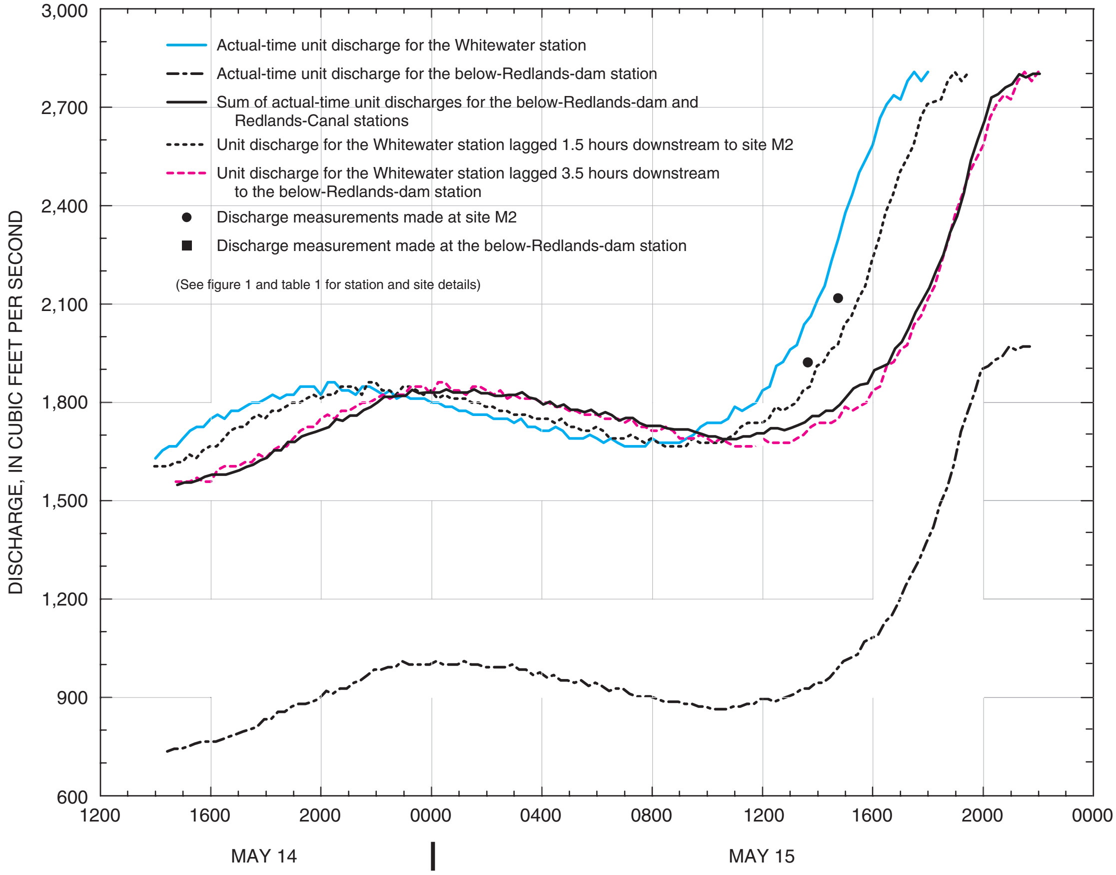

Figure 12. Unit discharges for stations at the upstream and downstream ends of the Gunnison River study reach and discharge measurements made at site M2 during measurement set 2, May 14–15, 2003.

Discussion of Streamflow Losses

Results of the mass-balance analyses shown in table 2 and figures 7–9 clearly show that, for WYs 1995–2002, the sum of recorded discharges at stations below-Redlands-dam and Redlands-Canal generally tend to be less than recorded discharges at the Whitewater station. Even on the basis of that time period alone, however, it cannot be concluded that the study reach is, in fact, a losing stream reach because

1. The lack of a final, quality-assured daily discharge record for the below-Redlands-dam station does not provide a quantitative estimate of the error in that discharge record, especially in light of the seemingly better discharge record during WY 2003 following the changes in equipment.
2. The water-year differences listed in table 1, even without any quantitative estimate of the error in the discharge record for the below-Redlands-dam station, mostly are less than 5 percent and within the stated 5-percent accuracy of the discharge measurements and the final, quality-assured daily discharge records for the Whitewater and Redlands-Canal stations.
3. Although some differences between daily mean discharge at the downstream and upstream stations are large, some of the differences are attributable to traveltime of streamflow through the reach, which is not entirely accounted for in the discharge record, especially in the daily mean values.

Additionally, results of the mass-balance analysis for WY 2003, which seem to indicate a change in the observed trend of streamflow losses during WYs 1995–2002 (table 2), and results of the two measurement sets, indicate that these losses only might be “perceived” because of inaccuracies in the real-time data and the effects of traveltime.

