APPENDIX N
Losses and Gains for Eight Unlined Canals Along the Purgatoire River near Trinidad, Colorado, 2000–2004
(U.S. Geological Survey SIR 2006-5164)

science for a changing world

Prepared in cooperation with the Purgatoire River Water Conservancy District, Colorado Water Conservation Board, and U.S. Bureau of Reclamation

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Scientific Investigations Report 2006–5164

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Application rate	
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year [(kg/ha)/yr]
	Leakance	
foot per day per foot [(ft/d)/ft]	1	meter per day per meter
inch per year per foot [(in/yr)/ft]	83.33	millimeter per year per meter [(mm/yr)/m]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Losses and Gains for Eight Unlined Canals Along the Purgatoire River near Trinidad, Colorado, 2000–2004

By Lisa D. Miller

Abstract

The U.S. Geological Survey conducted a field study from July 2000 through June 2004, in cooperation with the Purgatoire River Water Conservancy District, Colorado Water Conservation Board, and Bureau of Reclamation, to characterize and quantify losses and gains in Picketwire, Baca, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne irrigation canals. These canals divert streamflow from the Purgatoire River between Trinidad Dam and the city of Hoehne, Colorado. Discharge measurements were made along the eight canals during steady-state conditions to identify subreaches with losses or gains. Losses and gains were computed between main-channel measurement sites along each canal by equating inflows to outflows plus flow loss or gain in the subreach. As part of this study, multiple discharge measurements also were made at Picketwire, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canal headgates to compare standard Parshall flume-rated and measured discharge at the canal headgates.

Results from the discharge measurements showed that Picketwire, Chilili, and Hoehne Canals generally lose flow from the headgate to the end of the canal, although some subreaches showed gains during some measurements. Losses in Picketwire Canal ranged from about 7 percent to about 23 percent of the headgate inflow, and Chilili Canal losses ranged from about 2 percent to about 34 percent of the headgate inflow. Hoehne Canal losses ranged from only about 2 to 7 percent of the headgate inflow, which is within the uncertainty of the measurements.

El Moro Canal appears to lose flow in some subreaches and gain flow in other subreaches. Despite gains in some subreaches, measurements show flow losses of about 28 percent of the headgate inflow for the entire El Moro Canal.

Losses and gains in Baca, Picketwire, Chilili, and Enlarged Southside canals may be affected by the length of time that the canal has been flowing. Losses in these canals appear to decrease the longer the canal has been continuously flowing. In some cases, subreaches of some of these canals go from losing to gaining flow.

Unlike some of the other canals, losses and gains in El Moro and John Flood Canal do not appear to be related to how long the canal was flowing before the measurements were made. Losses and gains in El Moro Canal are probably related to the physical attributes of the canal, such as the canal construction and proximity to other canals. Field data indicate that El Moro Canal gains flow from and loses flow to other canals.

Measurements made from the Model Canal headgate to Model Reservoir show canal losses and gains ranging from 1 to 5 percent of the headgate inflow, which is less than the uncertainty of the measurements. However, measured canal losses and gains from Model Canal downstream from Model Reservoir ranged from a loss of 59 percent to a gain of 1 percent of the subreach inflow.

Measured discharges at the canal headgates were usually higher than the discharges determined using the standard Parshall flume discharge tables. Of the 102 discharge measurements made at the canal headgates, 72 of the measured discharges were higher than the corresponding discharges determined using the standard Parshall flume discharge tables. This means that about 70 percent of the time, the amount of flow that was diverted into the canals was underreported. All measured discharges at the Picketwire and El Moro headgates were higher than the corresponding flume-rated discharges, and all but one measured discharge at the Chilili headgate were higher than the corresponding flume-rated discharges. Discharges measured at the remaining headgates varied from 14 percent lower to 27 percent higher than the corresponding flume-rated discharges.

Introduction

Principal areas of irrigation in the upper Purgatoire River Basin include areas in the vicinity of Trinidad, Colorado (fig. 1). Irrigated lands near Trinidad extend down the valley for about 35 miles along gently sloping plateaus. Eleven canal systems downstream from Trinidad Dam are part of the Purgatoire River Water Conservancy District (PRWCD). These canals receive water from the U. S. Army Corps of Engineer's (Corps) Trinidad Dam and Reservoir Project to irrigate about 20,000 acres of cropland. Irrigation is conducted in accordance with Operating Principles and Operating Criteria established under the repayment contract for the irrigation portion of the Project. The Bureau of Reclamation (BOR) is responsible for administration of the repayment contract (U.S. Army Corps of Engineers, 1978).

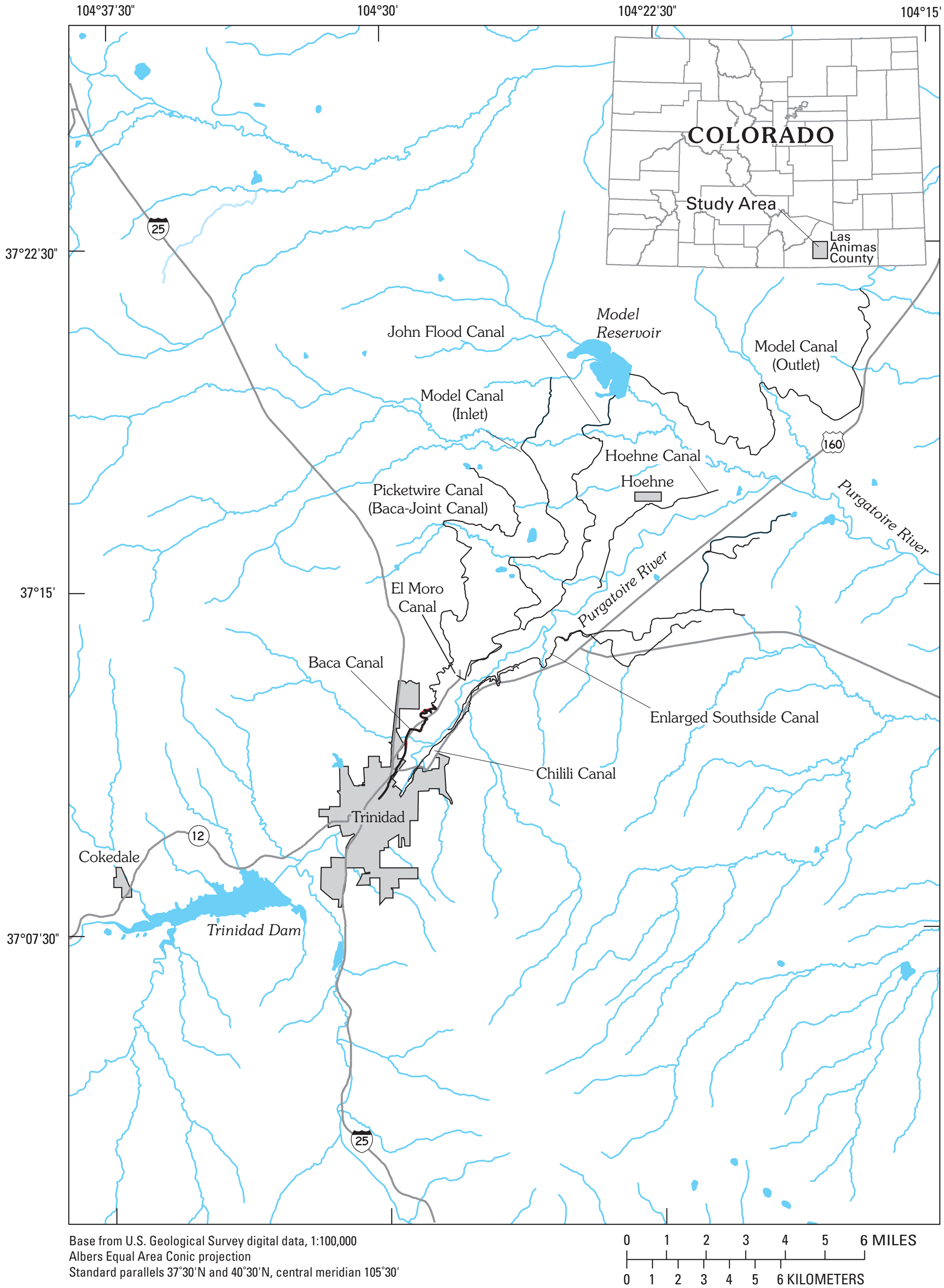


Figure 1. Location of study area and selected Purgatoire River Water Conservancy District Canals near Trinidad, Colorado.

Water supplies in the Purgatoire River Basin are overappropriated (Colorado Department of Natural Resources, 1975), and shortages of water occur when irrigation demand exceeds available streamflow. The U.S. Geological Survey (USGS) conducted a field study from July 2000 through June 2004, in cooperation with the PRWCD, the Colorado Water Conservation Board (CWCB), and the BOR, to characterize and quantify streamflow losses or gains in eight unlined irrigation canals that divert streamflow from the Purgatoire River between Trinidad Dam and the city of Hoehne, Colorado (fig. 1). Results from this study will provide area water managers with additional hydrologic information needed to more effectively manage water resources within the Purgatoire River Basin. Specifically, results from the canal loss and gain measurements will assist PRWCD and others in identifying areas within canal subreaches or entire canals where modifications or maintenance may be needed to reduce canal losses or improve irrigation water delivery efficiency.

Purpose and Scope

The purpose of this report is to present findings of a loss and gain study conducted for eight unlined canals (Picketwire, Baca, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canals) within the Purgatoire River Basin downstream from Trinidad Dam from July 2000 through June 2004. The major objectives of the study were to characterize losses or gains along the eight canals and to compare flume-rated and measured discharge at the canal headgates. The study area is in southeastern Colorado near Trinidad in Las Animas County (fig. 1).

Description of Study Area

Trinidad Dam and Trinidad Lake (hereinafter referred to as “Trinidad Dam”) were completed in 1976 on the upper Purgatoire River about 2.75 miles upstream from the city of Trinidad, Colorado (fig. 1). Trinidad Dam serves as a multipurpose reservoir authorized for flood control, irrigation, sediment retention, and recreation (U.S. Army Corps of Engineers, 1994). The Corps is responsible for the operation and maintenance of Trinidad Dam. The BOR administers the contract (which includes repayment of the costs of construction, operation, and maintenance allocated to the irrigation portion of Trinidad Dam) with PRWCD (U.S. Army Corps of Engineers, 1978). PRWCD is responsible for the regulation of irrigation water within the PRWCD that is consistent with administration of water rights by the Water Division 2, State Engineer’s Office, Colorado Division of Water Resources (U.S. Army Corps of Engineers, 1994).

The Purgatoire River originates in the Sangre de Cristo Mountains west of the study area. It flows in a generally northeasterly direction through parts of Las Animas, Otero, and Bent Counties to its confluence with the Arkansas River near Las Animas, Colorado. Trinidad Dam controls flow from 671 square miles of the 749-square-mile Purgatoire River Basin upstream from the city of Trinidad (U.S. Army Corps of Engineers, 1994). Trinidad Dam is in a narrow river valley bordered by mountainous foothills. Downstream from Trinidad Dam, the foothills transition to rolling, grassy plains, and the river valley widens.

The study area has a semiarid continental climate. Mean annual precipitation at the Trinidad Airport from 1948 through 2005 was 15.1 inches. Most precipitation falls during the spring and summer months. The average maximum daily temperature was 67.2 degrees Fahrenheit (°F), and the average minimum daily temperature was 37.4°F for the period January 1948 through December 2005 (*http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?cotrin*, accessed August 7, 2006). The highest temperatures generally are recorded in July, and the lowest temperatures in January.

Flow in the Purgatoire River, downstream from Trinidad Dam, is controlled by releases from the lake, inflow from downstream tributaries, and irrigation diversions. Little or no water is released from Trinidad Dam from about October 15 through April 15 because water is stored for irrigation purposes (U.S. Army Corps of Engineers, 1994). To protect downstream water rights, the original Model Reservoir (fig. 1) right to store 20,000 acre-feet of water from flows in the Purgatoire River was transferred to Trinidad Dam. During the irrigation season (as determined by PRWCD but falling between April 1 and October 15), downstream releases from Trinidad Dam range from about 100 to 300 cubic feet per second (ft^3/s).

Irrigation canals divert streamflow from the Purgatoire River downstream from Trinidad Dam, usually from April through the middle of November; diversions generally are largest from June through August. At times, little surface water flows in some river reaches downstream from the study area because the irrigation canals divert the entire flow of the river. Parshall flumes, ranging from small structures (9-ft^3/s free-flow capacity) to moderately large structures (300-ft^3/s free-flow capacity), are used to measure streamflow diverted into the irrigation canals. Daily diversions are recorded at the canal headgates. Diversion records and recording devices are maintained by Colorado Division of Water Resources (CDWR) (Steve Kastner, Colorado Department of Natural Resources, oral commun., 2000).

Picketwire, Model, Hoehne, Chilili, and Enlarged Southside canals divert water directly from the Purgatoire River (fig 1). The Baca Canal and El Moro Canal waters are diverted at the Picketwire (Baca Joint) headgate and are carried to their respective lands as a part of the Picketwire Canal. Baca Canal water is delivered to Baca lands through a series of lateral turnouts from the main Picketwire Canal beginning about 1.5 miles downstream from the Picketwire headgate. The Baca Canal lateral turnouts are distributed along about a

2-mile reach (located from about 1.5 miles to 3.5 miles downstream from the Picketwire headgate) of Picketwire Canal and deliver water directly to Baca lands.

El Moro Canal water is delivered through a single lateral turnout from the Picketwire Canal, measured through a Parshall flume, and then distributed through a discrete ditch to the El Moro lands. Similarly, the John Flood Canal water is diverted at the Model Canal headgate, carried in Model Canal about 1.5 miles, and then diverted into John Flood Canal through a turnout from Model Canal. The John Flood Canal water is measured using a Parshall flume and then distributed to John Flood lands (fig. 1).

Acknowledgments

The author wishes to thank many landowners within the study area for allowing access to their property to make discharge measurements along the canals. In addition, the author would like to thank Thelma Lujan from the Purgatoire River Water Conservancy District for her assistance in coordinating site visits and providing contact information and Danny Marques from the Colorado Division of Water Resources for providing detailed information on the operation of the canal system and answering many questions.

Methods for Loss and Gain Investigations

Field reconnaissance of diversion structures and location of measurement sites, discharge measurements, and loss and gain computations are discussed in this section of the report.

Field Reconnaissance

Field reconnaissance was conducted to locate diversion structures, select measurement locations, and arrange access to sites. All diversion structures along each main canal were located, and their latitude and longitude coordinates were determined using a global positioning system (table 1).

Parshall flumes used to measure irrigation diversion at the canal headgates ranged in size from 9 inches (9-ft^3/s free-flow capacity) to 10 feet (300-ft^3/s free-flow capacity). Figure 2 shows a photograph of the water-stage recorder and Parshall flume at the Hoehne Canal headgate (HOHG). Lateral turnouts with Parshall flumes and (or) splitter boxes are used to measure and divert water out of the main canal to shareholders along the canal for irrigation. Figure 3 shows an example of a splitter box located at site SS07 on Enlarged Southside Canal.

Discharge Measurements

Discharge measurements were made along the eight canals during steady-state conditions to identify subreaches with losses or gains. Steady-state conditions were defined as periods with little or no precipitation and stable canal inflows at the headgates for at least 4 to 7 days before measurements were made. Inflows were considered stable if flow did not vary by more than 5 percent at the canal headgates. Discharge measurements were made at main canal and lateral diversion sites using either an Acoustic Doppler Current Meter (ADCP) or a vertical-axis mechanical current meter. The ADCP measurements were made following methods described by Simpson and Oltmann (1993). Vertical-axis current-meter measurements were made following methods described by Rantz and others (1982).

The accuracy of a discharge measurement is affected by various factors such as condition of measuring equipment, characteristics of the measurement section, spacing of observation verticals, changing stage, measurement of depth and velocity, and other factors. Four accuracy classifications are used by the USGS to rate discharge measurements. A measurement rated excellent means that the measured discharge is probably within 2 percent of the true discharge; good, within 5 percent; fair, within 8 percent; and a measurement rated poor may be more than 8 percent different from the true discharge (Rantz and others, 1982). The accuracy classification of a discharge measurement is a somewhat subjective evaluation made by the field technician making the measurement. The field technician considers characteristics of the measurement section (type of channel bottom, flow distribution, and so forth), instrument performance, and other factors and then assigns a rating to the measurement.

Discharge measurements made during this study were generally rated good or fair, and a small number of measurements were rated poor. Because of measurement uncertainty, a single pair of measurements may not be sufficient to determine if a loss or gain occurs in a subreach. Measured losses or gains must be greater in magnitude than the uncertainty associated with the measurement to be considered meaningful. The uncertainty of a measurement is calculated on the basis of the measurement rating. For example, a measurement of 20 ft^3/s with a rating of good has an assumed uncertainty of 5 percent, or ±1 ft^3/s. Therefore, a loss or gain must be greater than 1 ft^3/s to be considered meaningful.

Discharge measurements began at the headgate flume in the main canal and were repeated, moving downstream, at multiple locations in the main canal, generally during a 1-day period. Discharge measurements were made over several days along Enlarged Southside Canal due to the canal length and number of measurement sites. When it was necessary to extend loss and gain discharge measurements in a canal over more than one day, the last site measured in the main canal

Table 1. Measurement site identification, canal name, distance downstream from canal headgate, site description, diversion type, flume size, latitude, and longitude for eight unlined canals along the Purgatoire River near Trinidad, Colorado.

[Site ID, site identification; PW, Picketwire Canal; HG, headgate; NA, not applicable; BA, Baca Canal; EM, El Moro Canal; CH, Chilili Canal; END, end of canal; SS, Enlarged Southside Canal; SP, Palaski Extension of Enlarged Southside Canal; SW, Wagner Extension of Enlarged Southside Canal; SSS, Enlarged Southside Canal Splitter; DD, bifurcation point; MO, Model Canal; --, missing value; JF, John Flood Canal; WG, waste gate; HO, Hoehne Canal]

Site ID	Canal name	Distance downstream from canal headgate (miles)	Site description	Diversion type	Flume size	Latitude	Longitude
PWHG	Picketwire Canal	0.0	Headgate	Parshall flume	8 feet	37.174	–104.504
PW01	Picketwire Canal	1.2	Lateral diversion	Box splitter	NA	37.188	–104.493
BA01	Baca Canal	1.5	Lateral diversion	Parshall flume	3 inch	37.192	–104.491
BA02	Baca Canal	1.6	Lateral diversion	Parshall flume	NA	37.194	–104.491
BA03	Baca Canal	2.1	Lateral diversion	Parshall flume	9 inch	37.199	–104.487
BA04	Baca Canal	2.2	Lateral diversion	Parshall flume	9 inch	37.198	–104.485
BA05	Baca Canal	2.3	Lateral diversion	Parshall flume	3 inch	37.200	–104.484
BA06	Baca Canal	2.6	Lateral diversion	Parshall flume	6 inch	37.203	–104.482
BA07	Baca Canal	2.6	Lateral diversion	Parshall flume	6 inch	37.203	–104.481
BA08	Baca Canal	2.7	Lateral diversion	Parshall flume	3 inch	37.204	–104.483
BA09	Baca Canal	3.2	Lateral diversion	Parshall flume	3 inch	37.206	–104.481
BA10	Baca Canal	3.5	Lateral diversion	Parshall flume	6 inch	37.207	–104.477
PW02	Picketwire Canal	3.9	Lateral diversion	Box splitter	NA	37.210	–104.477
PW03	Picketwire Canal	4.7	Lateral diversion	Box splitter	NA	37.216	–104.475
PW04	Picketwire Canal	5.4	Lateral diversion	Box splitter	NA	37.221	–104.472
EMDD	Picketwire Canal	5.4	Bifurcation point	Lateral turnout	NA	37.221	–104.472
PW05	Picketwire Canal	5.4	Lateral diversion	Box splitter	NA	37.221	–104.472
PW06	Picketwire Canal	5.7	Lateral diversion	Box splitter	NA	37.224	–104.469
PW07	Picketwire Canal	5.8	Lateral diversion	Box splitter	NA	37.225	–104.469
PW08	Picketwire Canal	5.8	Lateral diversion	Box splitter	NA	37.225	–104.469
PW09	Picketwire Canal	6.0	Lateral diversion	Box splitter	NA	37.227	–104.471
PW10	Picketwire Canal	6.2	Lateral diversion	Box splitter	NA	37.230	–104.471
PW11	Picketwire Canal	6.7	Lateral diversion	Box splitter	NA	37.236	–104.475
PW12	Picketwire Canal	6.7	Lateral diversion	Box splitter	NA	37.237	–104.475
PW13	Picketwire Canal	7.8	Lateral diversion	Box splitter	NA	37.239	–104.465
PW14	Picketwire Canal	7.8	Lateral diversion	Box splitter	NA	37.240	–104.464
PW15	Picketwire Canal	7.9	Lateral diversion	Box splitter	NA	37.240	–104.464
PW16	Picketwire Canal	8.3	Lateral diversion	Box splitter	NA	37.246	–104.462
PW17	Picketwire Canal	8.4	Lateral diversion	Box splitter	NA	37.247	–104.463
PW18	Picketwire Canal	8.6	Lateral diversion	Box splitter	NA	37.250	–104.463
PW19	Picketwire Canal	8.7	Lateral diversion	Box splitter	NA	37.252	–104.464
PW20	Picketwire Canal	10.0	Lateral diversion	Box splitter	NA	37.265	–104.460
PW21	Picketwire Canal	13.3	Lateral diversion	Box splitter	NA	37.270	–104.441
PW22	Picketwire Canal	13.7	Lateral diversion	Box splitter	NA	37.274	–104.438
PW23	Picketwire Canal	13.8	Lateral diversion	Box splitter	NA	37.275	–104.439
PW24	Picketwire Canal	14.3	Lateral diversion	Box splitter	NA	37.282	–104.440
PW25	Picketwire Canal	14.5	Lateral diversion	Box splitter	NA	37.284	–104.443
PW26	Picketwire Canal	15.1	Lateral diversion	Box splitter	NA	37.290	–104.451
PW27	Picketwire Canal	16.0	Lateral diversion	Box splitter	NA	37.295	–104.463
EMHG	El Moro Canal	0.0	Headgate-flume	Parshall flume	9 inch	37.219	–104.467
EM01	El Moro Canal	0.2	Lateral diversion	Box splitter	NA	37.217	–104.464
EM02	El Moro Canal	0.4	Lateral diversion	Box splitter	NA	37.220	–104.463
EM03	El Moro Canal	0.7	Lateral diversion	Box splitter	NA	37.223	–104.462
EM04	El Moro Canal	0.9	Lateral diversion	Box splitter	NA	37.224	–104.458
EM05	El Moro Canal	1.0	Lateral diversion	Box splitter	NA	37.224	–104.457
EM06	El Moro Canal	1.2	Lateral diversion	Box splitter	NA	37.225	–104.454
EM07	El Moro Canal	1.3	Lateral diversion	Box splitter	NA	37.227	–104.453
EM08	El Moro Canal	1.4	Lateral diversion	Box splitter	NA	37.227	–104.451
EM09	El Moro Canal	1.6	Lateral diversion	Box splitter	NA	37.229	–104.447

Table 1. Measurement site identification, canal name, distance downstream from canal headgate, site description, diversion type, flume size, latitude, and longitude for eight unlined canals along the Purgatoire River near Trinidad, Colorado.—Continued

[Site ID, site identification; PW, Picketwire Canal; HG, headgate; NA, not applicable; BA, Baca Canal; EM, El Moro Canal; CH, Chilili Canal; END, end of canal; SS, Enlarged Southside Canal; SP, Palaski Extension of Enlarged Southside Canal; SW, Wagner Extension of Enlarged Southside Canal; SSS, Enlarged Southside Canal Splitter; DD, bifurcation point; MO, Model Canal; --, missing value; JF, John Flood Canal; WG, waste gate; HO, Hoehne Canal]