Those involved in administration of water-use rights and management of water resources in the Gunnison River basin frequently look at web-based real-time discharge data for the three stations along the study reach. Often, there is some difference between the sum of the discharges at the two downstream stations (below-Redlands-dam and Redlands-Canal) and the upstream station (Whitewater). Because the study of streamflow losses in the reach described in this report indicated that there likely are no measurable losses, the differences between real-time upstream and downstream discharge primarily can be attributed to (1) traveltime of streamflow through the reach,

(2) inaccuracies in the real-time discharges because the real-time discharge rating shift corrections are not completely accurate, and (3) inaccuracies in the instantaneous measurement of stage at one or more of the stations.

Use of traveltime (discharge lagging) can provide some improvement in comparison of downstream and upstream discharges. The mass-balance analysis for WY 2003 included an additional analysis of a discharge data set of unit discharges for the three stations along the study reach that included some lagging for the discharge at the downstream stations (Coll Stanton, Bureau of Reclamation, written commun., 2003). Analysis of these data (similar to that in fig. 10) for the June 24–September 30, 2003, interval (the available period) indicated that differences between the daily mean discharge sum for the two downstream stations and the daily mean discharge for the upstream station were noticeably smaller than in comparison to using daily mean discharges that did not include an adjustment for traveltime. Traveltime through the reach, however, can vary substantially, from 12 hours or more during low discharge to 4 hours or less during high discharge. Variable traveltimes from a traveltime/discharge relation could be used to make one-time comparisons between real-time discharges at the stations, but simple tabulation of unit discharges for an extended period of time requires use of a single traveltime, which still results in some inaccuracy in the comparisons.

When using the real-time unit discharges for the three stations along the study reach, it is important to remember that there will always be some perceived differences between the discharge at the Whitewater station and the sum of the discharges at the below-Redlands-dam and Redlands-Canal stations because of random discharge computation errors. Even when using a lag time, the estimated difference between these discharges often will be 5 to 10 percent, and much more some of the time. Data for 1 or 2 additional years could be analyzed in a fashion similar to that used for WY 2003 to determine if the annual difference between upstream and downstream discharge will remain small and if the annual trend in variability (negative difference during low-discharge periods, positive difference during high-discharge periods; fig. 10) will be the same in future years. Lastly, if the likely 5 to 10 percent range of perceived difference is unacceptable for administration of water-use rights and management of water resources, new technologies, such as acoustic doppler velocity measurement, are becoming available that might improve the accuracy of real-time discharge data.

Summary

The U.S. Geological Survey began a study in 2003, in cooperation with the Colorado Water Conservation Board, the Upper Colorado River Endangered Fish Recovery Program, the Colorado River Water Conservation District, the Colorado Division of Water Resources, and the Bureau of Reclamation, to characterize streamflow losses in the reach of the Gunnison River from Whitewater downstream to the Redlands Canal diversion dam. The need for the study was related to two water-resource issues in the reach: (1) the use of web-based, real-time discharge data for three streamflow-gaging stations operated in the reach seemed to indicate that the sum of the discharges at the two downstream stations usually was less than the discharge at the upstream station, indicating the likelihood of a losing stream reach, and (2) the losses would need to be quantified for the possible delivery of upstream reservoir releases made in support of the Upper Colorado River Endangered Fish Recovery Program, a recovery program for four endangered upper Colorado River basin fish species. The releases would be made to augment low-flow discharges at a fish ladder that was completed in 1996 at the Redlands Canal diversion dam.

The two principal components of the study were a detailed mass-balance analysis of historical discharge records that were available for the three stations along the study reach and two sets of discharge measurements that were made at the three stations and at a number of additional locations along the study reach.

Data for these existing streamflow-gaging stations were compiled and analyzed: (1) Station 09152500 Gunnison River near Grand Junction (Whitewater station); (2) Station GUNREDCO Gunnison River below Redlands Canal diversion dam (below-Redlands-dam station); and (3) station RLCGRJCO Redlands Canal near Grand Junction (Redlands-Canal station). Data for water years (WY) 1995–2003 were used for the mass-balance analysis, because data for the below-Redlands-dam station were available only for this period. Streamflow losses were investigated directly (by making discharge measurements) for discharges of about 600 and 2,000 ft^3/s, and indirectly (by analysis of historical discharge records) for the complete range of discharges recorded along the study reach. Four intermediate sites (M1, M2, M3, and M4) were selected for discharge measurements in addition to the existing stations. The study reach is the approximate 12-mile reach of the Gunnison River from the Whitewater station downstream to the Redlands Canal diversion dam, which is about 3 miles upstream from the confluence with the Colorado River.