Site ID	Canal name	Distance downstream from canal headgate (miles)	Site description	Diversion type	Flume size	Latitude	Longitude
CHHG	Chilili Canal	0.0	Headgate	Parshall flume	2 feet	37.180	–104.490
CH01	Chilili Canal	0.4	Lateral diversion	Box splitter	NA	37.186	–104.486
CH02	Chilili Canal	0.6	Lateral diversion	Box splitter	NA	37.188	–104.484
CH03	Chilili Canal	0.7	Lateral diversion	Box splitter	NA	37.188	–104.483
CH04	Chilili Canal	0.7	Lateral diversion	Box splitter	NA	37.189	–104.483
CH05	Chilili Canal	0.7	Lateral diversion	Box splitter	NA	37.189	–104.482
CH06	Chilili Canal	0.8	Lateral diversion	Box splitter	NA	37.190	–104.481
CH07	Chilili Canal	0.9	Lateral diversion	Box splitter	NA	37.190	–104.481
CH08	Chilili Canal	0.9	Lateral diversion	Box splitter	NA	37.191	–104.480
CH09	Chilili Canal	1.2	Lateral diversion	Box splitter	NA	37.194	–104.477
CH10	Chilili Canal	1.4	Lateral diversion	Box splitter	NA	37.196	–104.474
CH11	Chilili Canal	1.5	Lateral diversion	Box splitter	NA	37.196	–104.474
CH12	Chilili Canal	1.8	Lateral diversion	Box splitter	NA	37.199	–104.470
CH13	Chilili Canal	2.0	Lateral diversion	Box splitter	NA	37.202	–104.467
CH14	Chilili Canal	2.2	Lateral diversion	Box splitter	NA	37.204	–104.465
CH15	Chilili Canal	2.2	Lateral diversion	Box splitter	NA	37.204	–104.465
CH16	Chilili Canal	2.4	Lateral diversion	Box splitter	NA	37.206	–104.463
CH17	Chilili Canal	2.5	Lateral diversion	Box splitter	NA	37.207	–104.462
CH18	Chilili Canal	2.7	Lateral diversion	Box splitter	NA	37.209	–104.462
CH19	Chilili Canal	2.9	Lateral diversion	Box splitter	NA	37.212	–104.461
CEND	Chilili Canal	4.9	End of ditch	NA	NA		
SSHG	Enlarged Southside Canal	0.0	Headgate	Parshall flume	10 feet	37.199	–104.469
S001	Enlarged Southside Canal	0.7	Lateral diversion	Box splitter	NA	37.208	–104.465
SO02	Enlarged Southside Canal	3.2	Lateral diversion	Box splitter	NA	37.225	–104.433
SSS1	Enlarged Southside Canal—Sandoval/Palaski Extension	4.7	Splitter	Box splitter	NA	37.232	–104.421
SP01	Enlarged Southside Canal—Palaski Extension	5.1	Lateral diversion	Box splitter	NA	37.233	–104.415
SP02	Enlarged Southside Canal—Palaski Extension	5.4	Lateral diversion	Box splitter	NA	37.234	–104.411
SP03	Enlarged Southside Canal—Palaski Extension	5.7	Lateral diversion	Box splitter	NA	37.233	–104.406
SP04	Enlarged Southside Canal—Palaski Extension	6.0	Lateral diversion	Box splitter	NA	37.230	–104.403
SP05	Enlarged Southside Canal—Palaski Extension	6.4	Lateral diversion	Parshall flume	9 inch	37.230	–104.396
SP06	Enlarged Southside Canal—Palaski Extension	7.0	Lateral diversion	Box splitter	NA	37.223	–104.394
SP07	Enlarged Southside Canal—Palaski Extension	7.7	Lateral diversion	Box splitter	NA	37.226	–104.384
SP08	Enlarged Southside Canal—Palaski Extension	8.3	Lateral diversion	Box splitter	NA	37.230	–104.376
SP09	Enlarged Southside Canal—Palaski Extension	9.1	Lateral diversion	Box splitter	NA	37.236	–104.366
SP10	Enlarged Southside Canal—Palaski Extension	9.7	Lateral diversion	End of ditch	NA	37.237	–104.356
SS01	Enlarged Southside Canal—Sandoval Extension	6.4	Lateral diversion	Box splitter	NA	37.234	–104.393
SS02	Enlarged Southside Canal—Sandoval Extension	7.9	Lateral diversion	Box splitter	NA	37.239	–104.376
SS03	Enlarged Southside Canal—Sandoval Extension	8.5	Lateral diversion	Box splitter	NA	37.240	–104.365

Table 1. Measurement site identification, canal name, distance downstream from canal headgate, site description, diversion type, flume size, latitude, and longitude for eight unlined canals along the Purgatoire River near Trinidad, Colorado.—Continued

[Site ID, site identification; PW, Picketwire Canal; HG, headgate; NA, not applicable; BA, Baca Canal; EM, El Moro Canal; CH, Chilili Canal; END, end of canal; SS, Enlarged Southside Canal; SP, Palaski Extension of Enlarged Southside Canal; SW, Wagner Extension of Enlarged Southside Canal; SSS, Enlarged Southside Canal Splitter; DD, bifurcation point; MO, Model Canal; --, missing value; JF, John Flood Canal; WG, waste gate; HO, Hoehne Canal]

Site ID	Canal name	Distance downstream from canal headgate (miles)	Site description	Diversion type	Flume size	Latitude	Longitude
SS04	Enlarged Southside Canal—Sandoval Extension	8.9	Lateral diversion	Box splitter	NA	37.242	–104.360
SSS2	Enlarged Southside Canal—Sandoval/Wagner Extension	9.1	Splitter	Box splitter	NA	37.242	–104.356
SS05	Enlarged Southside Canal—Sandoval Extension	9.4	Lateral diversion	Box splitter	NA	37.241	–104.351
SS06	Enlarged Southside Canal—Sandoval Extension	9.9	Lateral diversion	Box splitter	NA	37.242	–104.342
SS07	Enlarged Southside Canal—Sandoval Extension	10.2	Lateral diversion	Box splitter	NA	37.240	–104.338
SS08	Enlarged Southside Canal—Sandoval Extension	15.8	Lateral diversion	Box splitter	NA	37.239	–104.336
SSS3	Enlarged Southside—Wagner North & South Extension	10.6	Splitter	Box splitter	NA	37.262	–104.354
SW01	Enlarged Southside Canal—Wagner Extension	10.6	Lateral diversion	Box splitter	NA	37.262	–104.354
SW02	Enlarged Southside Canal—Wagner Extension	10.7	Lateral diversion	Box splitter	NA	37.263	–104.351
SW03	Enlarged Southside Canal—Wagner Extension	11.6	Lateral diversion	Box splitter	NA	37.263	–104.341
SW04	Enlarged Southside Canal—Wagner Extension	11.9	Lateral diversion	Box splitter	NA	37.265	–104.337
SW05	Enlarged Southside Canal—Wagner Extension	12.5	Lateral diversion	Box splitter	NA	37.268	–104.329
SW06	Enlarged Southside Canal—Wagner Extension	11.0	Lateral diversion	Box splitter	NA	37.266	–104.351
SW07	Enlarged Southside Canal—Wagner Extension	11.7	Lateral diversion	Box splitter	NA	37.268	–104.337
SW08	Enlarged Southside Canal—Wagner Extension	12.6	Lateral diversion	Box splitter	NA	37.270	–104.324
SW09	Enlarged Southside Canal—Wagner Extension	12.8	Lateral diversion	Box splitter	NA	37.273	–104.323
SW10	Enlarged Southside Canal—Wagner Extension	13.0	Lateral diversion	Box splitter	NA	37.275	–104.320
SW11	Enlarged Southside Canal—Wagner Extension	13.1	Lateral diversion	Box splitter	NA	37.275	–104.319
SW12	Enlarged Southside Canal—Wagner Extension	13.3	Lateral diversion	Box splitter	NA	37.276	–104.315
MOHG	Model Canal	0.0	Headgate-flume	Parshall flume	10 feet	37.218	–104.463
JFDD	Model Canal	2.4	Bifurcation point	Lateral turnout	NA	37.236	–104.439
MOT1	Model Canal	4.0	Measurement point	NA	NA	37.250	–104.433
MOT2	Model Canal	5.8	Measurement point	NA	NA	37.261	–104.429
MOT3	Model Canal	8.8	Measurement point	NA	NA	37.293	–104.429
MOT4	Model Canal	11.7	Measurement point	NA	NA	37.308	–104.430
M2HG	Model Canal	0.0	Headgate	Parshall flume	10 feet	37.328	–104.385
MOB3	Model Canal	4.8	Lateral diversion	Box splitter	NA	37.299	–104.328
MO01	Model Canal	10.4	Lateral diversion	Box splitter	NA	37.319	–104.282
M3HG	Model Canal	11.2	Headgate-Flume	--	--	37.329	–104.285
MO02	Model Canal	12.1	Lateral diversion	Box splitter	NA	37.341	–104.278
MO03	Model Canal	13.8	Lateral diversion	Box splitter	NA	37.354	–104.268
JF00	John Flood Canal	0.0	Lateral diversion	Parshall flume	9 inch	37.234	–104.444
JFHG	John Flood Canal	0.0	Headgate-flume	Parshall flume	8 feet	37.236	–104.438

Table 1. Measurement site identification, canal name, distance downstream from canal headgate, site description, diversion type, flume size, latitude, and longitude for eight unlined canals along the Purgatoire River near Trinidad, Colorado.—Continued

[Site ID, site identification; PW, Picketwire Canal; HG, headgate; NA, not applicable; BA, Baca Canal; EM, El Moro Canal; CH, Chilili Canal; END, end of canal; SS, Enlarged Southside Canal; SP, Palaski Extension of Enlarged Southside Canal; SW, Wagner Extension of Enlarged Southside Canal; SSS, Enlarged Southside Canal Splitter; DD, bifurcation point; MO, Model Canal; --, missing value; JF, John Flood Canal; WG, waste gate; HO, Hoehne Canal]

Site ID	Canal name	Distance downstream from canal headgate (miles)	Site description	Diversion type	Flume size	Latitude	Longitude
JF01	John Flood Canal	0.0	Lateral diversion	Parshall flume	9 inch	37.236	–104.438
JF02	John Flood Canal	1.2	Lateral diversion	Parshall flume	9 inch	37.244	–104.422
JF03	John Flood Canal	1.5	Lateral diversion	Parshall flume	9 inch	37.248	–104.418
JF04	John Flood Canal	1.6	Lateral diversion	Parshall flume	9 inch	37.248	–104.418
JF05	John Flood Canal	1.7	Lateral diversion	Parshall flume	9 inch	37.250	–104.418
JF06	John Flood Canal	1.8	Lateral diversion	Parshall flume	9 inch	37.251	–104.419
JFWG	John Flood Canal	1.8	Waste gate	NA	NA	37.252	–104.419
JF07A	John Flood Canal	1.8	Lateral diversion	Parshall flume	--	37.252	–104.419
JF07	John Flood Canal	2.0	Lateral diversion	Parshall flume	9 inch	37.253	–104.417
JF08	John Flood Canal	2.3	Lateral diversion	Parshall flume	9 inch	37.255	–104.413
JF09	John Flood Canal	2.4	Lateral diversion	Parshall flume	9 inch	37.257	–104.412
JF10	John Flood Canal	2.6	Lateral diversion	Parshall flume	9 inch	37.259	–104.411
JF11	John Flood Canal	2.8	Lateral diversion	Parshall flume	9 inch	37.262	–104.409
JF12	John Flood Canal	3.3	Lateral diversion	Parshall flume	18 inch	37.267	–104.406
JF13	John Flood Canal	4.3	Lateral diversion	Parshall flume	12 inch	37.276	–104.404
JF14	John Flood Canal	4.3	Lateral diversion	Parshall flume	9 inch	37.276	–104.404
JF15	John Flood Canal	4.4	Lateral diversion	Site not used	NA	37.278	–104.406
JF16	John Flood Canal	4.4	Lateral diversion	Parshall flume	9 inch	37.278	–104.406
JF17	John Flood Canal	6.1	Lateral diversion	Parshall flume	9 inch	37.294	–104.406
JF18	John Flood Canal	6.1	Lateral diversion	Parshall flume	9 inch	37.294	–104.406
JF19	John Flood Canal	6.2	Lateral diversion	Parshall flume	9 inch	37.296	–104.405
JF20	John Flood Canal	6.5	Lateral diversion	Parshall flume	9 inch	37.299	–104.402
JF21	John Flood Canal	6.5	Lateral diversion	Parshall flume	9 inch	37.299	–104.401
JF22	John Flood Canal	6.8	Lateral diversion	Parshall flume	9 inch	37.303	–104.400
JF23	John Flood Canal	8.1	Lateral diversion	Parshall flume	9 inch	37.309	–104.400
JF24	John Flood Canal	8.3	Lateral diversion	Parshall flume	9 inch	37.310	–104.397
JF25	John Flood Canal	8.4	Lateral diversion	Parshall flume	9 inch	37.311	–104.396
HOHG	Hoehne Canal	0.0	Headgate-flume	Parshall flume	4 feet	37.250	–104.403
HO1	Hoehne Canal	2.8	Lateral diversion	Box splitter	NA	37.280	–104.379
HO2	Hoehne Canal	3.2	Lateral diversion	Box splitter	NA	37.279	–104.371
HO2A	Hoehne Canal	--	Lateral diversion	Box splitter	NA	--	--
HO3	Hoehne Canal	4.2	Lateral diversion	Box splitter	NA	37.283	–104.355
HO4	Hoehne Canal	4.7	Lateral diversion	Box splitter	NA	37.285	–104.347

each day was repeated as the first measurement site the next day to check that steady-flow conditions existed in the canal. Steady-flow conditions were assumed to exist if flow in the canal had not changed by more than 5 percent from the preceding day.

In addition to direct measurements of canal discharge, estimates also were made at selected sites for several reasons: (1) discharge (usually leakage) was too low to measure, or (2) measured discharge at selected laterals was comparable to discharge estimated based on channel geometry during the first measurement period and, thus, estimates (based on channel geometry) were used in subsequent measurement periods to save time. Leakage was measured/estimated using a variety of methods: (1) vertical-axis mechanical current meter, (2) bucket method, (3) float method, or (4) visual observation. Current-meter measurements of leakage often were made using fewer cross sections (verticals) than recommended (Rantz and others, 1982) due to low-flow conditions. For this reason, these measurements were coded as estimated. Also discharge measurements made using the bucket method, float method, and visual observation were coded as estimated. Splitter boxes are the most commonly used method to divert flow from the main canal to laterals (see fig. 3 for an example of a splitter box). Estimates of the diverted discharge to the laterals were made by (1) measuring flow in the main canal just upstream from the lateral (splitter box), (2) measuring the total width of the main canal and laterals and, (3) proportioning the total flow measured upstream from the lateral on the basis of the width of the lateral.

Figure 2. Water-stage recorder and Parshall flume at measurement site HOHG (Hoehne Canal headgate).

Figure 3. Splitter box located at measurement site SS07 on the Enlarged Southside Canal.

Loss and Gain Computations

The canal loss or gain was computed between main-canal measurement sites (subreach) during steady-state conditions by equating inflows to outflows plus flow loss or gain in the subreach (Slade and others, 2002):

$$Q_i + Q_t + Q_r + Q_u = Q_o + Q_d + Q_e + Q_{l/g} \qquad (1)$$

where

- Q_i = reach inflow at upstream end of subreach, in cubic feet per second;
- Q_t = streamflow from tributaries into subreach, in cubic feet per second;
- Q_r = return flows to subreach, in cubic feet per second;
- Q_u = ground-water underflow, in cubic feet per second;
- Q_o = reach outflow at downstream end of subreach, in cubic feet per second;
- Q_d = diversions from subreach, in cubic feet per second;
- Q_e = evapotranspiration from subreach, in cubic feet per second; and
- $Q_{l/g}$ = loss (positive) or gain (negative) in subreach, in cubic feet per second.

In computations for this report, underflow (flow parallel to stream [canal] through shallow channel-bed deposits), evapotranspiration, tributary inflow, and direct surface-water irrigation return flow to the canals are considered negligible. Underflow is considered negligible for this study for several reasons: (1) it is assumed that the local ground-water table is well below the canal beds, (2) the weathered shale that underlies the canal beds is less permeable than the alluvium in the streambeds, and (3) the canal-bed elevations are higher than the Purgatoire River streambed (except at diversion points). Evapotranspiration is considered negligible because loss-gain studies were conducted for short subreaches over short-periods of time (that is, hours) in canals with widths mostly less than 15 feet. No inflow from intermittent tributaries was observed because gain-loss studies were conducted during dry periods. The canals studied do not have points of direct surface-water irrigation return flows (that is, irrigation water is not returned back to an individual canal). Thus, equation (1) can be reduced to:

$$Q_{l/g} = Q_i - Q_o - Q_d \qquad (2)$$

Many factors may affect the measured losses and gains along the canals such as canal size, construction, maintenance, infiltration rate of the bed material, the wetted perimeter, and the head (depth of water) in the canal. Changes in application of irrigation water on individual fields may potentially produce large variation in loss and gain measurements over short distances and timeframes. Losses and gains also may vary within the irrigation season. Generally, seepage losses would be expected to be highest in the early part of the season (initial wetting) and then tend to decrease and stabilize. However, in canals that have alternate wetting and drying cycles (do not flow continuously throughout the entire irrigation season) seepage losses would be variable.

Loss and gain measurements were made during 2000, 2001, 2003, and 2004. During 2002, drought conditions in the Purgatoire River Basin substantially reduced the streamflow. The reduced streamflow affected the amount of project storage water that was available for surface-water diversions. Because inflow to the project canals could not be held steady for several consecutive days during May 2002, it was decided that the loss and gain measurements would not be representative and the field investigation scheduled for May 2002 was canceled. Table 2 shows that the annual total acre-feet diverted from the Purgatoire River to Picketwire, Baca, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canals in irrigation years 2000 through 2004 ranged from 6,409 acre-feet in irrigation year 2002 (Nov. 1, 2001, through Oct. 31, 2002) to 60,228 acre-feet in irrigation year 2000 (Nov. 1, 1999, through Oct. 31, 2000).

Canal Losses and Gains

This section presents the measured losses and gains in Picketwire (Baca Joint), El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canals for the 2000, 2001, 2003, and 2004 loss and gain measurements. Losses and gains in canal subreaches were computed by subtracting the subreach outflow and diversions within the subreach (leakage is included as a diversion) from the subreach inflow.

Occasionally, estimates of discharge were made at some diversion sites because the flow was too low to measure, a suitable measurement section could not be found, or estimates were determined to be just as accurate as manual measurements. Estimates of discharge at Parshall flumes were determined using standard rating tables, and estimates at splitter laterals were made by measuring flow in the main canal just upstream from the splitter box and proportioning the total flow on the basis of the width of the lateral (see method description in “Discharge Measurements” section of this report).

Picketwire (Baca Joint) Canal

Water diverted into Picketwire Canal from the Purgatoire River at Trinidad is used to supply Picketwire, Baca, and El Moro canals with water for irrigation. Picketwire Canal flows along the northwest side (left bank) of the Purgatoire River (fig. 4). An 8-ft Parshall flume with a free-flow capacity of about 140 ft^3/s is used to measure irrigation diversions at the Picketwire headgate, and a 9-inch (0.75 ft) Parshall flume with a free-flow capacity of about 9 ft^3/s is used to measure irrigation diversions at the El Moro headgate. There is no single headgate for Baca Canal. Delivery is made to the Baca lands through a series of lateral turnouts from the main Picketwire

Table 2. Annual total acre-feet and total days used for eight Purgatoire River Water Conservancy District canals, irrigation years 2000–2004 (as reported by Colorado Division 7 Water Resources, State Engineers Office).

[NA, not applicable]

Canal name	Irrigation year: 2000		Irrigation year: 2001		Irrigation year: 2002		Irrigation year: 2003		Irrigation year: 2004	
	Annual total acre-feet	Total days used	Annual total acre-feet	Total days used	Annual total acre-feet	Total days used	Annual total acre-feet	Total days used	Annual total acre-feet	Total days used
Baca	1,279.08	166	1,381.49	178	509.38	79	1,177.90	152	993.55	133
Chilili	1,326.78	111	1,273.11	105	23.88	4	1,380.30	114	618.08	55
El Moro	538.10	106	473.46	126	58.69	18	630.93	143	366.59	78
Hoehne	5,039.72	120	5,345.53	138	2,795.80	80	5,209.74	127	5,215.63	139
John Flood	8,822.41	158	6,946.83	174	563.10	63	5,149.05	167	5,612.91	191
Model	10,974.01	108	7,544.00	119	1,660.92	29	2,275.95	29	10,574.08	120
Picketwire	10,021.00	186	6,011.59	165	649.28	65	4,675.29	145	5,387.27	127
Enlarged Southside	22,227.16	119	12,292.82	74	148.13	5	6,601.78	61	15,411.40	97
Total	60,228.26	NA	41,268.83	NA	6,409.18	NA	27,100.94	NA	44,179.51	NA

Canal, and each Baca turnout is equipped with a Parshall flume. Results from the Baca Canal loss and gain measurements are included in this section because, for purposes of this study, Baca Canal is considered to be a subreach of the Picketwire Canal that extends from about 1.5 miles to about 3.5 miles downstream from the Picketwire Canal headgate (PWHG) (fig. 1 and fig. 4). Losses and gains for selected subreaches of Picketwire Canal are shown in table 3, and losses and gains for Baca Canal are shown in table 4.

Loss and gain measurements were made at numerous locations (fig. 4) along Picketwire/Baca Canal on August 2, 2000, May 16, 2001, June 18, 2003, and June 10, 2004. Information for individual measurements is summarized in table A1 in the Appendix. Figure 5 shows losses and gains along Picketwire Canal in relation to distance downstream from the headgate for measurements made on August 2, 2000, May 16, 2001, June 18, 2003, and June 10, 2004.

On August 2, 2000, discharge measurements were made at main canal and diversion locations from the headgate (PWHG) to PW26, a distance of about 15.1 miles. Leakage was observed at three closed diversion gates (table A1). The total leakage from the three gates was estimated to be about 0.9 ft^3/s. A gain of about 1.2 ft^3/s (3 percent of the subreach inflow) was measured along the Baca subreach from BA01 to BA10 (table 4). The loss for the entire Picketwire Canal from PWHG to PW26 was computed to be 3.3 ft^3/s, or 7 percent of the headgate inflow (table 3 and fig. 5).

Discharge measurements were made at main canal and diversion locations from PWHG to PW27, a distance of about 16.0 miles, on May 16, 2001. No leakage was observed at the diversion gates (table A1). A loss of about 4.6 ft^3/s (13 percent of the subreach inflow) was measured from BA01 to PW02 (tables 3 and 4), a 2.4-mile reach. The loss from PWHG to PW27 (table 3) was computed to be 9.4 ft^3/s, or 23 percent of the headgate inflow (fig. 5).

Discharge measurements were made at main canal and diversion locations from PWHG to PW02 on June 18, 2003 (fig. 4). No leakage was observed at the diversion gates (table A1). The loss from PWHG to PW02, a 3.9-mile reach, was computed to be 2.0 ft^3/s, or 13 percent of the headgate inflow (fig. 5 and tables 3 and 4).

On June 10, 2004, discharge measurements were made at main canal and diversion locations from PWHG to PW26 (fig. 4). Minor leakage of less than 0.02 ft^3/s was estimated at three closed diversion gates (table A1). No leakage was observed at the remaining diversion gates. A loss of about 1.7 ft^3/s (4 percent of the subreach inflow) was measured along the Baca subreach from BA02 to BA10 (table 4), a 1.9-mile reach. The loss from PWHG to PW26 was computed to be 4.8 ft^3/s, or 12 percent of the headgate inflow (fig. 5 and table 3).

Loss and gain measurements showed that Picketwire Canal generally loses some flow from the headgate to the end of the canal (PWHG to PW26) (table 3 and fig. 5), although some subreaches showed gains in flow during the 2000 and 2004 studies. Losses in the canal appear to decrease the longer the canal flows. For example, the greatest loss (9.4 ft^3/s or 23 percent of the headgate inflow) was measured on May 16, 2001, when the canal had only been flowing for about 10 days before the measurement, whereas the smallest loss from the headgate to the end of the canal (3.3 ft^3/s, or 7 percent of the headgate inflow) was measured on August 2, 2000, when the canal had been flowing for about 107 days before the measurement (table 3).

Main canal measurements were not made at BA01 on June 18, 2003, and June 10, 2004, and main canal measurements were not made at BA10 on May 16, 2001, and June 18, 2003. As a result, losses and gains from BA01 to BA10 (Baca subreach) were not computed for the 2001, 2003, and 2004 measurements. Losses and gains are shown in table 4 for reaches from BA01 to PW02 on May 16, 2001, from PWHG to PW02 on June 18, 2003, and from BA02 to BA10 on June 10, 2004.

The losses and gains computed along the Baca subreach on August 2, 2000, and June 10, 2004, are small and are within the uncertainty of the measurements (±5 to 8 percent). The measurement made on June 18, 2003, also may indicate

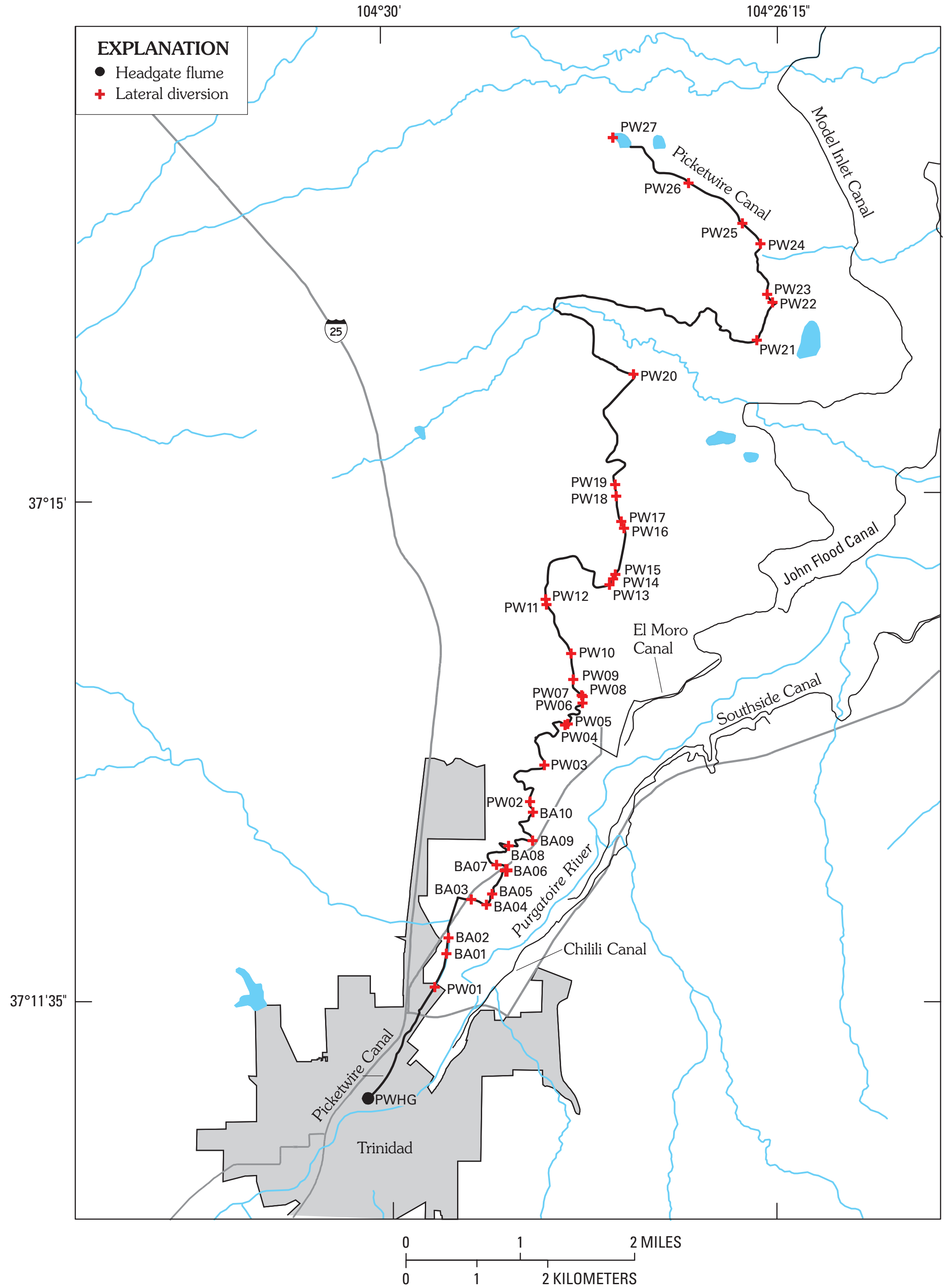


Figure 4. Location of measurement sites along Picketwire Canal (Baca Joint Canal).

Table 3. Losses and gains for selected subreaches of Picketwire Canal, 2000–2004.

[ft³/s, cubic feet per second; BA, Baca; PW, Picketwire; HG, headgate; inflows and outflows measured upstream from diversion structures unless otherwise noted]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft³/s)	Subreach outflow (ft³/s)	Cumulative diversions (ft³/s)	Loss or gain in subreach (ft³/s)[1]	Loss or gain in subreach (percent)[1]	Remarks
August 2, 2000	Picketwire	PWHG to PW26	47.3	2.9	41.1	3.3	7	
		PWHG to PW01	47.3	41.3	0	6.0	13	
		PW01 to BA01	41.3	40.2	1.2	–0.1	–0.2	
		BA01 to BA10	40.2	37.9	3.5	–1.2	–3	
		BA10 to PW03	37.9	36.4	2.3	–0.8	–2	
		PW03 to PW04	36.4	38.5	1.3	–3.4	–9	
		PW04 to PW05	38.5	32.2	4.2	2.1	5	
		PW05 to PW06	32.2	30.2	0.4	1.6	5	
		PW06 to PW07	30.2	29.1	0.2	0.9	3	
		PW07 to PW09	29.1	31.1	0.4	–2.4	–8	Gate open at 3-inch flume (no splitter); however, no measurement made. Flow estimated.
		PW09 to PW10	31.1	27.4	1.2	2.5	8	
		PW10 to PW11	27.4	27.7	3.2	–3.5	–13	
		PW11 to PW13	27.7	26.6	0.7	0.4	1	
		PW13 to PW16	26.6	21.5	4.8	0.3	1	
		PW16 to PW18	21.5	20.1	3.2	–1.8	–8	
		PW18 to PW20	20.1	15.9	5.5	–1.3	–6	
		PW20 to PW21	15.9	11.1	0.4	4.4	28	
		PW21 to PW26	11.1	2.9	8.6	–0.4	-4	
May 16, 2001	Picketwire	PWHG to PW27[2]	40.8	2.1	29.3	9.4	23	
		PWHG to BA01[2]	40.8	35.6	1.4	3.8	9	
		BA01[2] to PW02	35.6	26.7	4.3	4.6	13	
		PW02 to PW20[2]	26.7	9.8	16.4	0.5	2	
		PW20[2] thru PW27[2]	9.8	2.1	7.2	0.5	5	
June 18, 2003	Picketwire	PWHG to PW02	16.0	9.0	5.0	2.0	13	In year 2003, the reach was PWHG to PW02. No measurement made at BA01 or BA10.
June 10, 2004	Picketwire	PWHG to PW26[2]	41.2	2.0	34.4	4.8	12	
		PWHG to BA02	41.2	38.5	0.6	2.1	5	
		BA02 to BA10[2]	38.5	32.2	4.6	1.7	4	
		BA10[2] to PW10	32.2	24.8	6.3	1.1	3	
		PW10 to PW13	24.8	22.6	3.1	–0.9	–4	
		PW13 to PW20	22.6	11.1	12.0	–0.5	–2	
		PW20 to PW26[2]	11.1	2.0	7.8	1.3	12	

[1]A positive value indicates a loss of flow from the canal, and a negative value indicates a gain of flow to the canal.

[2]Measurement made on main canal downstream from diversion.

Table 4. Losses and gains for selected subreaches of Baca Canal, 2000–2004.

[ft^3/s, cubic feet per second; BA, Baca; PW, Picketwire; PWHG, Picketwire headgate; inflows and outflows measured upstream from diversion structures unless otherwise noted]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (in percent)[1]	Remarks
August 2, 2000	Baca	BA01 to BA10	40.2	37.9	3.5	–1.2	–3	
		BA01 to BA05	40.2	39.5	0.8	–0.1	–0.2	
		BA05 to BA07	39.5	38.7	0.6	0.2	0.5	
		BA07 to BA08	38.7	38.3	0.7	–0.3	–0.8	Gate open at 3-inch flume near BA08; however, no measurement made. Flow estimated.
		BA08 to BA10	38.3	37.9	1.4	–1.0	–3	
May 16, 2001	Baca	BA01[2] to PW02	35.6	26.7	4.3	4.6	13	No main canal measurement was made at BA10 in 2001.
June 18, 2003	Baca	PWHG to PW02	16.0	9.0	5.0	2.0	13	In 2003, reach was PWHG to PW02.
June 10, 2004	Baca	BA02 to BA10[2]	38.5	32.2	4.6	1.7	4	No main canal measurement was made at BA01 in 2004.

[1]A positive value indicates a loss of flow from the canal, and a negative value indicates a gain of flow to the canal.

[2]Discharge measurement made downstream from diversion on main canal.

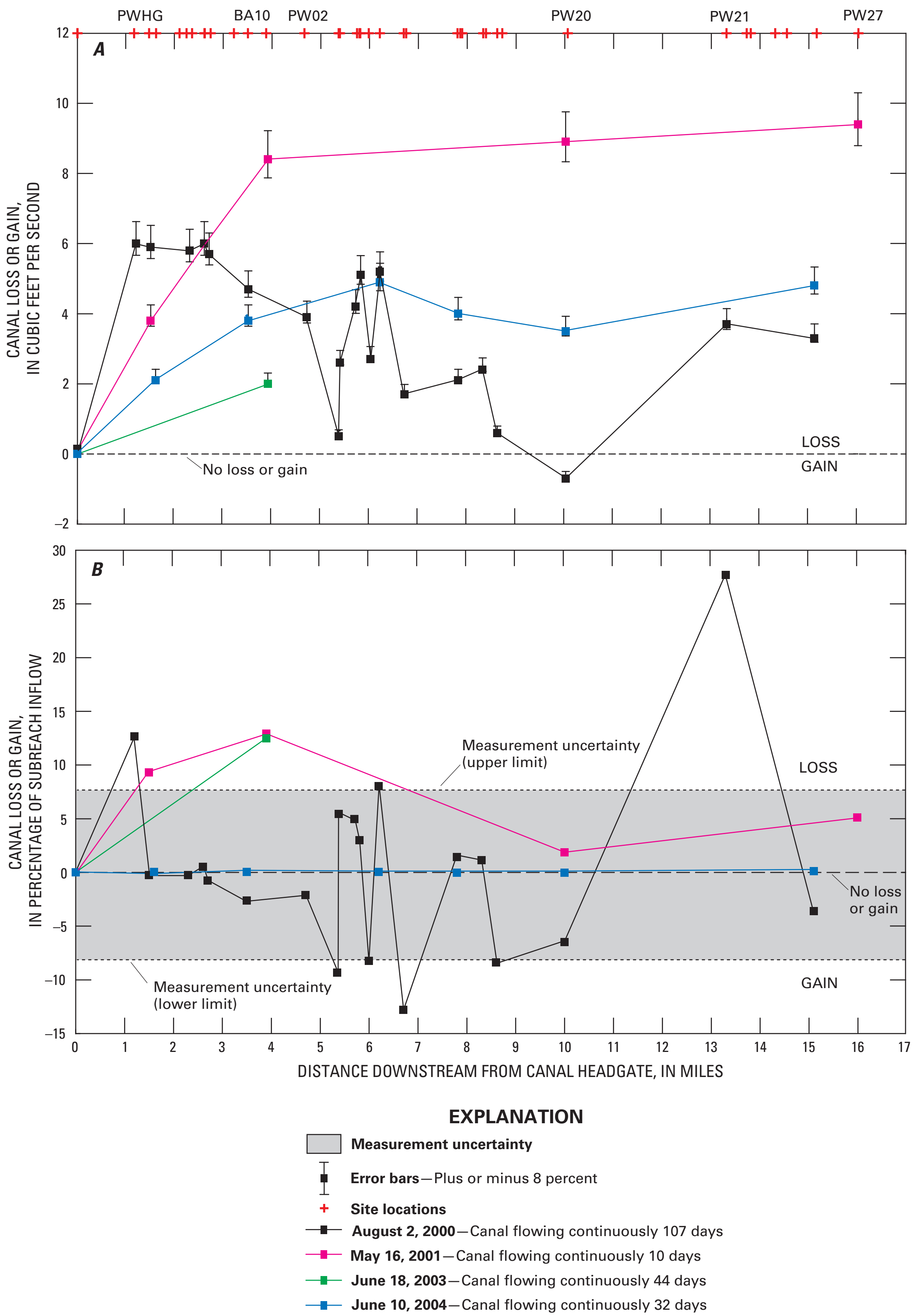


Figure 5. Losses and gains in (*A*) cubic feet per second and (*B*) percentage of subreach inflow in selected subreaches of the Picketwire Canal.

small losses or gains in this subreach. Even though the losses and gains in the Baca subreach are small, they may still be affected by the length of time that the canal has been flowing. For example, a loss of 4.6 ft^3/s (about 13 percent of the subreach inflow) was measured on May 16, 2001, from BA01 to PW02, when the canal had been flowing for only about 10 days. Measurements made on August 2, 2000, when the canal had been flowing about 107 days, showed a gain of about 1.2 ft^3/s, or 3 percent of the subreach inflow from BA01 to BA10 (table 4).

El Moro Canal

El Moro Canal diverts water from Picketwire Canal about 5.4 miles downstream from the Picketwire headgate (fig. 6). A 9-inch (0.75-ft) Parshall flume with a free-flow capacity of about 9 ft^3/s is used to measure irrigation diversions at the El Moro Canal headgate.

Loss and gain measurements were made along El Moro Canal on August 1, 2000, June 18, 2003, and June 16, 2004. Information for individual measurements is summarized in table A2 in the Appendix. Measurements were made on the main channel and the diversions from the headgate (EMHG) to the end of the canal, a distance of about 1.6 miles (fig. 6). The final measurement location (that is, end of the canal) was different during each of the three loss and gain measurements. Losses and gains for selected subreaches of El Moro Canal are shown in table 5. Figure 6 shows the measurement site locations, and figure 7 shows losses and gains along El Moro Canal in relation to distance downstream from the headgate.

On August 1, 2000, discharge measurements were made at main channel and diversion locations from the headgate (EMHG) to EM09, which is upstream from the final two diversions on El Moro Canal (fig. 6). Five diversion gates were closed on August 1, 2000 (table A2). Leakage of about 0.1 ft^3/s was estimated at one of the gates. No leakage was observed at the remaining gates. A gain of 0.4 ft^3/s, or 10 percent of the headgate inflow, was determined for El Moro Canal between EMHG and EM04, a distance of about 0.9 mile. This is compared to a loss of 1.1 ft^3/s (28 percent of the headgate inflow) computed between EMHG and EM09, a distance of about 1.6 miles (table 5 and fig. 7).

Losses and gains measured on August 1, 2000, between main-channel measurement locations ranged from a gain of 0.7 ft^3/s between sites EM02 and EM04 to a loss of 1.6 ft^3/s between sites EM07 and EM09 (table 5). Field observations indicate that a pipeline carrying water over El Moro Canal between sites EM02 and EM03 was overflowing during the measurement period. Notes also indicate that this probably is a common occurrence because a concrete apron has been poured to reduce bank erosion. In addition, field notes report that El Moro Canal water was spilling over into an adjacent ditch near EM08.

On June 18, 2003, discharge measurements were made from EMHG to EM08 (end of canal). Four diversions between EMHG and EM08 were not operational (that is, gates closed) on June 18, 2003. Leakage of 1.0 ft^3/s was measured at one of the diversions (table A2). No leakage was observed at the remaining three diversions. A loss of 1.1 ft^3/s (28 percent of the headgate inflow) was determined for El Moro Canal between EMHG and EM08 on June 18, 2003 (table 5).

On June 16, 2004, discharge measurements were made at main canal and diversion locations from EMHG to EM04 (end of ditch). A gain of 0.6 ft^3/s, or about 14 percent of the headgate inflow, was determined for the El Moro Canal between EMHG and EM04 on June 16, 2004 (table 5 and fig. 7).

El Moro Canal appears to lose flow in some subreaches and gain flow in other subreaches. Between EMHG and EM04, El Moro Canal gained water (0.4 ft^3/s on August 1, 2000, and 0.6 ft^3/s on June 16, 2004), roughly 10 to 14 percent of the headgate inflow (table 5). Based on field notes, the gain probably is due to inflow from the pipeline crossing over the canal between EM02 and EM03. Despite gains measured between EM02 and EM04 (listed in table 5), measurements show flow losses of about 28 percent of the headgate inflow for the entire canal. Much of this loss probably occurs near EM08 where field data indicate spilling of flow from El Moro to an adjacent canal (probably Model Canal).

Chilili Canal

Water is diverted into Chilili Canal from the Purgatoire River downstream from the Picketwire diversion at Trinidad (fig. 1). Chilili Canal flows along the southeast side (right bank) of the Purgatoire River. A 2-ft Parshall flume with a free-flow capacity of about 33 ft^3/s is used to measure irrigation diversions at the Chilili Canal headgate.

Discharge measurements were made along Chilili Canal on August 1, 2000, May 17, 2001, June 28, 2001, and June 19, 2003. Information for individual measurements is summarized in table A3 in the Appendix. Losses and gains for selected subreaches of Chilili Canal are shown in table 6. Figure 8 shows the measurement site locations, and figure 9 shows losses and gains along Chilili Canal in relation to distance downstream from the headgate.

On August 1, 2000, discharge measurements were made at main channel and diversion locations from the headgate (CHHG) to CEND, a distance of about 4.9 miles (fig. 8, and table A3). No leakage was observed at the diversion gates. The loss from CHHG to CEND was computed to be 0.2 ft^3/s, or 2 percent of the headgate inflow, which is within the uncertainty of the measurement (fig. 9 and table 6).

Discharge measurements were made at main channel and diversion locations from CHHG to CH10, a distance of about 1.4 miles, on May 17, 2001 (fig. 8 and table A3). Leakage of about 0.002 ft^3/s was estimated at one of the diversion gates. No leakage was observed at the other gates. Main canal loss and gain measurements were ended at CH10 due to a thunderstorm. The loss from CHHG to CH10 was computed to be 2.3 ft^3/s, or 25 percent of the headgate inflow (fig. 9 and table 6).

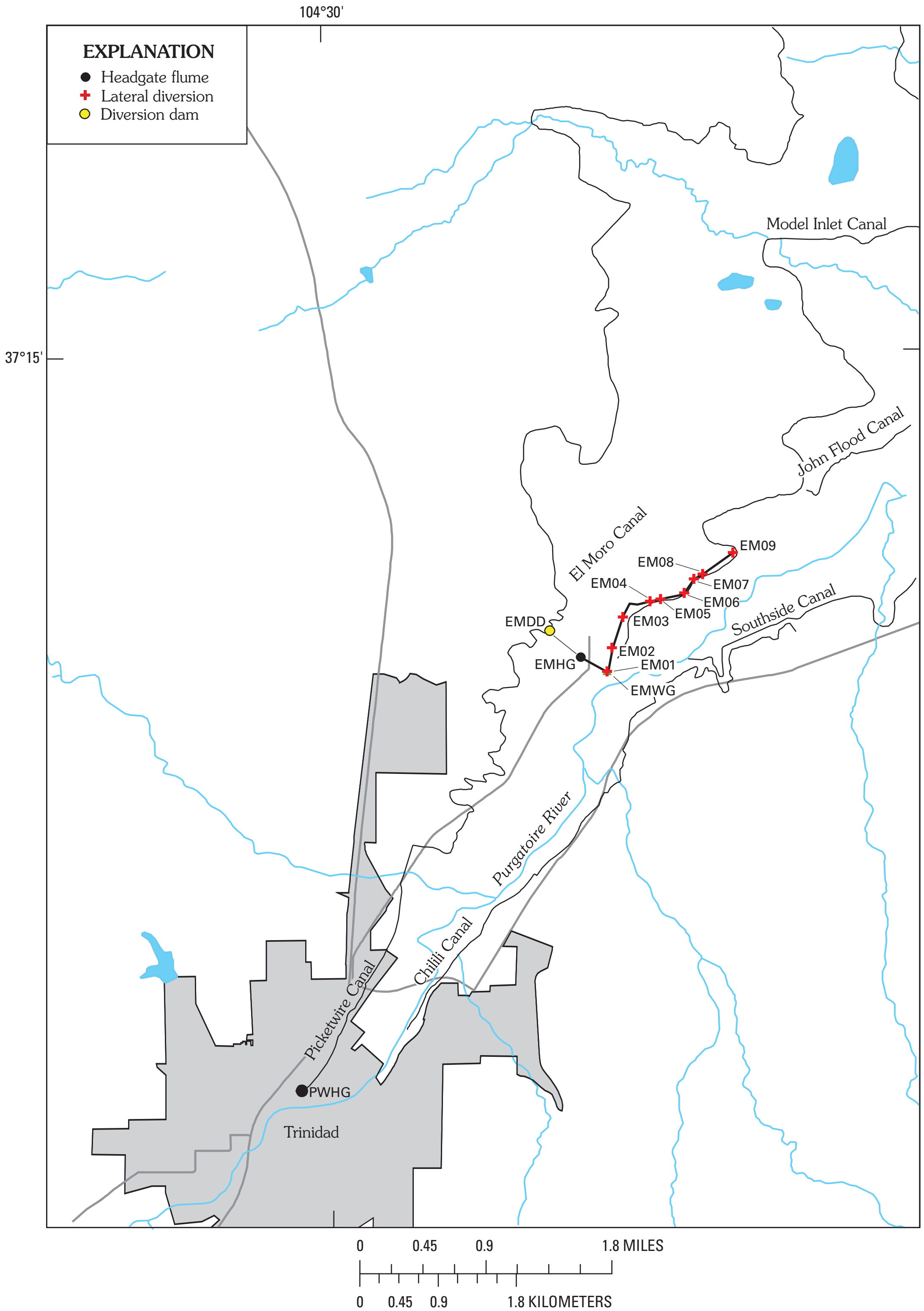


Figure 6. Location of measurement sites along El Moro Canal.

Table 5. Losses and gains for selected subreaches of El Moro Canal, 2000–2004.

[ft^3/s, cubic feet per second; EMHG, El Moro headgate; EM, El Moro; inflows and outflows measured upstream from diversion structures unless otherwise noted]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]	Results
August 1, 2000	El Moro	EMHG to EM09	3.9	1.2	1.6	1.1	28	
		EMHG to EM01	3.9	3.8	0.0	0.1	3	
		EM01 to EM02	3.8	2.7	0.9	0.2	5	
		EM02 to EM04	2.7	3.1	0.3	–0.7	26	Field notes indicate inflow from Picketwire (perhaps) between EM02 and EM03. “Pipeline carrying water across El Moro is overflowing.”
		EM04 to EM07	3.1	3.2	0.0	–0.1	–3	
		EM07 to EM09	3.2	1.2	0.4	1.6	50	Field notes indicate water spilling from El Moro to Picketwire at EM08.
June 18, 2003	El Moro	EMHG to EM08	3.9	0.0	2.8	1.1	28	New 9-inch Parshall flume installed in 2003.
June 16, 2004	El Moro	EMHG to EM04[2]	4.3	0.0	4.9	–0.6	–14	Field notes indicate depth bias on left side of flume opposite to staff plate. Flume may not be level or approach section may have debris. Standard Parshall flume rating should be checked.
		EMHG to EM02	4.3	1.9	1.5	0.9	21	
		EM02 to EM04	1.9	0	3.4	–1.5	–79	

[1]A positive value indicates a loss of flow from the canal, and a negative value indicates a gain of flow to the canal.

[2]End of canal at site EM04 on June 16, 2004.

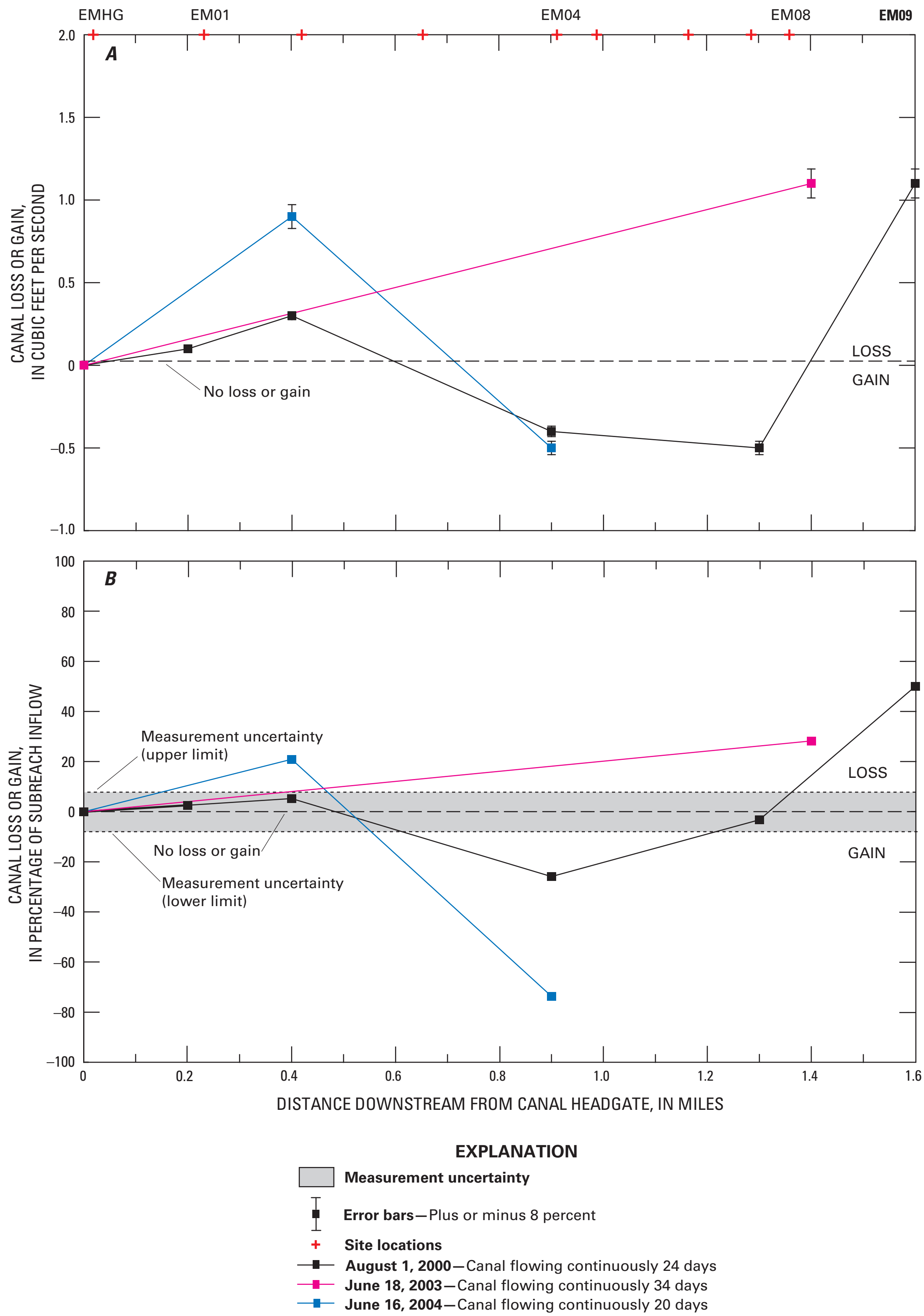


Figure 7. Losses and gains in (*A*) cubic feet per second and (*B*) percentage of subreach inflow in selected subreaches of the El Moro Canal.