For the mass-balance analysis, daily mean discharges at the two downstream stations (below-Redlands-dam and Redlands-Canal) were summed to provide an estimate of the total downstream daily mean discharge; this value was subtracted from the daily mean discharge at the Whitewater station (the upstream discharge). Excluding the partial data for WY 1995, the annual differences between the daily mean discharge sums at the downstream stations and the daily mean discharges at the upstream station ranged from about –28,700 to –69,800 acre-ft, or about –1.1 to –5.8 percent of the upstream discharge, indicating that the downstream discharges generally were less than the upstream discharges.

Moving 3-day daily mean discharges also were computed for each of the three stations to smooth out some of the abrupt differences between the daily mean discharges that are due to traveltime. Discharge differences and percentage differences between the moving 3-day daily mean discharges at the downstream and upstream stations during WYs 1995–2002 were between about –200 and +100 ft^3/s during about one-half of the time [within the inter-quartile range (IQR)], but had absolute values as large as about 500 to 1,000 ft^3/s during the other one-half of the time (outside the IQR). Percentage differences almost always were between 0 and –10 percent within the IQR and were as small or large as about –60 to +50 percent outside the IQR.

Recorded discharge data for WY 2003 also were analyzed after the end of the water year because use of the real-time discharge data for the year seemed to indicate a change in the previously observed trend of losing streamflow along the study reach. The annual difference between downstream and upstream discharge and the percentage difference for WY 2003 were substantially smaller than for any of the previously analyzed years (WYs 1995–2002). WY 2003 was the only year for which the medians were near zero. In addition to a smaller annual difference for WY 2003, the variability in the differences between downstream and upstream discharge also was much less during WY 2003 than during the previous years.

Two discharge measurement sets were obtained, one during February 2003, and one during May 2003. Discharge measurements for measurement set 1 were obtained during February 5–6, near the lowest discharge period during WY 2003. Discharge was measured 5–8 times over a 24-hour period during the 2-day period at sites M1–M4. Temporary staff gages also were installed at the four sites, and stage was observed about every hour and more frequently during each measurement. Maximum change in observed stage was small at the sites, ranging from 0.03 to 0.05 ft. Discharge was measured once each day at the Whitewater and below-Redlands-dam stations to verify discharge rating shifts; the Redlands Canal was not in operation, so measurements were not needed at the Redlands-Canal station.

Measured discharges at sites M1–M4 ranged from 527 to 608 ft^3/s, measured discharges at the Whitewater station were 628 and 588 ft^3/s, and measured discharges at the below-Redlands-dam station were 579 and 565 ft^3/s. Recorded unit discharges at the Whitewater station ranged from about 575 to 615 ft^3/s, and recorded unit discharges at the below-Redlands-dam station ranged from about 560 to 600 ft^3/s during the 2-day period. Because of the expected 5-percent differences in discharge measurements, and because the mean discharge at the below-Redlands-dam station, about 580 ft^3/s, was only about 2.5 percent smaller than the mean discharge at the Whitewater station, about 595 ft^3/s, it was concluded that there was no measurable streamflow loss along the study reach during measurement set 1.

Discharge in the Gunnison River during measurement set 2 (May 14–15) was about 2,000 ft^3/s and increasing because of high-elevation snowmelt. Discharge measurements were made at the three gaging stations to verify discharge rating shifts. Five discharge measurements also were made at site M2 and ranged from 1,668 to 2,117 ft^3/s. Discharges measured at the gaging stations were 2,730 ft^3/s (on May 16) at the Whitewater station, 1,268 ft^3/s at the below-Redlands-dam station, and 819 ft^3/s at the Redlands-Canal station.

Because of the change in discharge during measurement set 2, consideration of traveltime was of critical importance in evaluating any streamflow losses. In a hydrographic analysis of unit discharges during May 14–15, and using an estimated traveltime of about 1.5 hours, the discharge measurements made at site M2 correlated closely with the discharges recorded about 1.5 hours earlier at the Whitewater station. Using an estimated traveltime of about 3.5 hours, the sum of the unit discharges at the below-Redlands-dam and Redlands-Canal stations also correlated closely to the unit discharges recorded about 3.5 hours earlier at the Whitewater station. These results for measurement set 2 also indicate no measurable streamflow loss along the study reach.

On the basis of the study results, it cannot be concluded that the study reach is, in fact, a losing stream reach because

1. The lack of a final, quality-assured discharge record for the below-Redlands-dam station does not provide a quantitative estimate of the error in that discharge record.

2. Even without any quantitative estimate of the error in the discharge record for the below-Redlands-dam station, the annual water-year differences between downstream and upstream discharge mostly are less than 5 percent and within the stated 5-percent accuracy of discharge measurements and the finalized discharge records for the Whitewater and Redlands-Canal stations.

3. Although some differences between the sum of the daily mean discharge at the downstream stations and the daily mean discharge at the upstream station are large, some of the differences are attributable to traveltime of streamflow through the reach, which is not entirely accounted for in the discharge record, especially in the daily mean values.

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