Table 6. Losses and gains for selected subreaches of Chilili Canal, 2000–2004.

[ft^3/s, cubic feet per second; CHHG, Chilili headgate; CH, Chilili; CEND, end of Chilili Canal]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]	Remarks
August 1, 2000	Chilili	CHHG to CEND	9.4	2.6	6.6	0.2	2	
		CHHG to CH02	9.4	8.6	0.0	0.8	9	
		CH02 to CH03	8.6	7.4	0.2	1.0	12	
		CH03 to CH05	7.4	5.7	1.9	–0.2	–3	
		CH05 to CH06	5.7	6.2	1.3	–1.8	–32	
		CH06 to CH08	6.2	5.7	0.3	0.2	3	
		CH08 to CH09	5.7	5.1	0.4	0.2	4	Water being pumped from canal about 100 feet downstream from flume at CH08. Consequently, subreach loss may be overestimated.
		CH09 to CH11	5.1	3.8	1.0	0.3	6	
		CH11 to CH16	3.8	3.5	0.9	–0.6	–16	
		CH16 to CH18	3.5	3.5	0.3	–0.3	–9	
		CH18 to CH19	3.5	3.1	0.0	0.4	11	
		CH19 to CEND	3.1	2.6	0.3	0.2	6	
May 17, 2001	Chilili	CHHG to CH10	9.3	5.2	1.8	2.3	25	
		CHHG to CH02	9.3	9.0	0.0	0.3	3	
		CH02 to CH10	9.0	5.2	1.8	2.0	22	
June 28, 2001	Chilili	CH09 to CEND	5.0	1.9	1.7	1.4	28	
June 19, 2003	Chilili	CHHG to CEND	8.2	3.2	2.2	2.8	34	
		CHHG to CH09	8.2	7.3	0.2	0.7	9	
		CH09 to CH19	7.3	3.9	2.0	1.4	19	
		CH19 to CEND	3.9	3.2	0.0	0.7	18	

[1]A positive value indicates a loss of flow from the canal and a negative value indicates a gain of flow to the canal.

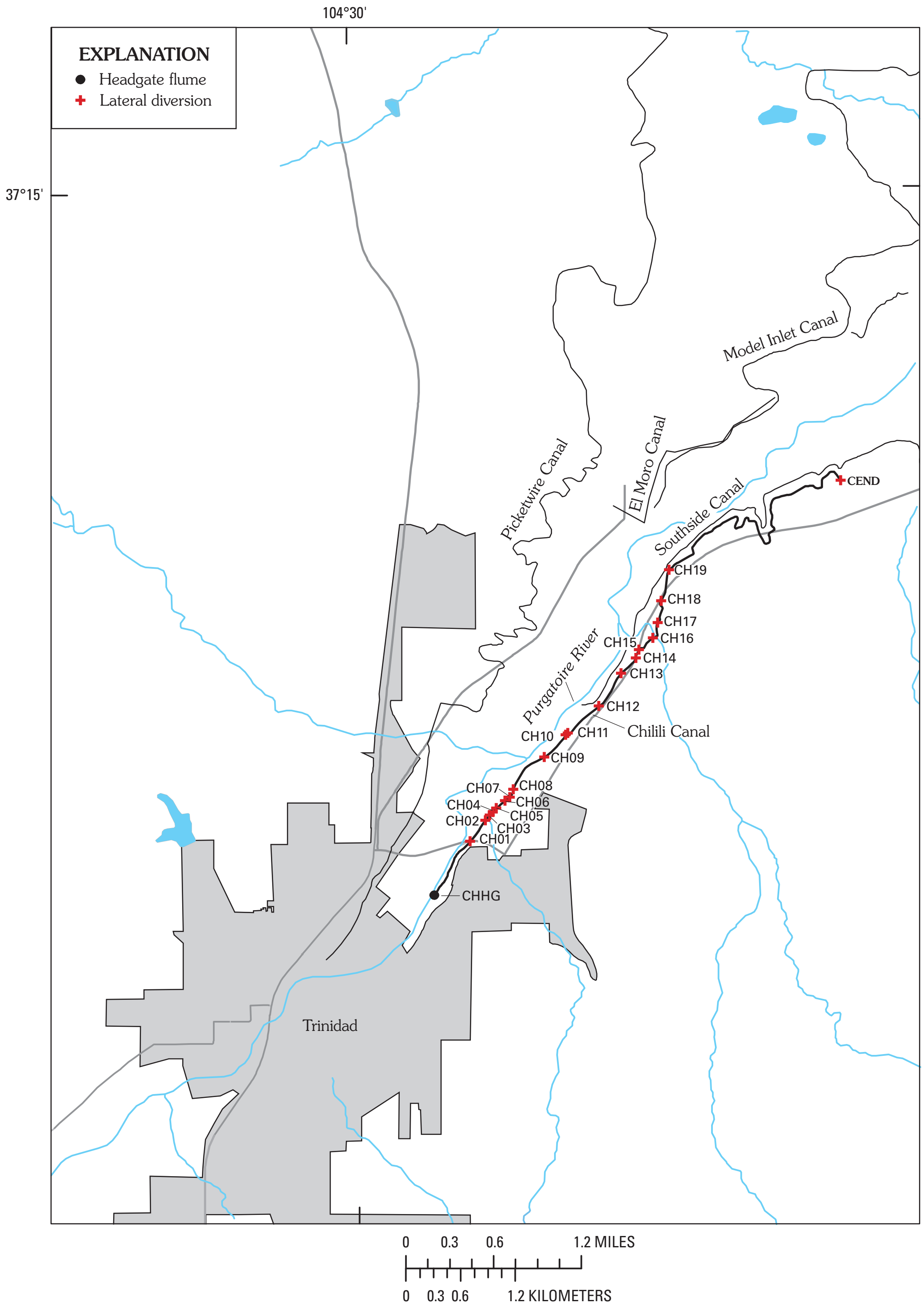


Figure 8. Location of measurement sites along Chilili Canal.

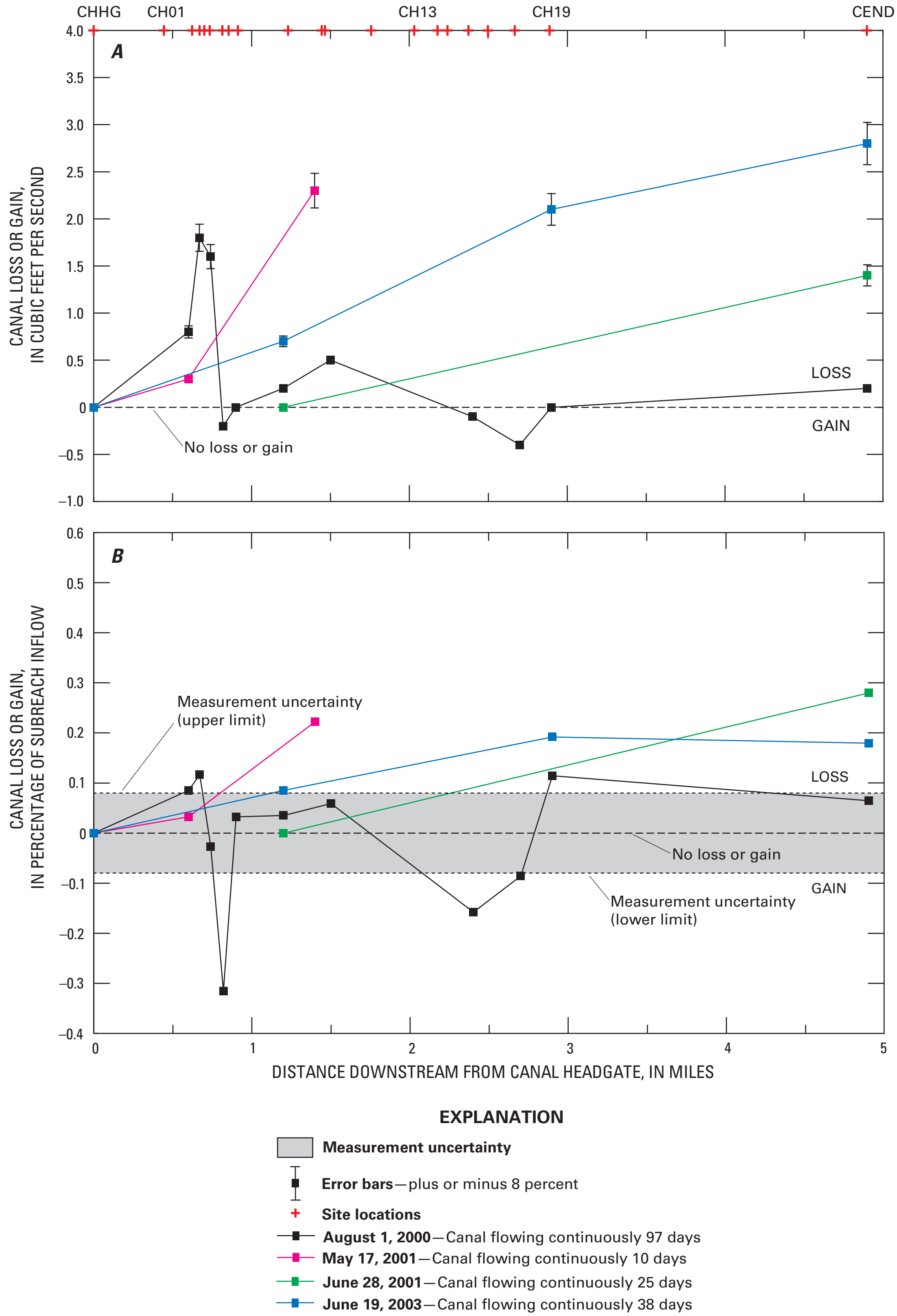


Figure 9. Losses and gains in (*A*) cubic feet per second and (*B*) percentage of subreach inflow in selected subreaches of the Chilili Canal.

On June 28, 2001, discharge measurements were made at main canal and diversion locations from CH09 to CEND, a 3.7-mile subreach of Chilili Canal beginning about 1.2 miles downstream from the headgate (fig. 8 and table A3). No leakage was observed at the diversion gates. The loss from CH09 to CEND was computed to be 1.4 ft^3/s, or 28 percent of the subreach inflow (fig. 9 and table 6).

On June 19, 2003, discharge measurements were made at main canal and diversion locations from CHHG to CEND, a distance of about 4.9 miles (fig. 8 and table A3). Minor leakage of about 0.002 ft^3/s was estimated at each of two diversion gates (table A3). The loss from CHHG to CEND was computed to be 2.8 ft^3/s, or 34 percent of the headgate inflow (fig. 9 and table 6).

Losses in Chilili Canal ranged from about 2 percent of the headgate inflow to about 34 percent of the headgate inflow (table 6). The variability in losses may be somewhat related to length of time the canal was flowing before the measurement. For example, the canal had been flowing continuously for about 97 days before the loss and gain measurements on August 1, 2000. A loss of about 0.2 ft^3/s, or 2 percent of the headgate inflow, was measured on August 1, 2000. This is compared with a loss of 2.8 ft^3/s, or 34 percent of the headgate inflow measured on June 19, 2003, when the canal had been flowing for about 38 days before the measurements were made.

Enlarged Southside Canal

Enlarged Southside Canal diverts water from the right bank of the Purgatoire River downstream from the Picketwire and Chilili canal diversions. Enlarged Southside Canal flows along the southeast side (right bank) of the Purgatoire River (fig. 10). A 10-ft Parshall flume with a free-flow capacity of about 300 ft^3/s is used to measure irrigation diversions at the Enlarged Southside Canal headgate.

Loss and gain measurements were made along Enlarged Southside Canal on August 9–11, 2000, May 22–23, 2001, June 27, 2001, and June 8–9, 2004. Information for individual measurements is summarized in table A4 in the Appendix. The computed losses and gains for seven main canal subreaches, including main Enlarged Southside Canal from the headgate (SSHG) to the Palaski Extension (SSS1), Palaski Extension (SSS1 to SP10), main Enlarged Southside Canal to the Sandoval/Wagner split (SSS1 to SSS2), Sandoval Extension (SSS2 to SS08), Enlarged Southside Canal from SSS2 to SSS3 (fig. 10), South Wagner Extension (SSS3 to SW05), and the North Wagner Extension (SSS3 to SW12) are listed in table 7. Measurement site locations are shown in figure 10. Figure 11 shows losses and gains in relation to distance downstream from the Enlarged Southside Canal headgate.

On August 9–11, 2000, discharge measurements were made at main channel and diversion locations along Enlarged Southside Canal (fig. 10). Leakage was reported at one closed diversion gate. The leakage was determined to be about 0.1 ft^3/s. Before the measurements were made, the canal had been continuously flowing for about 92 days. Losses and gains only were computed between SSS2 and SS07 along the Sandoval Extension, because a main-channel measurement was not made at SS08 during 2000. A gain of about 3.4 ft^3/s (19 percent of the subreach inflow) was determined between SSS1 and SP10 (Palaski Extension), and losses of 3.5 ft^3/s (10 percent of the subreach inflow) and 1.2 ft^3/s (13 percent of the subreach inflow) were determined between SSS2 and SS07 (Sandoval Extension) and SSS3 and SW05 (South Wagner Extension), respectively (table 7 and figs. 10 and 11). All other losses and gains were within the measurement uncertainty.

Discharge measurements were made from SSHG to SSS1, SSS1 to SP10, SSS1 to SSS2, SSS2 to SS08, and SSS2 to SSS3 on May 22–23, 2001 (fig. 10). One diversion gate (SP05) was closed with some leakage reported; however, no estimate of leakage was made. Before the measurements, the canal had been continuously flowing for only about 10 days. Computed losses and gains in the subreaches were all within the measurement error of 8 percent except along the Sandoval Extension between sites SSS2 to SS08. This subreach had a computed loss of 2.9 ft^3/s, or about 11 percent of the subreach inflow (fig. 11 and table 7).

Discharge measurements were made from SSS1 to SSS2, SSS2 to SSS3, SSS3 to SW05, and SSS3 to SW12 on June 27, 2001 (fig. 10). One diversion gate was closed with no leakage observed (table A4). Before the measurements were made, the canal had been continuously flowing for about 45 days. Computed losses and gains in the subreaches were all within the measurement error of 8 percent except along the main Enlarged Southside Canal between sites SSS2 and SSS3. This subreach had a computed loss of 5.0 ft^3/s, or about 14 percent of the subreach inflow (fig. 11 and table 7).

On June 8–9, 2004, discharge measurements were made at main channel and diversion locations along Enlarged Southside Canal (fig. 10). Two diversion gates were closed. Some leakage was reported at one of the closed gates (SP05); however, no estimate of leakage was made (table A4). Before the measurements were made, the canal had been continuously flowing for about 32 days. Computed losses and gains in the subreaches were all within the measurement error of 8 percent except along the North Wagner Extension between sites SSS3 and SW12. This subreach had a computed loss of 1.5 ft^3/s, or about 9 percent of the subreach inflow (table 7 and fig. 11).

Model Inlet and Outlet Canals

Model Canal diverts water from the left bank of Purgatoire River downstream from the Picketwire, Chilili, and Enlarged Southside canal diversions (fig. 1). Water diverted into Model Canal is used to supply Model and John Flood Canals with water for irrigation. A 10-ft Parshall flume with a free-flow capacity of about 300 ft^3/s is used to measure irrigation diversions at the Model Canal headgate. Model Inlet Canal (Model Canal upstream from the Model Reservoir)

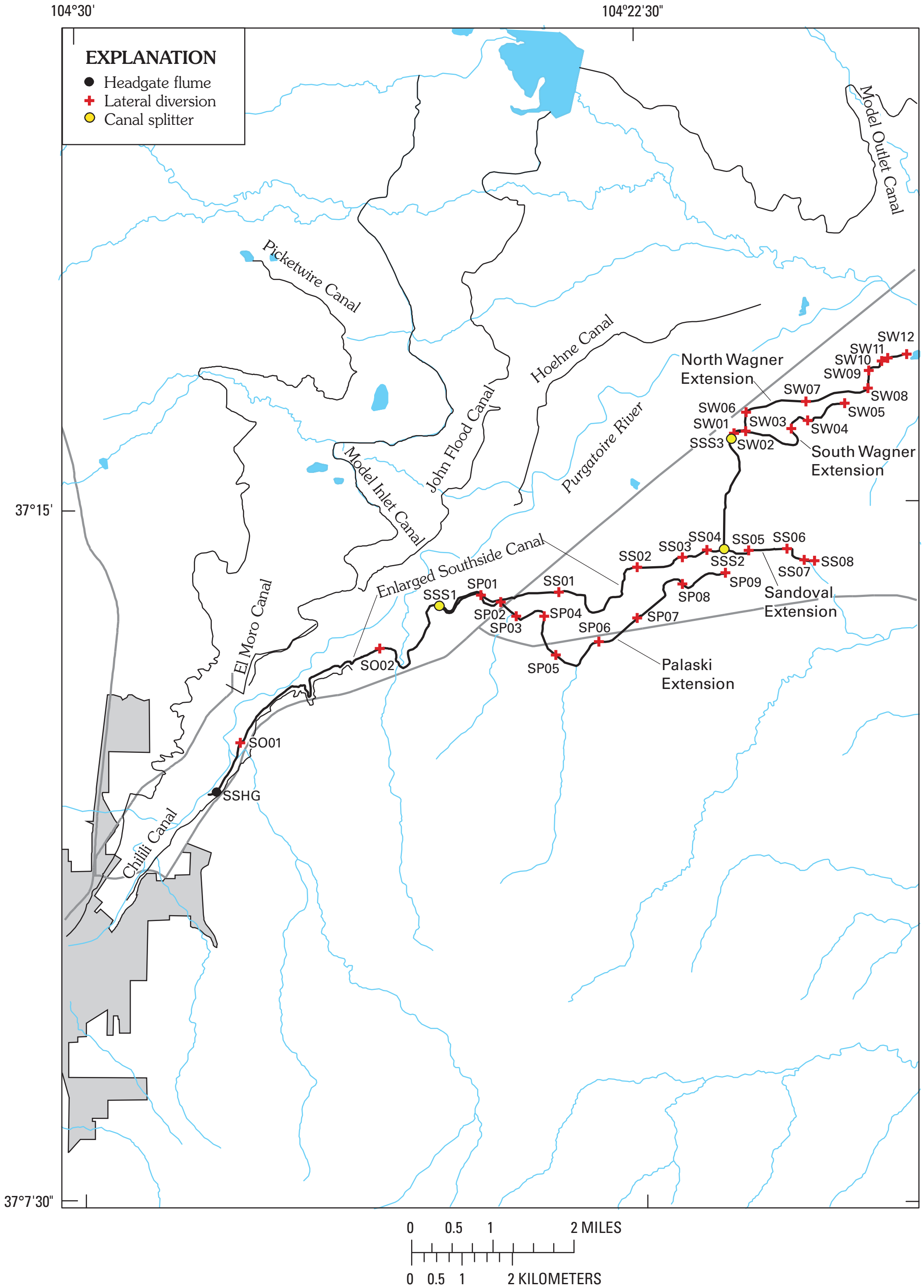


Figure 10. Location of measurement sites along Enlarged Southside Canal.

Table 7. Losses and gains for selected subreaches of Enlarged Southside Canal, 2000–2004.

[ft^3/s, cubic feet per second; SS, Southside Canal; HG, headgate; SSS, Southside Canal splitter; SW, Southside—Wagner Extension, SP, Southside—Palaski Extension]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]
August 9–11, 2000	Enlarged Southside						
08/09/2000	Southside	SSHG to SSS1	69.5	68.2	1.5	–0.2	–0.3
08/09/2000	Palaski Extension	SSS1 to SP10	18.2	3.3	18.3	–3.4	–19
08/10/2000	Sandoval/Wagner Extension	SSS1 to SSS2	68.2	35.8	37.0	–4.6	–7
08/10/2000	Sandoval Extension	SSS2 to SS07	35.8	2.4	29.9	3.5	10
08/10/2000	Southside	SSS2 to SSS3	35.8	29.6	4.6	1.6	4
08/11/2000	South Wagner Extension	SSS3 to SW05	9.2	4.5	3.5	1.2	13
08/11/2000	North Wagner Extension	SSS3 to SW12	12.9	5.2	8.5	–0.8	–6
May 22–23, 2001	Enlarged Southside						
05/22/01	Southside	SSHG to SSS1	68.7	62.2	3.4	3.1	5
05/22/01	Palaski Extension	SSS1 to SP10	16.0	2.4	13.3	0.3	2
05/23/01	Sandoval/Wagner Extension	SSS1 to SSS2	62.2	26.3	34.2	1.7	3
05/23/01	Sandoval Extension	SSS2 to SS08	26.3	1.1	22.3	2.9	11
05/23/01	Southside	SSS2 to SSS3	26.3	19.1	5.5	1.7	6
June 27, 2001	Enlarged Southside						
06/27/01	Sandoval/Wagner Extension	SSS1 to SSS2	85.9	35.7	45.2	5.0	6
06/27/01	Southside	SSS2 to SSS3	35.7	21.9	8.8	5.0	14
06/27/01	South Wagner Extension	SSS3 to SW05	7.8	2.5	5.5	–0.2	–3
06/27/01	North Wagner Extension	SSS3 to SW12	12.7	4.5	7.8	0.4	3
June 8–9, 2004	Enlarged Southside						
06/08/04	Southside	SSHG to SSS1	99.9	91.2	2.5	6.2	6
06/08/04	Palaski Extension	SSS1 to SP10	21.1	4.5	17.2	–0.6	–3
06/08/04	Southside	SSS1 to SSS2	91.2	43.4	45.5	2.3	3
06/09/04	Sandoval Extension	SSS2 to SS08	43.4	2.1	40.9	0.4	1
06/09/04	Southside	SSS2 to SSS3	43.4	32.2	11.2	0.0	0
06/09/04	South Wagner Extension	SSS3 to SW05	9.8	3.3	6.1	0.4	4
06/09/04	North Wagner Extension	SSS3 to SW12	16.5	3.4	11.6	1.5	9

[1]A positive value indicates a loss of flow from the canal and a negative value indicates a gain of flow to the canal.

flows about 17 miles from the headgate to Model Reservoir. Model Outlet Canal (Model Canal downstream from Model Reservoir) flows about 14 miles from below Model Reservoir to the end of the canal (fig. 12).

Loss and gain measurements were made along Model Canal on August 10, 2000, August 23, 2000, May 24, 2001, and June 12, 2001, by the Colorado Division of Water Resources. Additional loss and gain measurements were made by the USGS on May 18 and 21, 2001, June 26, 2001, and June 11, 2004. Information for individual measurements (made by the USGS) is summarized in table A5 in the Appendix. Losses and gains for selected subreaches of Model Canal are listed in table 8. Figure 12 shows the measurement site locations, and figure 13 shows losses and gains along Model Inlet and Outlet canals in relation to distance downstream from the headgate for measurements made by the USGS.

On May 18, 2001, discharge measurements were made at main channel and diversion locations from the headgate (MOHG) to MOT3 along Model Inlet Canal (fig. 12 and table A5). The loss from MOHG to MOT3 was computed to be 1.9 ft^3/s, or 3 percent of the headgate inflow (table 8 and fig. 13).

Discharge measurements were made at main channel and diversion locations from MOHG to MOT3 along Model Inlet Canal on May 21, 2001 (fig. 12). The gain from MOHG to MOT3 was computed to be 1.2 ft^3/s, or 2 percent of the headgate inflow (table 8 and fig. 13).

Discharge measurements were made at main channel and diversion locations from M2HG to MO03 along Model Outlet Canal on June 26, 2001 (fig. 12). Two diversion gates were closed. Leakage of about 0.4 ft^3/s was measured at one of the gates, and no leakage was observed at the other gate. A loss of 11.5 ft^3/s, or 30 percent of the headgate inflow, was determined between M2HG and M3HG, and a gain of 0.4 ft^3/s (2 percent of the subreach inflow) was determined between M3HG and MO03 (table 8 and fig. 13).

On June 11, 2004, discharge measurements were made at main channel and diversion locations along Model Inlet and Outlet canals from MOHG to MO03 (fig. 12). Minor leakage was reported at three diversion gates (table A5). No estimate of leakage was made. Loss from MOHG to MOEND (upstream from Model Reservoir) was computed to be 2.3 ft^3/s, or 4 percent of the headgate inflow; whereas, a loss of 11.6 ft^3/s, or 39 percent of the subreach inflow, was measured from M2HG to MO03 (table 8).

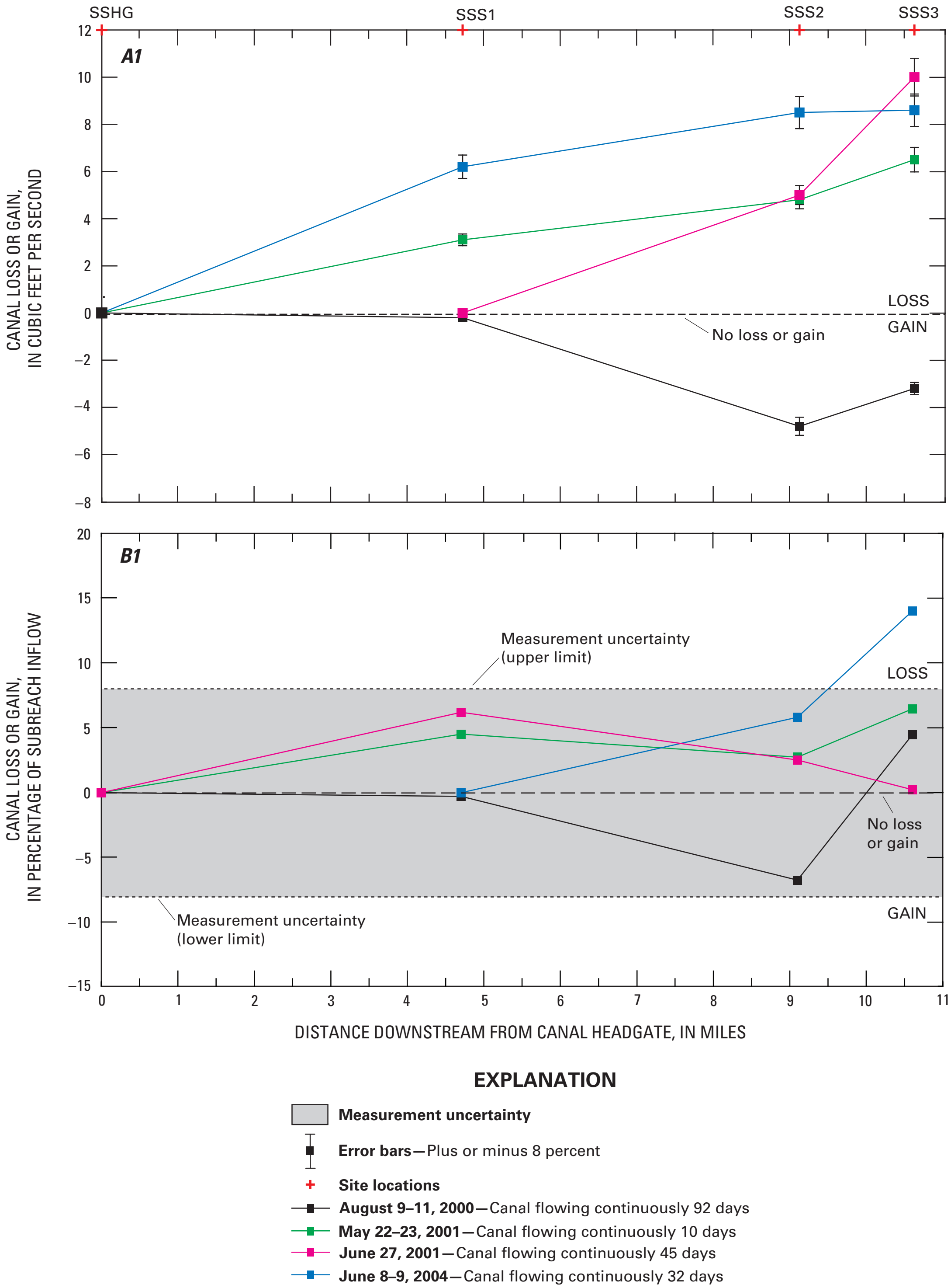
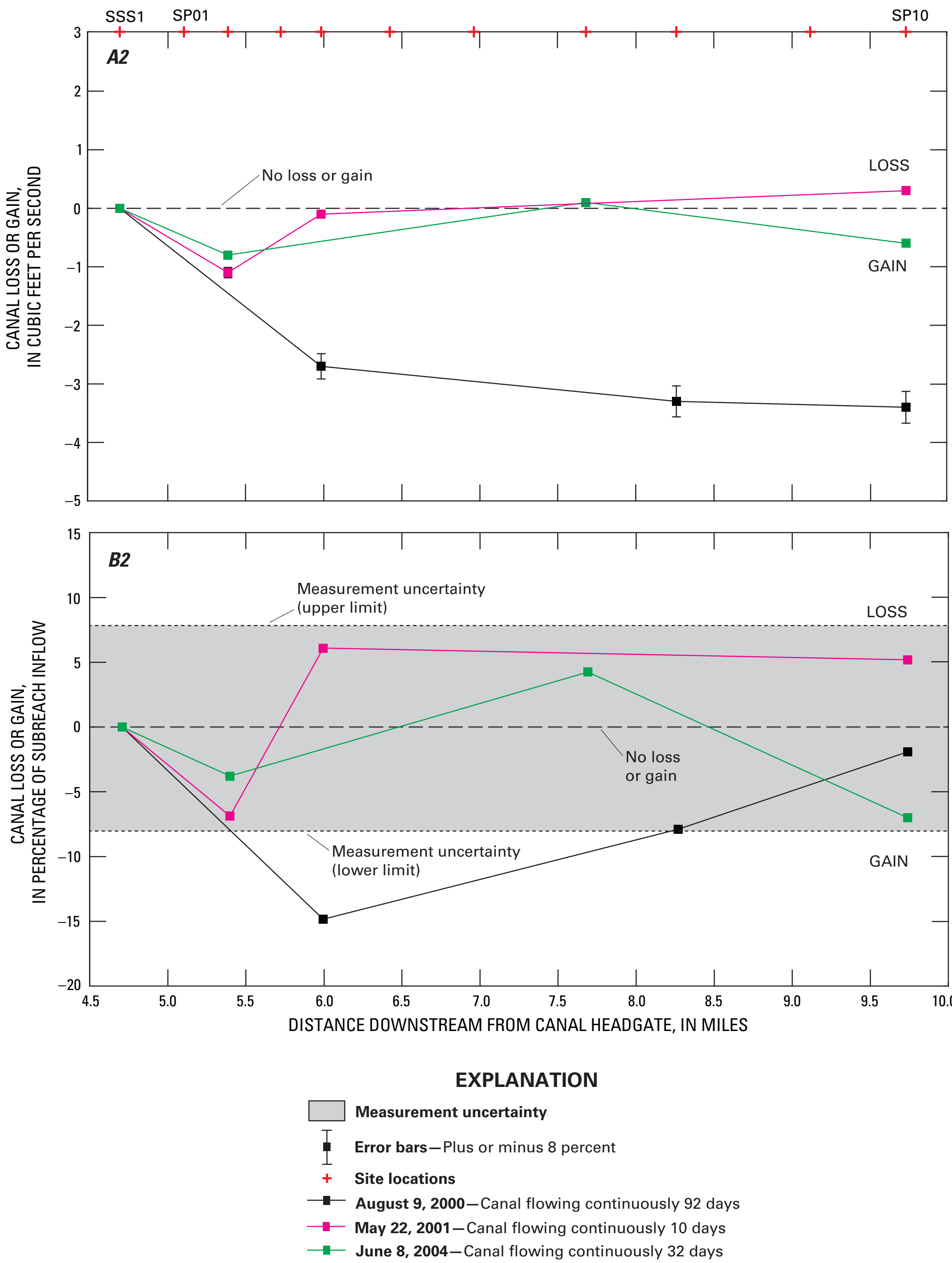


Figure 11. Losses and gains in (*A1*) cubic feet per second and (*B1*) percentage of subreach inflow in selected subreaches of the main Enlarged Southside Canal, losses and gains in (*A2*) cubic feet per second and (*B2*) percentage of subreach inflow in selected subreaches of the Palaski Extension of the Enlarged Southside Canal, losses and gains in (*A3*) cubic feet per second and (*B3*) percentage of subreach inflow in selected subreaches of the Sandoval Extension of the Enlarged Southside Canal, losses and gains in (*A4*) cubic feet per second and (*B4*) percentage of subreach inflow in selected subreaches of the South Wagner Extension of the Enlarged Southside Canal, and losses and gains in (*A5*) cubic feet per second and (*B5*) percentage of subreach inflow in selected subreaches of the North Wagner Extension of the Enlarged Southside Canal.



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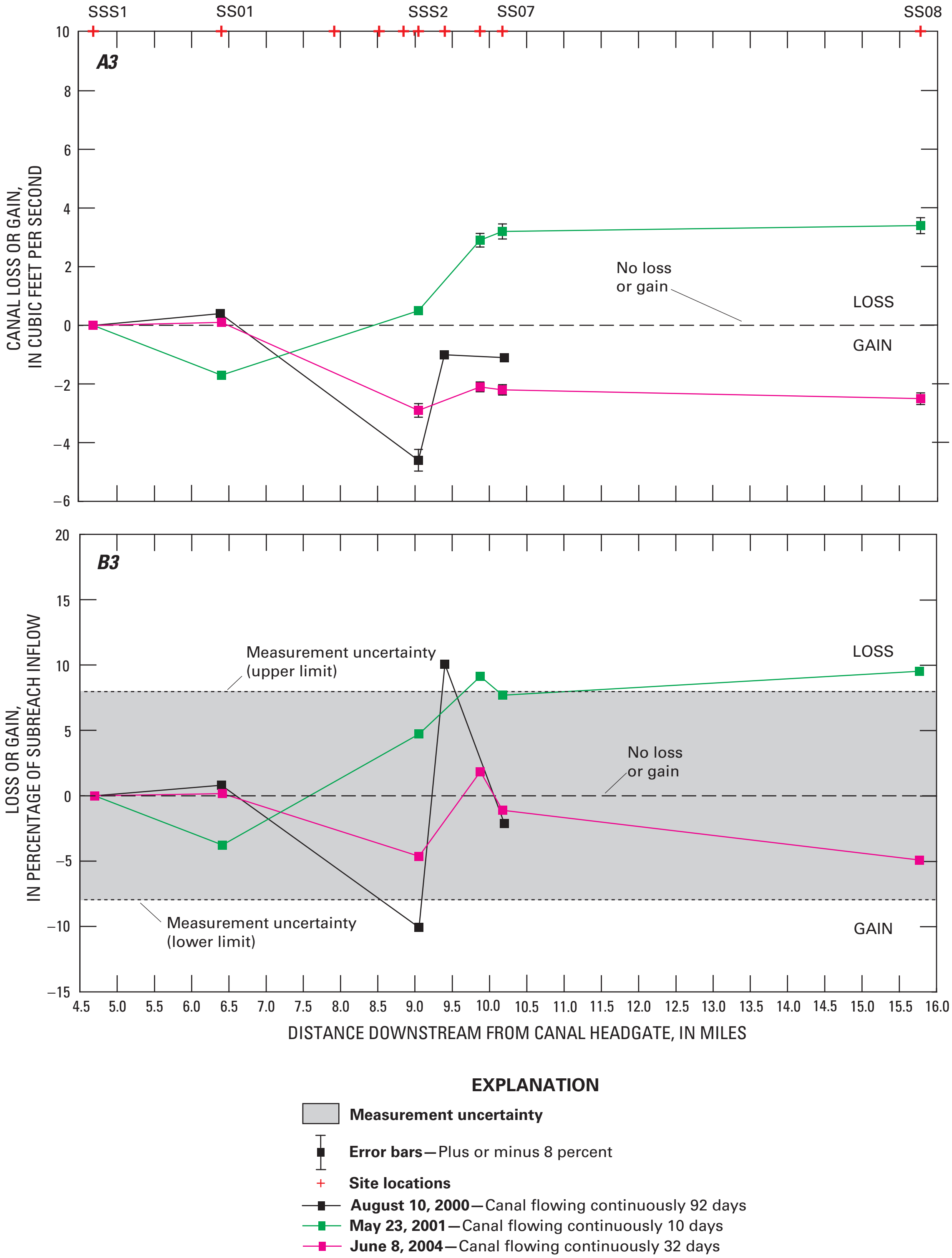
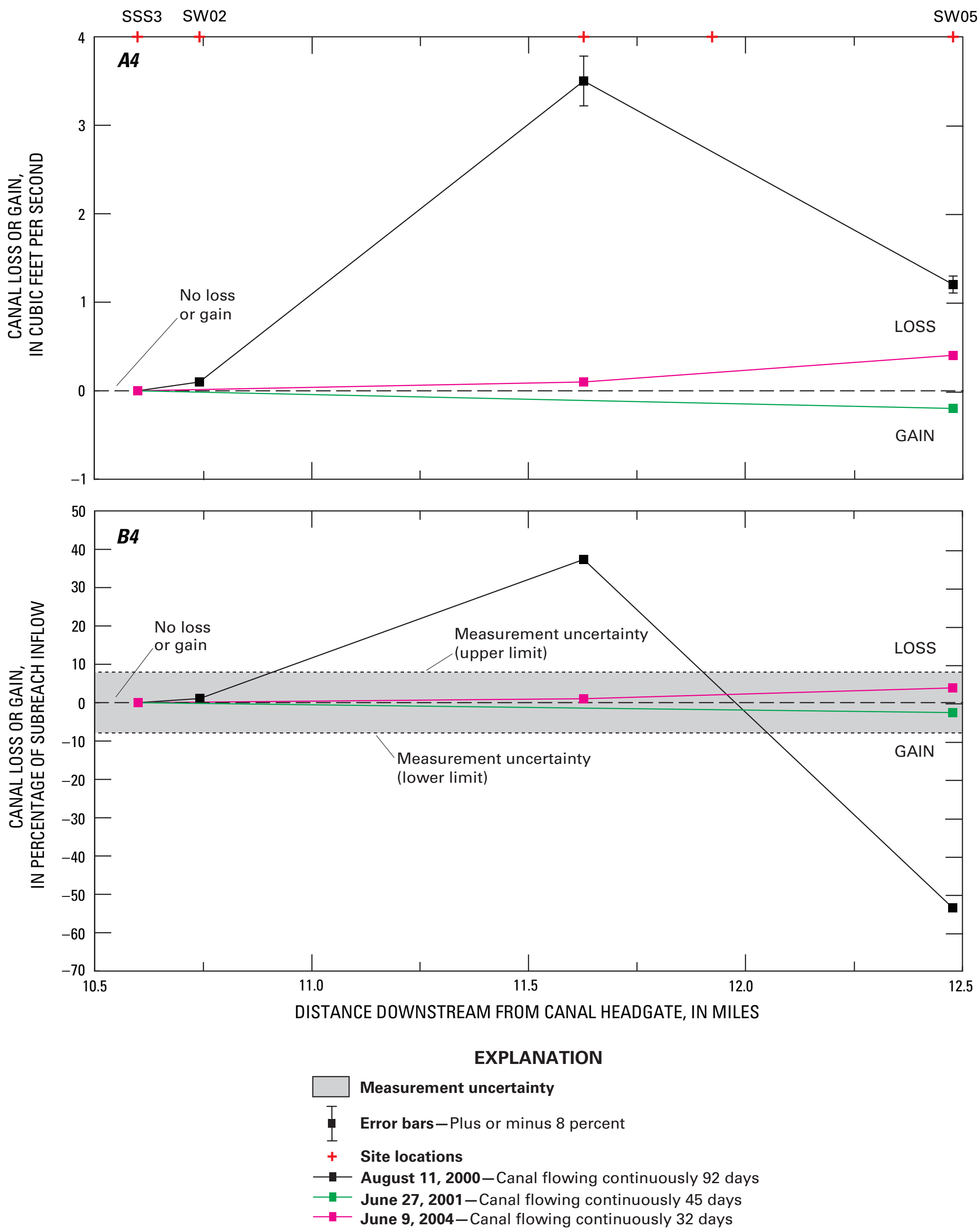


Figure 11. Losses and gains in (*A1*) cubic feet per second and (*B1*) percentage of subreach inflow in selected subreaches of the main Enlarged Southside Canal, losses and gains in (*A2*) cubic feet per second and (*B2*) percentage of subreach inflow in selected subreaches of the Palaski Extension of the Enlarged Southside Canal, losses and gains in (*A3*) cubic feet per second and (*B3*) percentage of subreach inflow in selected subreaches of the Sandoval Extension of the Enlarged Southside Canal, losses and gains in (*A4*) cubic feet per second and (*B4*) percentage of subreach inflow in selected subreaches of the South Wagner Extension of the Enlarged Southside Canal, and losses and gains in (*A5*) cubic feet per second and (*B5*) percentage of subreach inflow in selected subreaches of the North Wagner Extension of the Enlarged Southside Canal.—Continued



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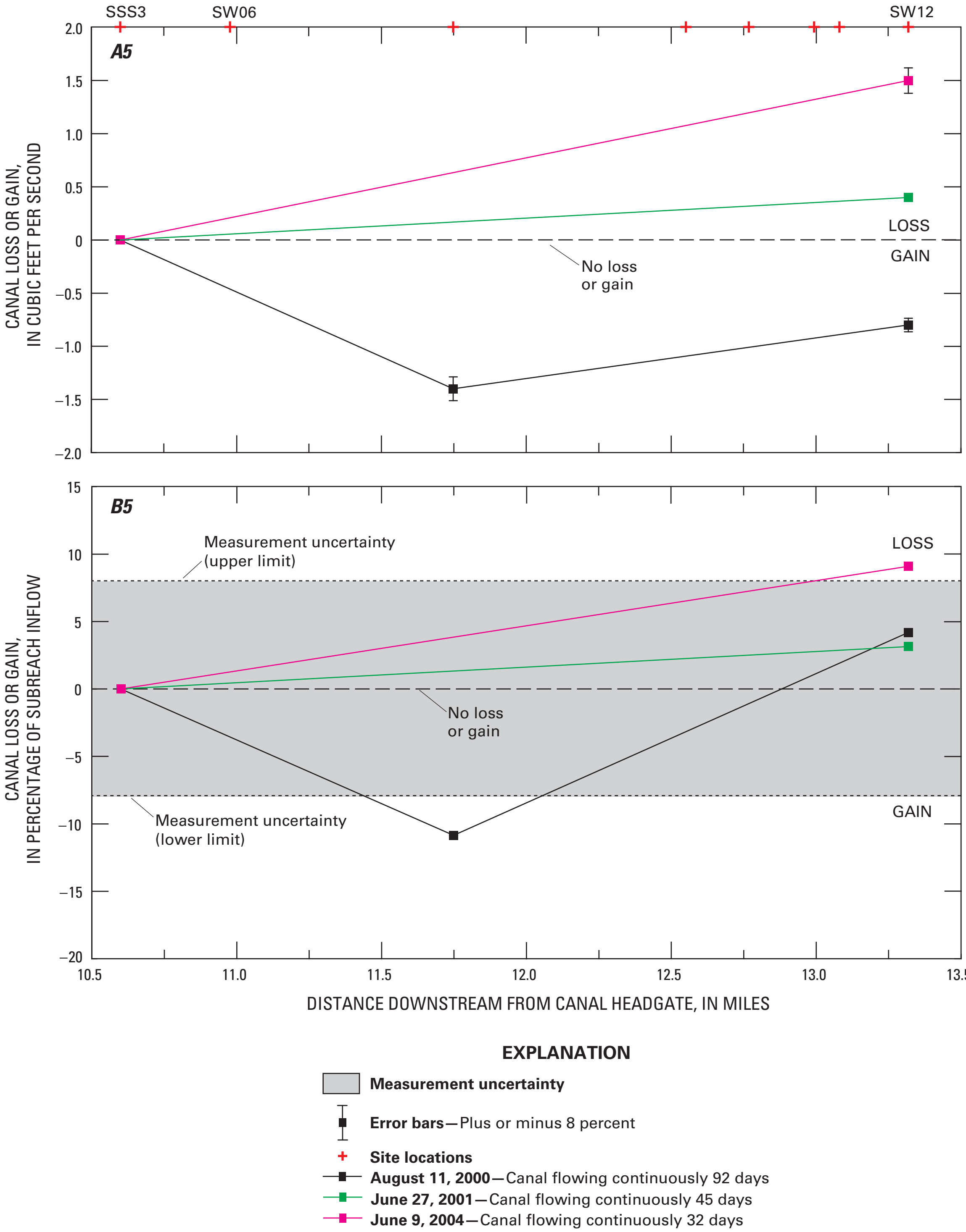

Figure 11. Losses and gains in (*A1*) cubic feet per second and (*B1*) percentage of subreach inflow in selected subreaches of the main Enlarged Southside Canal, losses and gains in (*A2*) cubic feet per second and (*B2*) percentage of subreach inflow in selected subreaches of the Palaski Extension of the Enlarged Southside Canal, losses and gains in (*A3*) cubic feet per second and (*B3*) percentage of subreach inflow in selected subreaches of the Sandoval Extension of the Enlarged Southside Canal, losses and gains in (*A4*) cubic feet per second and (*B4*) percentage of subreach inflow in selected subreaches of the South Wagner Extension of the Enlarged Southside Canal, and losses and gains in (*A5*) cubic feet per second and (*B5*) percentage of subreach inflow in selected subreaches of the North Wagner Extension of the Enlarged Southside Canal.—Continued

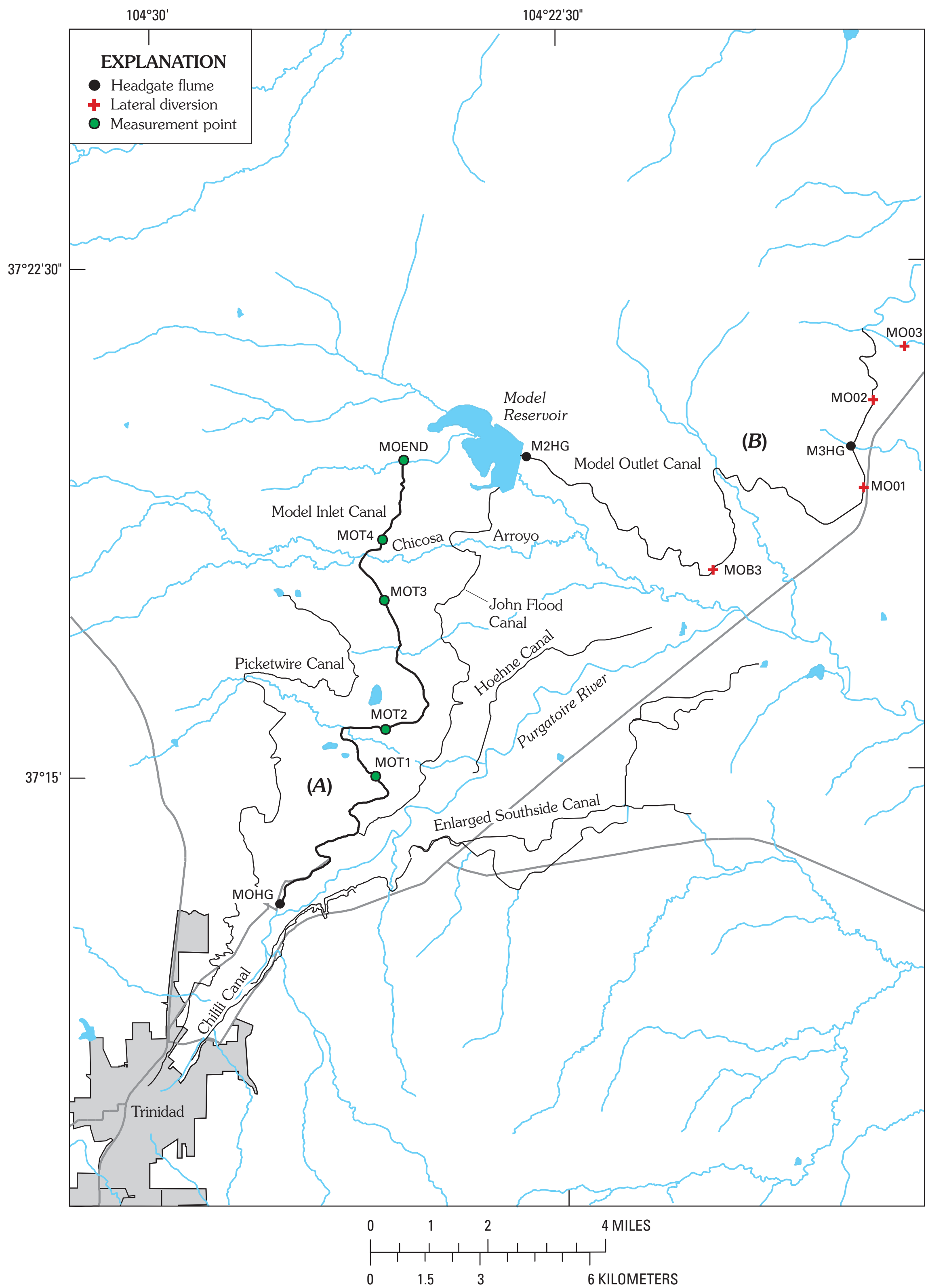

Figure 12. Location of measurement sites along Model Inlet and Outlet Canals.

Table 8. Losses and gains for selected subreaches of Model Canal, 2000–2004.

[PRWCD, Purgatoire River Water Conservancy District; ft^3/s, cubic feet per second; MO, Model; HG, headgate; MOT, Model Canal measurement site; gray shading indicates data collected by Colorado Division of Water Resources]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]	Remarks
August 10, 2000	Model Inlet Canal	MOHG to above Model Reservoir	60.1	33.7	26.0	0.4	1	As reported by Colorado Division of Water Resources.
	Model Outlet Canal	M2HG to M3HG	40.6	40.9	0.0	–0.3	–1	As reported by Colorado Division of Water Resources.
August 23, 2000	Model Inlet Canal	MOHG to above Model Reservoir	58.8	30.9	26.1	1.8	3	As reported by Colorado Division of Water Resources.
	Model Outlet Canal	M2HG to M3HG	32.5	30.0	0.0	2.5	8	As reported by Colorado Division of Water Resources.
May 18, 2001	Model Inlet Canal	MOHG to MOT3	55.5	29.3	24.3	1.9	3	
		MOHG to MOT1	55.5	30.5	24.3	0.7	1	
		MOT1 to MOT2	30.5	31.2	0.0	–0.7	–2	
		MOT2 to MOT3	31.2	29.3	0.0	1.9	6	
May 21, 2001	Model Inlet Canal	MOHG to MOT3	56.1	31.0	26.3	–1.2	–2	
		MOHG to MOT0	56.1	29.1	26.3	0.7	1	
		MOT0 to MOT2	29.1	33.1	0.0	–4.0	–14	
		MOT2 to MOT3	33.1	31.0	0.0	2.1	6	
May 24, 2001	Model Inlet Canal	MOHG to above Model Reservoir	58.5	29.6	25.9	3.0	5	As reported by Colorado Division of Water Resources.
	Model Outlet Canal	M2HG to M3HG	35.6	29.8	0.0	5.8	16	As reported by Colorado Division of Water Resources.
June 12, 2001	Model Outlet Canal	M2HG to M3HG	27.6	22.7	0.0	4.9	18	As reported by Colorado Division of Water Resources.
June 26, 2001	Model Outlet Canal	M2HG to M3HG	38.1	26.6	0.0	11.5	30	
		M3HG to MO03	26.6	10.1	16.9	–0.4	–2	
June 11, 2004	Model Inlet/Outlet Canal	MOHG to MOEND	58.1	36.3	19.5	2.3	4	
	Model Inlet Canal	MOHG to MOT2	58.1	39.2	19.5	–0.6	–1	
		MOT2 to MOT3	39.2	37.3	0.0	1.9	5	
		MOT3 to MOEND	37.3	36.3	0.0	1.0	3	
	Model Outlet Canal	M2HG to M3HG	30.0	12.4	0.0	17.6	59	
		M3HG to MO03	12.4	18.4	0.0	–6.0	–48	

[1]A positive value indicates a loss of flow from the canal and a negative value indicates a gain of flow to the canal.

Loss and gain measurements made by CDWR in Model Inlet Canal (table 8) showed small losses ranging from 1 to 5 percent of the headgate inflow (losses within the uncertainty of the measurements). The USGS also found losses and gains in Model Inlet Canal to be within the uncertainty of the measurements, with the exception of one reach (MOT0 to MOT2) (fig. 13–*A2* and table 8).

Measurements made by CDWR showed losses of 8, 16, and 18 percent of the subreach inflow to a gain of 1 percent of the subreach inflow in Model Outlet Canal from M2HG to M3HG (table 8). Downstream from Model Reservoir, along Model Outlet Canal from M2HG to M3HG, the USGS measured canal losses of 30 and 59 percent of the subreach inflow. The large variability in measured losses and gains from M2HG to M3HG may be due to unsteady-flow conditions during the measurement period. The flow may have changed substantially in days preceding some measurements. The variability also may be due to length of time the canal was running before the measurements were made. However, because CDWR does not report flow downstream from Model Reservoir at M2HG, there is no record of daily streamflow available to determine if steady-flow conditions existed before the measurement period or to determine the number of days the canal had been flowing before the measurement. It is interesting to note that the largest losses from M2HG to M3HG were computed for measurements made in May and June (early in irrigation season), and the smallest losses were determined for measurements made in August (later in the irrigation season).

John Flood Canal

John Flood Canal diverts water from Model Canal about 2.4 miles downstream from the Model headgate. An 8-ft Parshall flume with a free-flow capacity of about 140 ft^3/s is used to measure irrigation diversions at the John Flood Canal headgate.

Loss and gain measurements were made along John Flood Canal on August 8, 2000, May 24, 2001, June 17, 2003, and June 15, 2004. Information for individual measurements is summarized in table A6 in the Appendix. Discharge measurements were made on the main channel and diversions from the John Flood headgate (JFHG) to the end of the canal at JF25 (fig. 14). Losses and gains for selected subreaches of John Flood Canal are listed in table 9. Figure 14 shows the measurement site locations, and figure 15 shows losses and gains along John Flood Canal in relation to distance downstream from the headgate.

On August 8, 2000, discharge measurements were made at main channel and diversion locations from JFHG to JF25 (fig. 14). Three closed diversion gates were noted as having leakage. The total leakage was estimated to be about 0.12 ft^3/s (table A6). Flow at the Parshall flume diversion at JF12 was not measured but was determined using standard Parshall flume tables. A gain of 2.6 ft^3/s, or about 11 percent of the headgate inflow, was determined for John Flood Canal from JFHG to JF25 on August 8, 2000 (table 9 and fig. 15).

On May 24, 2001, discharge measurements were made at main channel and diversion locations from JFHG to JF25 (table A6). Leakage was reported at four closed diversion gates (two gates reported as having minor leakage). A gain of 2.7 ft^3/s, or about 11 percent of the headgate inflow, was determined for John Flood Canal from JFHG to JF25 on May 24, 2001 (table 9 and fig. 15).

On June 17, 2003, discharge measurements were made at main channel and diversion locations from JFHG to JF25 (fig. 14). Leakage was noted at four closed diversion gates. The total leakage was estimated to be about 0.3 ft^3/s. A loss of 2.6 ft^3/s, or about 9 percent of the headgate inflow, was determined for John Flood Canal from JFHG to JF25 on June 17, 2003 (table 9 and fig. 15).

On June 15, 2004, discharge measurements were made at main channel and diversion locations from JFHG to JF25 (fig. 14). Leakage was reported at six closed diversion gates (five gates reported as having only minor leakage), but leakage was measured at only one gate. A loss of 0.2 ft^3/s, or about 1 percent of the headgate inflow, was determined for John Flood Canal from JFHG to JF25 on June 15, 2004 (table 9 and fig. 15).

Measured losses and gains for John Flood Canal ranged from a gain of 2.7 ft^3/s on May 24, 2001, to a loss of 2.6 ft^3/s on June 17, 2003. All measurements showed gains in flow between JFHG and JFWG and losses in flow between JF17 and JF25. Gains ranged from about 0.8 ft^3/s (4 percent of the headgate inflow) to about 4.8 ft^3/s (20 percent of the headgate inflow) between JFHG and JFWG, and losses ranged from 0.4 ft^3/s (3 percent of the subreach inflow) to 5.1 ft^3/s (30 percent of the subreach inflow) between JF17 and JF25 (table 9).

It is not known why the losses and gains in John Flood Canal are variable. Unlike some of the other canals, losses and gains do not appear to be related to how long the canal was flowing before the measurement. For example, a gain in flow of 11 percent was measured on August 8, 2000, and on May 24, 2001 (table 9). John Flood Canal had been flowing continuously for about 98 days before the August 8, 2000, measurement but only about 15 days before the May 24, 2001, measurement. The differences in losses and gains probably cannot be explained by changes in flow at the headgate either because flow in the canal was stable (did not vary by more than 6 percent from day to day) in days preceding and following the measurements. It is possible that diversion gates along the canal could have been recently opened or closed, which might have affected stage in the canal; thus, bank storage may have increased or decreased during the measurement period.

Hoehne Canal

Hoehne Canal diverts water from the left bank of the Purgatoire River near the city of Hoehne downstream from the Picketwire, Chilili, Enlarged Southside, and Model canal diversions (fig. 1). A 4-ft Parshall flume with a free-flow capacity of about 68 ft^3/s is used to measure irrigation diversions at the Hoehne Canal headgate.

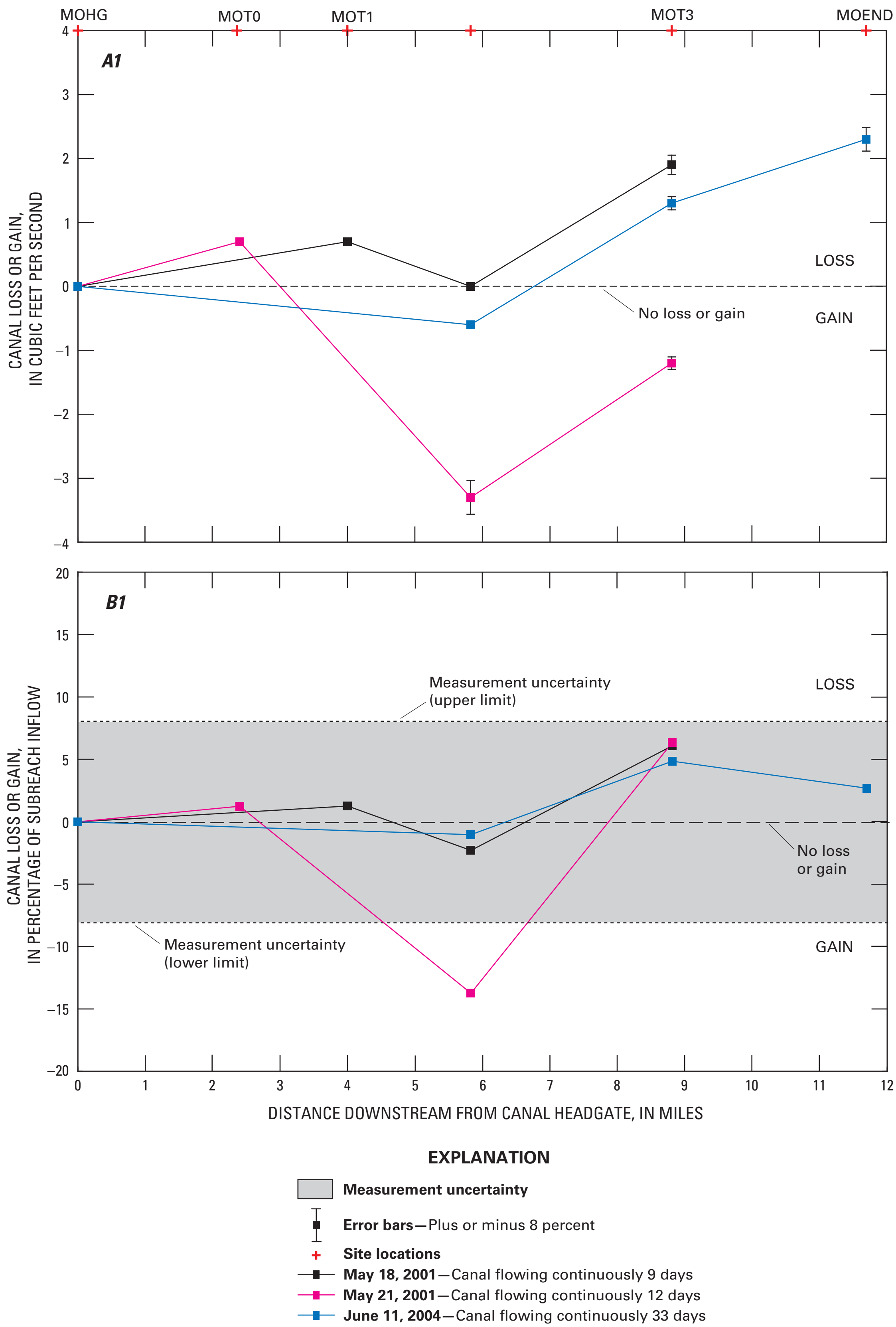

Figure 13. Losses and gains in (*A1*) cubic feet per second and (*B1*) percentage of subreach inflow in selected subreaches of the Model Inlet Canal and losses and gains in (*A2*) cubic feet per second and (*B2*) percentage of subreach inflow in selected subreaches of the Model Outlet Canal.

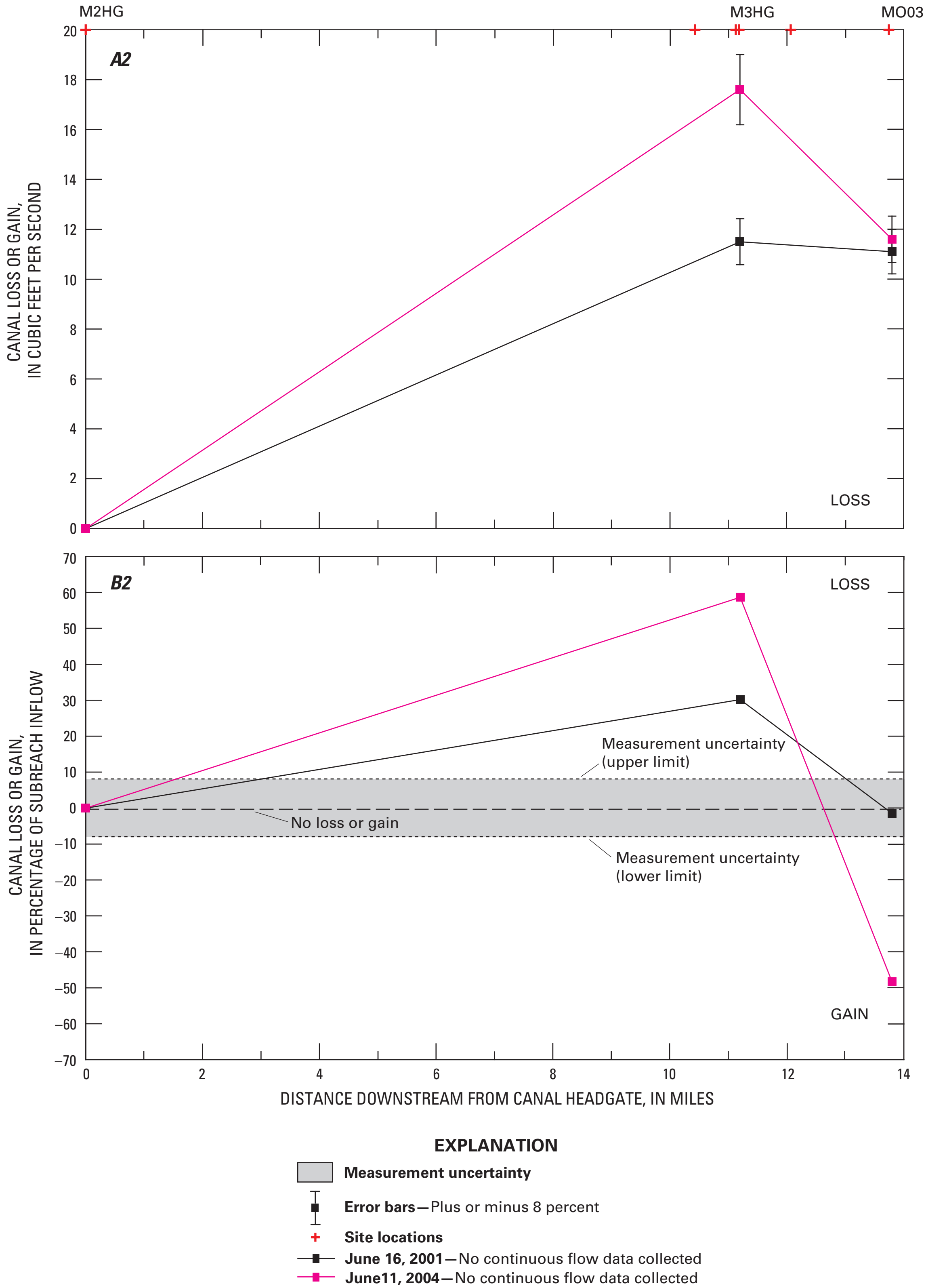

Figure 13.—Continued.

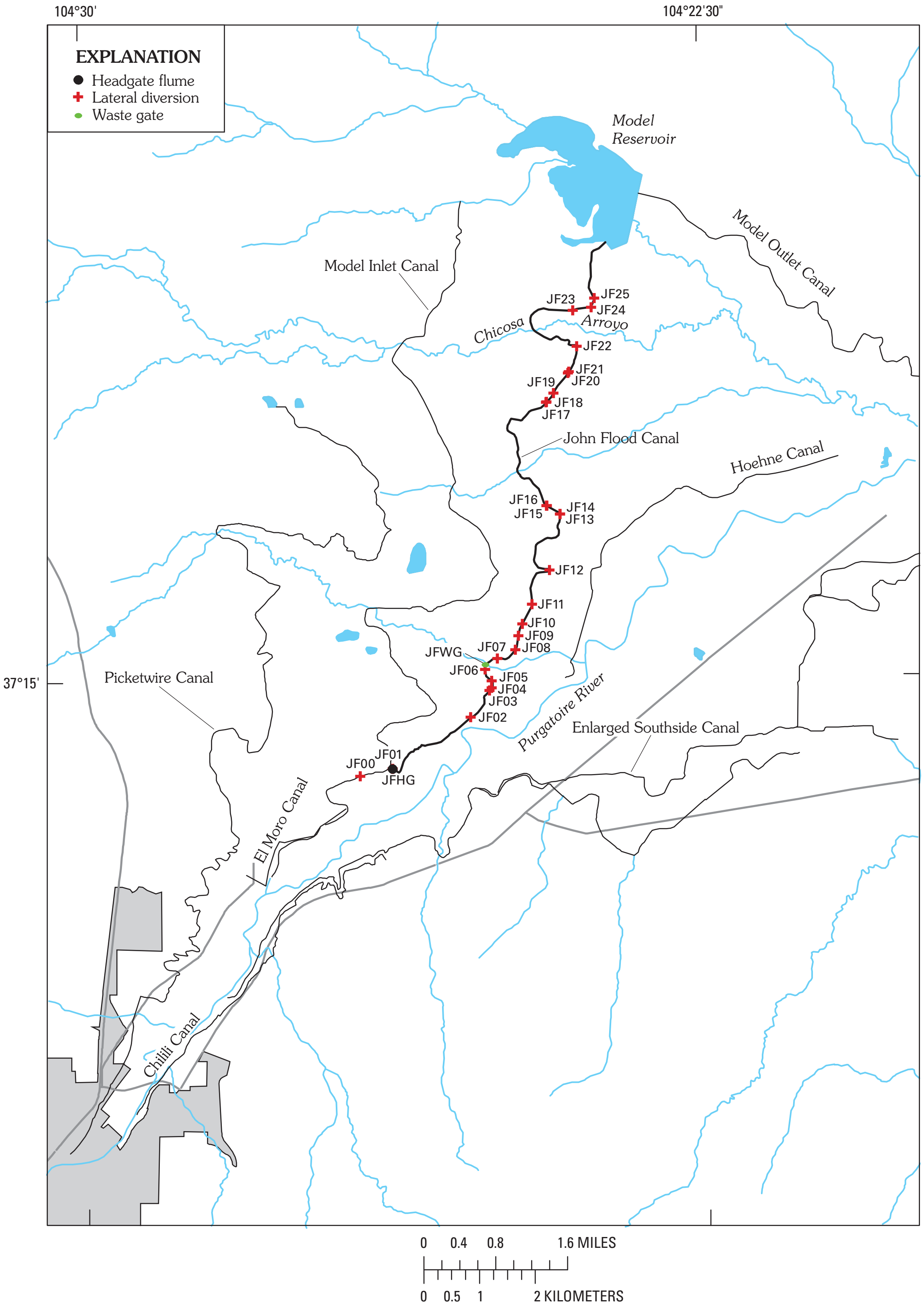

Figure 14. Location of measurement sites along John Flood Canal.

Table 9. Losses and gains for selected subreaches of John Flood Canal, 2000–2004.

[ft^3/s, cubic feet per second; JFHG, John Flood headgate; JFWG, John Flood waste gate; JF, John Flood; main, John Flood main channel site; inflows and outflows measured upstream from diversion structures unless otherwise noted]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]	Remarks
August 8, 2000	John Flood	JFHG to JF25	24.0	0.0	26.6	–2.6	–11	
		JFHG to JFWG	24.0	20.4	6.7	–3.1	–13	
		JFWG to JF17	20.4	17.2	7.8	–4.6	–23	
		JF17 to JF25	17.2	0.0	12.1	5.1	30	
May 24, 2001	John Flood	JFHG to JF25	23.7	0.0	26.4	–2.7	–11	Minor leakage was observed at two gates; however, no estimate of leakage was made.
		JFHG to JFWG[2]	23.7	22.5	6.0	–4.8	–20	
		JFWG[2] to JF16[2]	22.5	12.9	8.5	1.1	5	
		JF16[2] to JF17	12.9	12.3	0.0	0.6	5	
		JF17 to JF25	12.3	0.0	11.9	0.4	3	
June 17, 2003	John Flood	JFHG to JF25	30.0	0.0	27.4	2.6	9	
June 15, 2004	John Flood	JFHG to JF25	18.3	0.0	18.1	0.2	1	Minor leakage was observed at five gates; however, the leakage was not estimated.
		JFHG to JFWG[2]	18.3	14.1	5.0	–0.8	–4	
		JFWG[2] to JF16[2]	14.1	7.3	6.7	0.1	1	
		JF16[2] to JF25	7.3	0.0	6.4	0.9	13	

[1]A positive value indicates a loss of flow from the canal, and a negative value indicates a gain of flow to the canal.

[2]Measurement taken on main channel downstream from diversion.

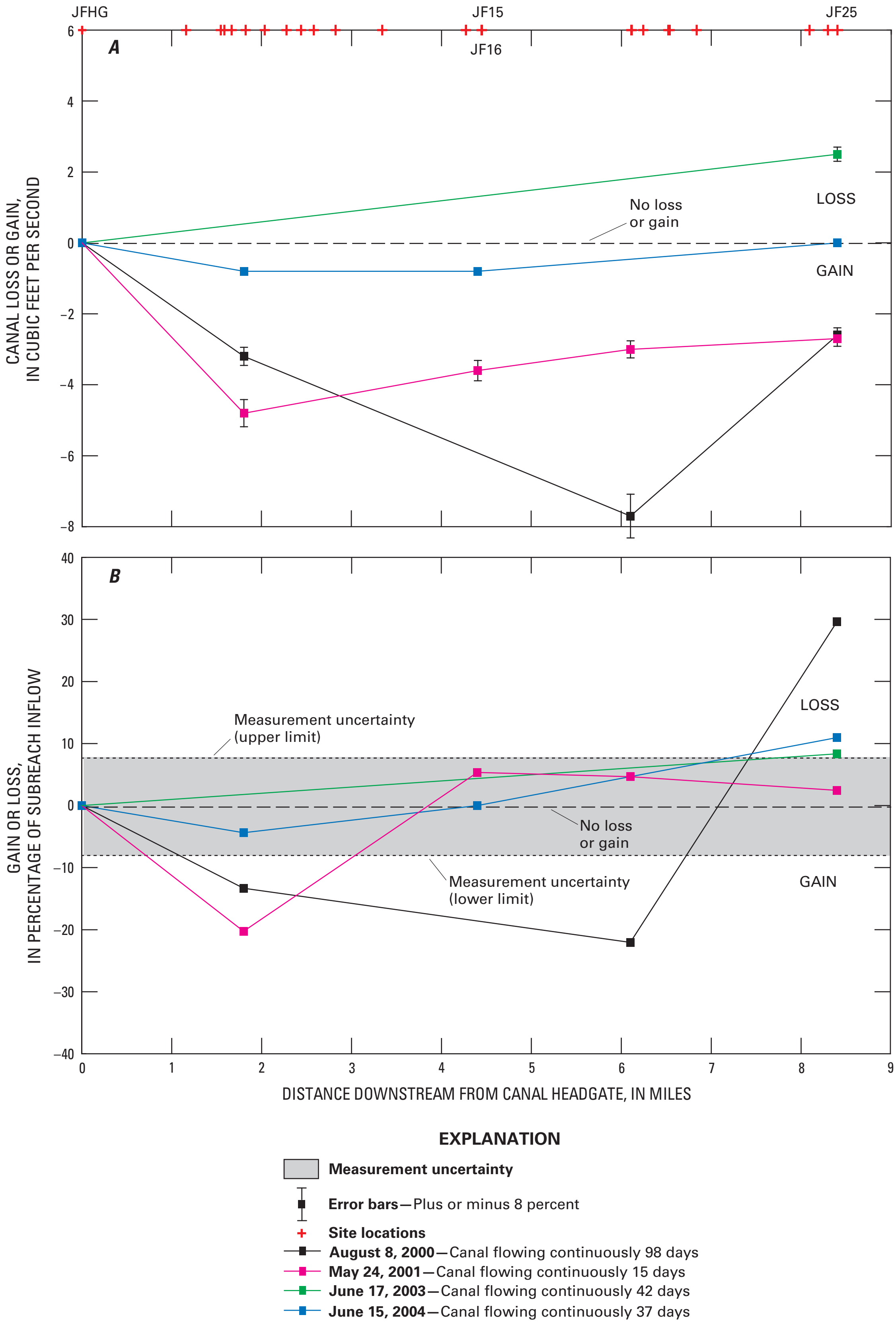

Figure 15. Losses and gains in (*A*) cubic feet per second and (*B*) percentage of subreach inflow in selected subreaches the John Flood Canal.

Loss and gain measurements were made along Hoehne Canal on July 31, 2000, May 15, 2001, and June 16 and 18, 2003. Information for individual measurements is summarized in table A7 in the Appendix. Losses and gains for selected subreaches of Hoehne Canal are listed in table 10. Figure 16 shows the measurement site locations, and figure 17 shows losses and gains along Hoehne Canal in relation to distance downstream from the headgate.

On July 31, 2000, discharge measurements were made at main channel and diversion locations from HOHG to HO4 (end of ditch) (fig. 16). The loss or gain was not computed between HOHG and HO4 because a diversion near HO4 was not measured. However, losses and gains from HOHG to HO1, HO1 to HO2, and HO2 to HO3 were computed and are listed in table 10.

On May 15, 2001, discharge measurements were made at main channel and diversion locations from HOHG to HO4. A loss of about 1.7 ft^3/s, or 7 percent of the headgate inflow, was measured for Hoehne Canal from HOHG to HO4 on May 15, 2001 (table 10).

On June 16 and 18, 2003, discharge measurements were made at main channel and diversion locations from HOHG to HO4. A new diversion structure was installed in 2003 near HO2, which may have changed downstream loss and gain characteristics. Installation of the new diversion structure may have affected downstream loss and gain characteristics by possibly (1) applying irrigation water to previously unirrigated lands or more water to existing fields and, as a result, increasing the potential for indirect irrigation return flow, or (2) changing the amount of flow in the canal downstream from the diversion. Main channel measurements were made downstream from the diversions at HO1, HO2, HO2A, HO3, and HO4 on June 16 and 18, 2003. Main channel subreach inflows and outflows at these sites were determined by summing the flow measured downstream from the diversion on the main channel and flow measured in the diversions. For example, subreach inflow for HO1 to HO2 on June 16, 2003, was 20.4 ft^3/s. This value was determined by adding the measured flow in the left (1.7 ft^3/s), right (13.4 ft^3/s), and middle (5.3 ft^3/s) channels downstream from the diversion at HO1. A loss of about 0.4 ft^3/s, or 2 percent of the headgate inflow, was measured for Hoehne Canal from HOHG to HO4 on June 16, 2003, and a loss of 0.6 ft^3/s, or 3 percent of the headgate inflow, was measured on June 18, 2003 (table 10 and fig. 17).

Some subreaches of Hoehne Canal show losses and others show gains, and these losses and gains were variable from measurement to measurement. For example, from the headgate (HOHG) to HO1, measurements showed losses ranging from 0.5 ft^3/s (2 percent of the headgate inflow) on May 15, 2001, to 2.9 ft^3/s (12 percent of the headgate inflow) on July 31, 2000 (table 10 and fig. 17). Measurements on July 31, 2000, indicate a loss of about 5 percent between sites HO1 and HO2; whereas, measurements on May 15, 2001, and June 16 and 18, 2003, indicate gains of about 4, 10, and 8 percent, respectively. Between sites HO3 and HO4 measurements on May 15, 2001, indicate a loss of about 12 percent compared to measurements on June 16 and 18, 2003, which indicate gains of 16 and 21 percent, respectively (table 10 and fig. 17).

Small losses (less than the measurement uncertainty) were measured in Hoehne Canal during the three loss and gain measurements that extended from the headgate to the end of the canal. These losses ranged from 0.4 ft^3/s to 1.7 ft^3/s, or 2 to 7 percent of the headgate inflow, respectively (table 10 and fig. 17).

Even though the losses in Hoehne Canal were small, within the measurement uncertainty, the variability in the quantity of flow lost from the canal may be somewhat related to how many days the canal had been flowing before the loss and gain measurements or to short-term changes in canal stage affecting bank storage. For example, a short-term change in canal stage occurred before the May 15, 2001, measurement. Diversion records published by the CDWR indicate that flow in Hoehne Canal was relatively stable before May 14, 2001 (the day before the loss and gain measurement). On May 14, 2001, flow decreased by roughly 14 percent from the previous day and then increased by roughly 18 percent between May 14 and May 15, 2001. This change in flow may have affected bank storage, because the largest loss between HOHG and HO04 (7 percent of the headgate inflow) was measured on May 15, 2001 (table 10).

Comparison of Flume-Rated and Measured Discharges at Canal Headgates

Parshall flumes used to measure irrigation diversion at the Picketwire, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canal headgates range in size from 9 inches (0.75 foot) to 10 feet (table 11). Discharge (irrigation diversion) is determined at the canal headgates by CDWR using predefined stage-discharge relations for the Parshall flumes, with few exceptions. Shifts occasionally are applied to the predefined stage-discharge relations when measured discharge varies substantially from the predefined relation (flume-rated discharge).

Discharge measurements were made at Picketwire, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canal headgates to compare flume-rated discharges and measured discharges. Water stage was recorded before and after each discharge measurement, and the average stage was computed. However, water stage remained constant during most measurements. Flume-rated discharge values were determined using the average stage and free-flow Parshall flume discharge tables (Grant, 1991).

The differences from flume-rated and measured discharge at Picketwire, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne canal headgates are listed in table 11. During this study, a modified (adjusted) stage-discharge

Table 10. Losses and gains for selected subreaches of Hoehne Canal, 2000–2003.

[ft^3/s, cubic feet per second; HO, Hoehne; HG, headgate; --, value not determined]

Date	PRWCD canal name	Canal subreach (site to site)	Subreach inflow (ft^3/s)	Subreach outflow (ft^3/s)	Cumulative diversions (ft^3/s)	Loss or gain in subreach (ft^3/s)[1]	Loss or gain in subreach (percent)[1]	Remarks
July 31, 2000	Hoehne	HOHG to HO4	24.0	0	--	--	--	Cumulative gain or loss not computed because diversion near HO4 not measured or estimated.
		HOHG to HO1	24.0	21.1	0.0	2.9	12	
		HO1 to HO2	21.1	14.0	6.1	1.0	5	
		HO2 to HO3	14.0	8.9	5.7	–0.6	–4	
		HO3 to HO4	8.9	0.0	--	--	--	Reach gain or loss not computed. Diversion near HO4 was missed.
May 15, 2001	Hoehne	HOHG to HO4	25.0	0.0	23.3	1.7	7	
		HOHG to HO1	25.0	24.5	0.0	0.5	2	
		HO1 to HO2	24.5	19.1	6.3	–0.9	–4	
		HO2 to HO3	19.1	9.9	8.3	0.9	5	
		HO3 to HO4	9.9	0.0	8.7	1.2	12	
June 16, 2003	Hoehne	HOHG to HO4[2]	23.2	0.0	22.8	0.4	2	
		HOHG to HO1	23.2	20.4	0.0	2.8	12	
		HO1[2] to HO2[2]	20.4	15.5	7.0	–2.1	–10	
		HO2[2] to HO2A[2]	15.5	10.9	4.1	0.5	3	
		HO2A[2] to HO3[2]	10.9	7.3	3.2	0.4	4	
		HO3[2] to HO4[2]	7.3	0.0	8.5	–1.2	–16	
June 18, 2003	Hoehne	HOHG to HO4[2]	23.4	0.0	22.8	0.6	3	
		HOHG to HO1[2]	23.4	21.7	0.0	1.7	7	
		HO1[2] to HO2[2]	21.7	17.2	6.3	–1.8	–8	
		HO2[2] to HO2A[2]	17.2	10.6	4.8	1.8	10	
		HO2A[2] to HO3[2]	10.6	7.3	2.9	0.4	4	
		HO3[2] to HO4[2]	7.3	0.0	8.8	–1.5	–21	

[1]A positive value indicates a loss of flow from the canal and a negative value indicates a gain of flow to the canal.

[2]Reach inflow and outflow were determined by summing the flows measured downstream from the splitter on the main channel and diversions.

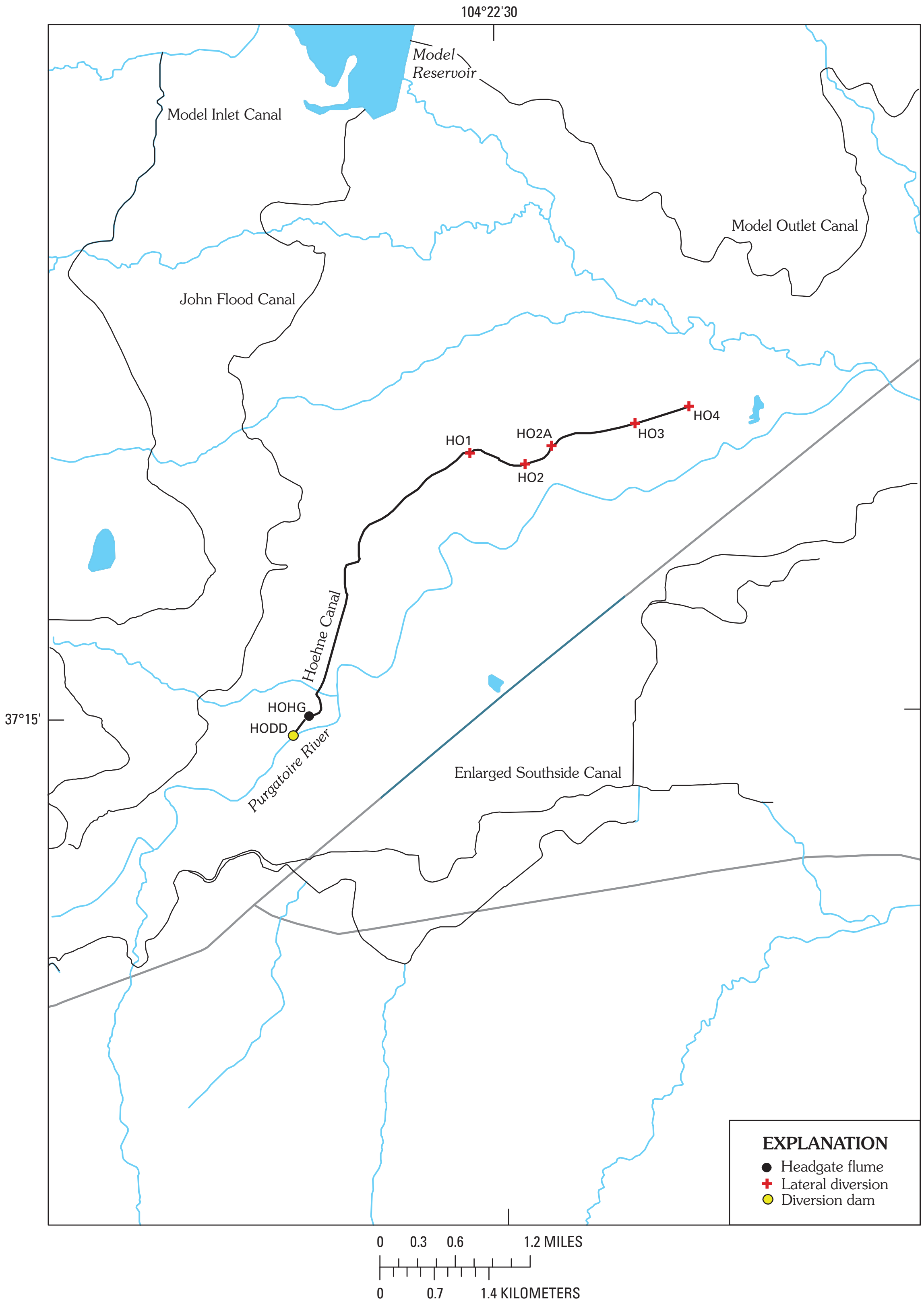

Figure 16. Location of measurement sites along Hoehne Canal.

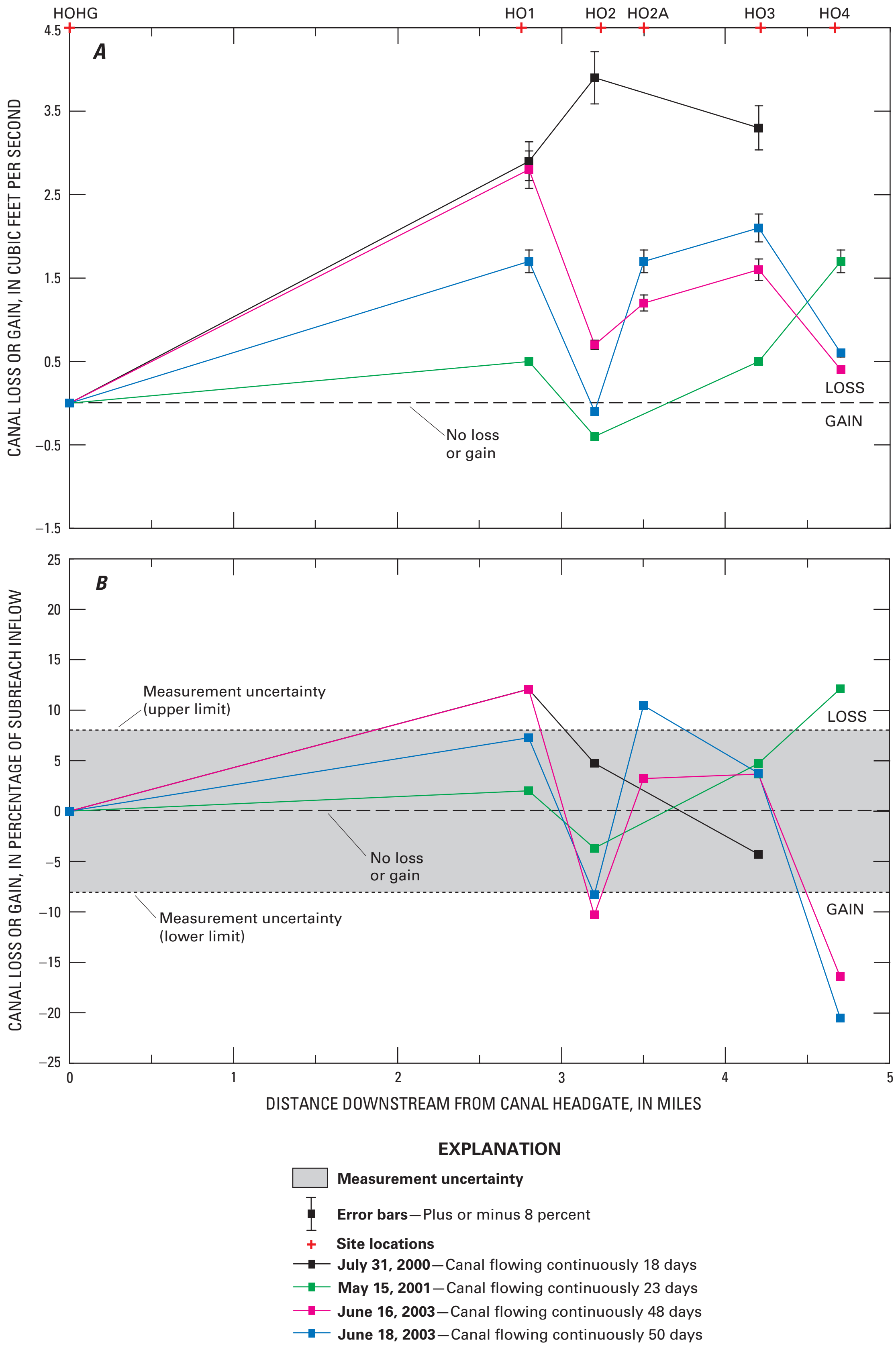

Figure 17. Losses and gains in (*A*) cubic feet per second and (*B*) percentage of subreach inflow in selected subreaches of the Hoehne Canal.

Table 11. Measured discharge and differences from standard flume ratings at Purgatoire River Water Conservancy District canal headgates, 2000–2004.

[meas., measured; ft^3/s, cubic feet per second; CHHG, Chilili headgate; EMHG, El Moro headgate; HOHG, Hoehne headgate; JFHG, John Flood headgate; MOHG, Model headgate; PWHG, Picketwire headgate; SSHG, Enlarged Southside headgate; ft/s, foot per second; --, measurement not rated]

Site name	Date	Flume size (feet)	Staff reading (feet)	Flume-rated discharge (ft^3/s)	Measured discharge (ft^3/s)	Measurement rating (percent)	Difference flume-meas. (ft^3/s)	Difference flume-meas. (percent)	Remarks
PWHG	08/02/00	8	1.10 ± .05	37	47	8	–10	–21	
PWHG	08/02/00	8	1.10 ± .05	37	48	8	–11	–23	
PWHG	08/03/00	8	1.24 ± .02	45	52	2	–7	–13	
PWHG	08/07/00	8	1.24 ± .02	45	52	5	–7	–13	
PWHG	08/09/00	8	1.25 ± .01	46	52	5	–6	–12	
PWHG	05/14/01	8	1.00 ± .02	32	39	8	–7	–18	
PWHG	05/14/01	8	1.00 ± .02	32	36	8+	–4	–11	
PWHG	05/14/01	8	1.01 ± .02	32	36	8+	–4	–11	
PWHG	05/16/01	8	1.02 ± .04	33	41	8	–8	–20	
PWHG	05/24/01	8	1.05	35	37	--	–2	–5	As reported by Colorado Division of Water Resources.
PWHG	06/18/03	8	0.62	15	16	8	–1	–6	
PWHG	06/07/04	8	1.14 ± .02	40	44	--	–4	–9	
PWHG	06/07/04	8	1.14 ± .02	40	41	5	–1	–2	
PWHG	06/07/04	8	1.14 ± .02	40	42	--	–2	–5	
PWHG	06/10/04	8	1.12 ± .02	38	42	5	–4	–10	
PWHG	06/10/04	8	1.12 ± .02	38	41	5	–3	–7	
EMHG	08/01/00	0.75	0.99	3.0	3.8	8	–0.8	–21	
EMHG	08/01/00	0.75	1.00 ± .02	3.1	3.9	8	–0.8	–21	
EMHG	08/02/00	0.75	.99 ± .01	3.0	3.9	8	–0.9	–23	
EMHG	06/18/03	0.75	1.04	3.3	3.9	--	–0.6	–15	New 9-inch parshall flume installed 2003.
EMHG	06/18/03	0.75	1.05	3.3	3.9	--	–0.6	–15	
EMHG	06/20/03	0.75	1.03 ± .01	3.2	3.7	--	–0.5	–14	
EMHG	06/16/04	0.75	1.13 ± .01	3.7	4.1	--	–0.4	–10	
EMHG	06/16/04	0.75	1.13 ± .01	3.7	4.5	--	–0.8	–18	
CHHG	08/01/00	2	1.10 ± .02	9.3	9.4	5	–0.1	–1	
CHHG	08/03/00	2	1.10 ± .02	9.3	9.2	8	0.1	1	
CHHG	08/07/00	2	1.10	9.3	10	8	–0.7	–7	
CHHG	05/14/01	2	0.96 ± .02	7.5	7.7	8	–0.2	–3	
CHHG	05/14/01	2	0.96 ± .04	7.5	8.7	5	–1.2	–14	
CHHG	05/14/01	2	1.00 ± .02	8.0	8.4	8	–0.4	–5	
CHHG	05/17/01	2	1.00 ± .02	8.0	9.3	8	–1	–14	
CHHG	06/25/01	2	0.65 ± .02	4.1	4.7	8	–0.6	–13	
CHHG	06/25/01	2	0.65 ± .02	4.1	4.4	5	–0.3	–7	
CHHG	06/26/01	2	0.49 ± .02	2.6					No measurement due to a changing stage.
CHHG	06/28/01	2	0.75 ± .03	5.1	6.1	6	–1	–16	
CHHG	06/28/01	2	0.74	5.0	6.2	8	–1	–19	
CHHG	06/28/01	2	0.74	5.0	6.2	8	–1	–19	
CHHG	06/19/03	2	0.94 ± .02	7.3	8.6	--	–1	–15	

Table 11. Measured discharge and differences from standard flume ratings at Purgatoire River Water Conservancy District canal headgates, 2000–2004.—Continued

[meas., measured; ft^3/s, cubic feet per second; CHHG, Chilili headgate; EMHG, El Moro headgate; HOHG, Hoehne headgate; JFHG, John Flood headgate; MOHG, Model headgate; PWHG, Picketwire headgate; SSHG, Enlarged Southside headgate; ft/s, foot per second; --, measurement not rated]

Site name	Date	Flume size (feet)	Staff reading (feet)	Flume-rated discharge (ft^3/s)	Measured discharge (ft^3/s)	Measurement rating (percent)	Difference flume-meas. (ft^3/s)	Difference flume-meas. (percent)	Remarks
CHHG	06/19/03	2	0.91 ± .02	6.9	8.8	8	–2	–22	
CHHG	06/19/03	2	0.91 ± .02	6.9	8.0	--	–1	–14	
CHHG	06/19/03	2	0.91 ± .02	6.9	7.9	8+	–1	–13	
SSHG	08/03/00	10	1.30 ± .05	67	62	8	5	8	
SSHG	08/07/00	10	1.25 ± .05	63	64	8+	–1	–2	Pymgy meter used; most velocities >2.5 ft/s.
SSHG	08/09/00	10	1.40 ± .05	75	70	8	5	7	
SSHG	05/18/01	10	1.38 ± .04	73	71	8	2	3	
SSHG	05/18/01	10	1.36 ± .03	72	70	8	2	3	
SSHG	05/21/01	10	1.36 ± .05	72	78	5	–6	–8	
SSHG	05/21/01	10	1.36 ± .03	72	70	8	2	3	
SSHG	05/22/01	10	1.34 ± .04	70	69	8	1	1	
SSHG	06/26/01	10	1.58 ± .04	90	103	5	–13	–13	
SSHG	06/27/01	10	1.56 ± .04	88	87	6	1	1	
SSHG	06/07/04	10	1.60 ± 0.1	92	98	--	–6	–6	
SSHG	06/07/04	10	1.62 ± 0.06	94	91	--	3	3	
SSHG	06/07/04	10	1.62 ± 0.07	94	90	--	4	4	
SSHG	06/08/04	10	1.64 ± 0.06	96	100	5	–4	–4	
MOHG	08/07/00	10	1.30 ± .02	60	66	8	–6	–9	
MOHG	08/09/00	10	1.28	58	60	--	–2	–3	As reported by Colorado Division of Water Resources.
MOHG	08/09/00	10	1.28	58	60	--	–2	–3	As reported by Colorado Division of Water Resources.
MOHG	08/09/00	10	1.28	58	60	--	–2	–3	As reported by Colorado Division of Water Resources.
MOHG	08/10/00	10	1.28	58	60	--	–2	–3	As reported by Colorado Division of Water Resources.
MOHG	08/23/00	10	1.27	58	59	--	–1	–2	As reported by Colorado Division of Water Resources.
MOHG	05/18/01	10	1.25 ± .03	56	57	8+	–1	–2	
MOHG	05/18/01	10	1.23 ± .04	55	58	8	–3	–5	
MOHG	05/18/01	10	1.17 ± .02	51	52	8	–1	–2	
MOHG	05/21/01	10	1.26 ± .02	57	57	5	0	0	
MOHG	05/21/01	10	1.26 ± .02	57	55	8	2	4	
MOHG	05/24/01	10	1.28	58	58	--	0	0	As reported by Colorado Division of Water Resources.
MOHG	06/17/03	10	0.88	32	30	8	2	7	
MOHG	06/07/04	10	1.30 ± .02	60	60	--	0	0	
MOHG	06/07/04	10	1.28 ± .02	58	63	8	–5	–8	
MOHG	06/11/04	10	1.32	61	55	8+	6	11	
MOHG	06/11/04	10	1.32 ± .02	61	59	5	2	3	
MOHG	06/11/04	10	1.32 ± .02	61	60	5	1	2	
JFHG	08/03/00	8	0.82 ± .02	23	23	5	0	0	
JFHG	08/07/00	8	0.85	25	23	8	2	9	
JFHG	08/08/00	8	0.86 ± .02	25	24	8	1	4	

Table 11. Measured discharge and differences from standard flume ratings at Purgatoire River Water Conservancy District canal headgates, 2000–2004.—Continued

[meas., measured; ft³/s, cubic feet per second; CHHG, Chilili headgate; EMHG, El Moro headgate; HOHG, Hoehne headgate; JFHG, John Flood headgate; MOHG, Model headgate; PWHG, Picketwire headgate; SSHG, Enlarged Southside headgate; ft/s, foot per second; --, measurement not rated]

Site name	Date	Flume size (feet)	Staff reading (feet)	Flume-rated discharge (ft³/s)	Measured discharge (ft³/s)	Measurement rating (percent)	Difference flume-meas. (ft³/s)	Difference flume-meas. (percent)	Remarks
JFHG	08/09/00	8	0.85	25	26	--	–1	–4	As reported by Colorado Division of Water Resources.
JFHG	08/09/00	8	0.85	25	26	--	–1	–4	As reported by Colorado Division of Water Resources.
JFHG	08/09/00	8	0.85	25	26	--	–1	–4	As reported by Colorado Division of Water Resources.
JFHG	08/10/00	8	0.85	25	26	--	–1	–4	As reported by Colorado Division of Water Resources.
JFHG	08/23/00	8	0.86	25	26	--	–1	–4	As reported by Colorado Division of Water Resources.
JFHG	05/17/01	8	0.80 ± .03	22	25	8	–3	–12	
JFHG	05/18/01	8	0.83 ± .03	24	23	8	1	4	
JFHG	05/18/01	8	0.81 ± .03	23	24	8	–1	–4	
JFHG	05/21/01	8	0.86 ± .04	25	26	8	–1	–4	
JFHG	05/24/01	8	0.85 ± .03	25	24	8	1	4	
JFHG	05/24/01	8	0.85	25	25	--	0	0	As reported by Colorado Division of Water Resources.
JFHG	06/17/03	8	0.80	22	30	8	–8	–27	
JFHG	06/17/03	8	0.80	22	30	5	–8	–27	
JFHG	06/20/03	8	0.76	21	27	8	–6	–22	
JFHG	06/15/04	8	0.71 ± .01	18	18	--	0	0	
HOHG	07/31/00	4	1.20 ± .02	21	24	8	–3	–12	
HOHG	08/03/00	4	1.16 ± .02	20	21	8	–1	–5	
HOHG	08/07/00	4	1.28	24	21	8+	3	14	Potential submergence observed.
HOHG	05/14/01	4	1.32 ± .02	25	25	8+	0	0	
HOHG	05/14/01	4	1.30 ± .02	24	25	8	–1	–4	
HOHG	05/14/01	4	1.30 ± .02	24	24	8	0	0	
HOHG	05/15/01	4	1.30 ± .02	24	25	8	–1	–4	
HOHG	06/16/03	4	1.20 ± .02	21	23	--	–2	–9	
HOHG	06/16/03	4	1.21 ± .02	22	24	8+	–2	–8	
HOHG	06/16/03	4	1.21 ± .02	22	22	8	0	0	
HOHG	06/20/03	4	1.26 ± .03	23	24	--	–1	–4	

relation was in use at the Enlarged Southside Canal headgate (Danny Marques, Colorado Division of Water Resources, oral commun., 2005). Flume-rated discharge values for the Enlarged Southside Canal headgate were determined using this modified relation. Standard predefined Parshall flume tables (see, for example, Grant, 1991) were used to determine the flume-rated discharge at all other headgates listed in table 11.

Measured discharges were usually higher than flume-rated discharges. Of the 102 discharge measurements made at the canal headgates, 72 of the measured discharges were higher than the corresponding discharges determined using the standard Parshall flume discharge tables. This means that about 70 percent of the time, the amount of flow that was diverted into the canals was underreported.

All measured discharges at the Picketwire and El Moro headgates were higher than the corresponding flume-rated discharges, and all but one measured discharge at the Chilili headgate were higher than the corresponding flume-rated discharges (table 11). Discharges measured at Picketwire headgate were 2 to 23 percent higher than the corresponding flume-rated discharges. Discharges measured at El Moro headgate were 10 to 23 percent higher than the corresponding flume-rated discharges. Discharges measured at Chilili headgate were 1 percent lower to 22 percent higher than the corresponding flume-rated discharges. Discharges measured at Enlarged Southside headgate were 8 percent lower to 13 percent higher than the corresponding adjusted flume-rated discharges. Discharges measured at Model headgate were 11 percent lower to 9 percent higher than the corresponding flume-rated discharges. Discharges measured at John Flood headgate were 9 percent lower to 27 percent higher than the corresponding flume-rated discharges. Finally, discharges measured at Hoehne headgate were 14 percent lower (based on one measurement) to 12 percent higher than the corresponding flume-rated discharges. However, only one measurement made on August 7, 2000, at Hoehne headgate showed a flume-rated discharge higher than the measured discharge. Field notes indicate that the flume may have been partially submerged during this measurement. If the flume was submerged, the Parshall flume tables would have overestimated the flow. All other discharges measured at Hoehne headgate were zero to 12 percent higher than the corresponding flume-rated discharges.

Temporary and(or) long-term differences between the precalibrated Parshall flume ratings and measured discharges appear to occur at the PRWCD headgates. Temporary changes may be due to debris buildup immediately upstream from the flume or in the converging section upstream from the flume throat. Long-term differences between the precalibrated Parshall flume ratings and measured discharges may occur due to uneven settling of the Parshall flume itself or some other change in the converging or diverging section of the flume.

Factors Affecting Canal Losses and Gains and Changes in Headgate Stage-Discharge Relations

Many factors may affect the measured losses and gains along the canals such as canal size, construction, maintenance, infiltration rate of the bed material, the wetted perimeter, and the head (depth of water) in the canal. Changes in application of irrigation water on individual fields may potentially produce large variation in loss and gain measurements over short distances and timeframes by affecting subsurface irrigation return flow. Losses and gains also may vary within the irrigation season based on length of time that the canal has been continuously flowing. Generally, seepage losses would be expected to be highest in the early part of the season (initial wetting) and then tend to decrease and stabilize. However, in canals that have alternate wetting and drying cycles (do not flow continuously throughout the entire irrigation season), seepage losses would be variable.

The length of time that the canal has been flowing may affect such things as subsurface irrigation return flow and bank storage. The potential for subsurface irrigation return flow likely increases with the length of time the canal has been flowing because more irrigation water is applied to adjacent fields. Changes in bank storage that are related to channel dimensions occur whenever streamflow and corresponding stage change within a given stream subreach. This condition may occur when headgate inflows change or diversion gates are opened or closed. During these conditions, flow will vary throughout the channel because of changes in bank storage. For example, if simultaneous measurements are made at upstream and downstream sites during a rising stage, flow at the upstream site will exceed flow at the downstream site because bank storage increases as stage increases. Conversely, downstream flow will exceed upstream flow for simultaneous measurements made during a falling stage. Thus, changes in bank storage can affect losses and gains, with maximum effects resulting from large changes in flow, and associated stage, in long stream subreaches with wide channels.

The large variability in measured losses and gains from M2HG to M3HG may be due to unsteady-flow conditions during the measurement period. The flow may have changed substantially in days preceding some measurements. The variability also may be due to length of time the canal was running before the measurements were made. However, because CDWR does not report flow downstream from Model Reservoir at M2HG, there is no record of daily streamflow available to determine if steady-flow conditions existed before the measurement period or to determine the number of days the canal had been flowing before the measurement. It is interesting to note that the largest losses from M2HG to M3HG were computed for measurements made in May and June, and the smallest losses were determined for measurements made in August.

Differences between the precalibrated Parshall flume ratings and measured discharges appear to occur at the PRWCD headgates. These differences probably occur due to changes over time in the flume or in the canal channel immediately upstream or downstream from the flume. To accurately measure flow with a flume using precalibrated discharge ratings, the flume must be level, free of debris, and have good approach (that is, entering flow should be well distributed across the width and parallel to the flume centerline) and exit conditions. Shifts (difference between precalibrated discharge ratings and measured discharge) in the stage-discharge relation of a critical-flow flume are most commonly caused by changes in the approach section—either in the channel immediately upstream from the flume or in the converging section upstream from the flume throat (Kilpatrick and Schneider, 1983). Deposition of rocks and debris upstream from the flume may divert most of the flow to the gage-side of the flume, resulting in a higher stage reading for a given discharge. Conversely, if most of the water is diverted to the side opposite of the gage, the observed stage would be lower for the measured discharge.

Summary

The U.S. Geological Survey conducted a field study from July 2000 through June 2004, in cooperation with the Purgatoire River Water Conservancy District, Colorado Water Conservation Board, and Bureau of Reclamation, to characterize and quantify streamflow losses and gains in Picketwire, Baca, El Moro, Chilili, Enlarged Southside, Model, John Flood, and Hoehne irrigation canals. These canals divert streamflow from the Purgatoire River between the Trinidad Dam and the city of Hoehne, Colorado. As part of this study, discharge measurements were made along the eight unlined canals during steady-state conditions to identify subreaches with losses or gains. The canal loss or gain was computed between main-channel measurement sites (subreaches) by equating inflows to outflows plus flow loss or gain in the subreach.

Results from the loss and gain measurements showed that Picketwire, Chilili, and Hoehne Canals lose flow from the headgate to the end of the canal, although some subreaches showed gains during some measurements. Losses in Picketwire Canal ranged from about 7 percent to about 23 percent of the headgate inflow, and Chilili Canal losses ranged from about 2 percent to about 34 percent of the headgate inflow. Hoehne Canal losses ranged from only about 2 to 7 percent of the headgate inflow, which is within the measurement uncertainty.

El Moro Canal appears to lose flow in some subreaches and gain flow in other subreaches. Between EMHG and EM04, El Moro Canal gains water, approximately 10 to 14 percent of the headgate inflow. Based on field observations, the gain is probably due to inflow from the pipeline crossing over the canal between EM02 and EM03. Despite gains in some subreaches, measurements show flow losses for the entire canal (EMHG to EM09). Much of this loss probably occurs near EM08 where flow spills from El Moro to an adjacent canal (probably Model Canal).

Measurements made from MOHG to Model Reservoir show canal losses and gains ranging from 1 to 5 percent of the headgate inflow, which is within the uncertainty of the measurements. However, measured losses and gains from MHG2 to MHG3 ranged from a loss of 59 percent to a gain of 1 percent of the subreach inflow. Measurements made by CDWR showed losses of 8, 16, and 18 percent of the subreach inflow to a gain of 1 percent of the subreach inflow in Model Canal downstream from Model Reservoir. Downstream from Model Reservoir, from M2HG to M3HG, the USGS measured canal losses of 30 and 59 percent of the subreach inflow.

Measured losses and gains for John Flood Canal ranged from a gain of 2.7 ft^3/s or 11 percent of the headgate inflow on May 24, 2001, to a loss of 2.6 ft^3/s or 9 percent of the headgate inflow on June 17, 2003. All measurements showed gains in flow between JFHG and JFWG and losses in flow between JF17 and JF25. Measured gains between JFHG and JFWG ranged from 0.8 ft^3/s (4 percent of the headgate inflow) to 4.8 ft^3/s (20 percent of the headgate inflow), and measured losses between JF17 and JF25 ranged from 0.4 ft^3/s (3 percent of the subreach inflow) to 5.1 ft^3/s (30 percent of the subreach inflow).

Generally, measured discharges at the canal headgates were higher than flume-rated discharges. Of the 102 discharge measurements made at the canal headgates, 72 of the measured discharges were higher than the corresponding discharges determined using the standard Parshall flume discharge tables. This means that about 70 percent of the time, the amount of flow that was diverted into the canals was underreported. All measured discharges at the Picketwire and El Moro headgates were higher than the corresponding flume-rated discharges, and all but one measured discharge at the Chilili headgate were higher than the corresponding flume-rated discharges. Discharges measured at the remaining headgates varied from 14 percent lower to 27 percent higher than the corresponding flume-rated discharges.

Discharges measured at Picketwire headgate were 2 to 23 percent higher than the corresponding flume-rated discharges. Discharges measured at El Moro headgate were 10 to 23 percent higher than the corresponding flume-rated discharges. Discharges measured at Chilili headgate were 1 percent lower to 22 percent higher than the corresponding flume-rated discharges. Discharges measured at Enlarged Southside headgate were 8 percent lower to 13 percent higher than the corresponding adjusted flume-rated discharges. Discharges measured at Model headgate were 11 percent lower to 9 percent higher than the corresponding flume-rated discharges. Discharges measured at John Flood headgate were 9 percent lower to 27 percent higher than the corresponding flume-rated discharges. Finally, discharges measured at Hoehne headgate were 14 percent lower (based on one measurement) to 12 percent higher than the corresponding flume-rated discharges.

Many factors may affect the measured losses and gains along the canals, such as canal size, construction, maintenance, infiltration rate of the bed material, the wetted perimeter, and the head (depth of water) in the canal. Changes in application of irrigation water on individual fields may potentially produce large variation in loss and gain measurements over short distances and timeframes by affecting subsurface irrigation return flow. Losses and gains also may vary within the irrigation season based on length of time that the canal has been continuously flowing. The potential for subsurface irrigation return flow likely increases with the length of time the canal has been flowing because more irrigation water is applied to adjacent fields. Generally, seepage losses would be expected to be highest in the early part of the season (initial wetting) and then tend to decrease and stabilize. However, in canals that have alternate wetting and drying cycles (do not flow continuously throughout the entire irrigation season), seepage losses would be variable.

Losses in Baca, Picketwire, Chilili, and Enlarged Southside canals appear to decrease the longer the canal has been continuously flowing. In some cases, subreaches of some of these canals go from losing to gaining flow.

Differences between the precalibrated Parshall flume ratings and measured discharges appear to occur at the PRWCD headgates. These differences probably occur due to changes over time in the flume or in the canal channel immediately upstream or downstream from the flume. To accurately measure flow with a flume using precalibrated discharge ratings, the flume must be level, free of debris, and have good approach (that is, entering flow should be well distributed across the width and parallel to the flume centerline) and exit conditions. Difference between precalibrated discharge ratings and measured discharges are most commonly caused by changes in the approach section—either in the channel immediately upstream from the flume or in the converging section upstream from the flume throat. Deposition of rocks and debris upstream from the flume may divert most of the flow to the gage-side of the flume, resulting in a higher stage reading for a given discharge. Conversely, if most of the water is diverted to the side opposite of the gage, the observed stage would be lower for the measured discharge.

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Appendix

Summaries of loss and gain measurements for eight unlined canals along the Purgatoire River near Trinidad, Colorado

Table A1. Summary of loss and gain measurements made along Picketwire Canal, 2000–2004.

[ft³/s, cubic feet per second; PW, Picketwire; HG, headgate; A, discharge measurement made on main canal upstream from diversions; B, discharge measurement made on main canal downstream from diversions; BA, Baca; EMDD, El Moro Canal diversion dam; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 2, 2000			May 16, 2001			June 18, 2003			June 10, 2004		
	Main channel discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main channel discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main channel discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main channel discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)
PWHG	47.3			40.8			16			41.2		
PW01-A	41.3			--			--			--		
PW01		1.2			0.8			Closed	0		Closed	0
BA01-A	40.2			--			--			--		
BA01		0.8e			0.6			0.5			0.6e	
BA01-B	--			35.6			--			--		
BA02-A	--			--			--			38.5		
BA02		Closed	0		Closed	0		Closed	0		Closed	0
BAWG		No documentation			Closed	0		Closed	0		Closed	0
BA03		Closed	0		Closed	0		1.2			1.2e	
BA04		Closed	0		0.2			Closed	0		1	
BA05-A	39.5			--			--			--		
BA05		0.6			0.3			0.9			0.4e	
BA06		Closed	0		1.9			Closed	0		Closed	0
BA07-A	38.7			--			--			--		
BA07		Closed	0.7		1.9			1.3			1.1	
BA08-A	38.3			--			--			--		
BA08		0.5e			Closed	0		Closed	0		Closed	0
BA09-A	36.3			--			--			--		
BA09		0.9			Closed	0		Closed	0		0.9e	
BA10-A	37.9			--			--			--		
BA10		1.2			Closed	0		1.1			Closed	< 0.02
BA10-B	--			--			--			32.2		
PW02-A	--			26.7			9			--		
PW02		1.1			0.5			--			Closed	0
PW03-A	36.4			--			--			--		
PW03		1.3e			1.1			--			1.2	
PW04-A	38.5			--			--			--		
PW04		0.3e			0.1			--			Closed	< 0.02
EMDD		3.9			Closed	0		--			3.8	
PW05-A	32.2			--			--			--		
PW05		0.4e			0.3			--			0.2	
PW06-A	30.2			--			--			--		
PW06		0.2e			0.2e			--			Closed	0
PW07-A	29.1			--			--			--		
PW07		0.2			0.3			--			0.2	

Table A1. Summary of loss and gain measurements made along Picketwire Canal, 2000–2004.—Continued

[ft^3/s, cubic feet per second; PW, Picketwire; HG, headgate; A, discharge measurement made on main canal upstream from diversions; B, discharge measurement made on main canal downstream from diversions; BA, Baca; EMDD, El Moro Canal diversion dam; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 2, 2000			May 16, 2001			June 18, 2003			June 10, 2004		
	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
PW08		Closed	0.2e		Closed	0		--			Closed	0
PW09-A	31.1			--			--			--		
PW09		1.2			0.9			--			0.9	
PW10-A	27.4			--			--			24.8		
PW10		3.2e			1.9			--			2.7	
PW10-B				--			--			22.1		
PWW3		Closed	0.02e		Closed	0		--			Closed	<0.02
PW11-A	27.7			--			--					
PW11		0.4			0.3			--			0.4e	
PW12		0.3e			0.2e			--			Closed	0
PW13-A	26.6			--			--			22.6		
PW13		0.9			0.7			--			0.7	
PW14		2.3			2			--			1.8	
PW15		1.6			1.5			--			1.8	
PW16-A	21.5			--			--			--		
PW16		3.1			2.4			--			2.5	
PW17		0.1			0.4			--			0.1e	
PW18-A	20.1			--			--			--		
PW18		2.5			0.4			--			2.2	
PW19		3			2.3			--			2.1	
PW20-A	15.9			--			--			--		
PW20		0.4			0.9			--			0.8	
PW20-B	--			9.8						11.1		
PWW4		Closed	0		Closed	0		--			Closed	0
PWW5		Closed	0		Closed	0		--			Closed	0
PW21-A	11.1			--			--					
PW21		2.9			2.4			--			1.2	
PW22		1.2			0.9			--			1.2	
PW23		2.5			1.8			--			2.3	
PW24		1.9			1.9			--			1.2	
PW25		0.1			0.03			--			1.2	
PW26-A	2.9			--			--			--		
PW26		0.2			0.2			--			0.7	
PW26-B	--			--			--			2.0		
PW27		--			Closed	0		--			--	
PW27-B	--			2.1			--			--		

Table A2. Summary of loss and gain measurements made along El Moro Canal, 2000–2004.

[ft^3/s, cubic feet per second; A, discharge measurement made on main canal upstream from diversions; B, discharge measurement made on main canal downstream from diversions; EM, El Moro Canal; HG, headgate; WG, wastegate; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 1, 2000			June 18, 2003			June 16, 2004		
	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
EMHG	3.9			3.9			4.3		
EM01-A	3.8			--			--		
EM01		0.9			1.3			1.5	
EM02-A	2.7			--			1.9		
EM02		0.4			0.1			0.1e	
EM03		Closed	0		0.1			2.8	
EM03-B								–0.2[1]	
EMWG		–0.1			No documentation			Closed	0
EM04-A	3.1			--			--		
EM04		Closed	0		Closed	0		0.7	
EM05		Closed	0		Closed	0	0		
EM06		Closed	0		Closed	0			
EM07-A	3.2			--					
EM07		0.3			Closed	1.0			
EM08		Closed	0.1		0.3				
EM09-A	1.2			0.0					

[1]Tailwater downstream from EM03.

Table A3. Summary of loss and gain measurements made along Chilili Canal, 2000–2003.

[ft^3/s, cubic feet per second; A, discharge measurement made on main canal upstream from diversions; CH, Chillili Canal; HG, headgate; CEND, end of canal; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 1, 2000			May 17, 2001			June 28, 2001			June 19, 2003		
	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
CHHG	9.4			9.3			6.2			8.2		
CH01-A	13			--			--			--		
CH01		Closed	0		Closed	0		--			Closed	0
CH02-A	8.6			9.0			--			--		
CH02		0.2			1.2			--			Closed	0
CH03-A	7.4			--			--			--		
CH03		0.16e			0.2e			--			Closed	0
CH04		1.8e			Closed	0		--			Closed	0
CH05-A	5.7			--			--			--		
CH05		1.3			0.4			--			Closed	0.002e
CH06-A	6.2			--			--			--		
CH06		Closed	0		Closed	0		--			Closed	0.002e
CH07		0.33			Closed	0.002e		--			Closed	0
CH08-A	5.7			--			--			--		
CH08		0.36e			Closed	0		--			0.2	
CH09-A	5.1			--			5.0			7.3		
CH09		0.96			Closed	0		Closed	0		0.1	
CH10		Closed	0		Closed	0		Closed	0		Closed	0
CH11-A	3.8			5.2			--			--		
CH11		0.93e			0.5			0.4			Closed	0
CH12		Closed	0		0.1			0.4			Closed	0
CH13		Closed	0		Closed	0		Closed	0		Closed	0
CH14		Closed	0		Closed	0		Closed	0		Closed	0
CH15		Closed	0		0.3			0.3			0.4	
CH16-A	3.5			--			--			--		
CH16		0.34			Closed	0		Closed	0		Closed	0
CH17		Closed	0		0.4e			0.1			0.8	
CH18-A	3.5			--			--			--		
CH18		Closed	0		0.4e			0.4e			0.7	
CH19-A	3.1			--			--			3.9		
CH19		0.3			Closed	0		0.1			0.1	
CEND	2.6			--			1.9			3.2		

Table A4. Summary of loss and gain measurements made along Enlarged Southside Canal, 2000–2004.

[ft^3/s, cubic feet per second; SSHG, Enlarged Southside Canal headgate; Div, discharge measurement made on diversion; A, discharge measurement made on main canal upstream from diversion; B, discharge measurement made on main canal downstream from diversion; SO, Enlarged Southside Canal; SS, Enlarged Southside Canal Sandoval Extension; SSS, Enlarged Southside Canal Split; SP, Enlarged Southside Canal Palaski Extension; SW, Enlarged Southside Canal Wagner Extension; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 9–11, 2000			May 22–23, 2001			June 27, 2001			June 8–9, 2004		
	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
SSHG	69.5			68.7			--			99.9		
SO01-Div		Closed	0		0[1]			--			0[1]	
SO02-Div		1.5			2.6			--			2.5	
SO03-Div		--			0.8			--			0	
SSS1-A (main)	68.2			62.2			85.9			91.2		
SSS1-SS (LF)	48.9				49.4			--			64.9	
SSS1-SP (RT)	18.2				16.0			--			21.1	
Palaski Extension												
SSS1-SP (RT)	18.2			16.0			21.9			21.1		
SP01-Div		1.2			0.7			--			0.7	
SP02-A	--			16.4			--			21.2		
SP02-Div		7.9			3.2[2]			--			3.4[2]	
SP02-B	--			13.2			--			17.8		
SP03-Div		4.2			4.5			--			5.5	
SP04-A	7.6			7.7			--					
SP04-Div		0.7			0.7			--			0.8	
SP05-Div		1.5			Closed—some leakage			--			Closed—some leakage	
SP06-Div		0.8			1.2			--			0.6	
SP07-A	--			--			--			10		
SP07-Div		Closed	0		0.8			--			2.4[2]	
SP07-B	--			--			--			7.6		
SP08-A	5.2			--			--			--		
SP08-Div		Closed	0		1.0			--			1.2	
SP09-Div		2.0			1.2			--			2.6	
SP10 (END)	3.3			2.4						4.5		

Table A4. Summary of loss and gain measurements made along Enlarged Southside Canal, 2000–2004.—Continued

[ft³/s, cubic feet per second; SSHG, Enlarged Southside Canal headgate; Div, discharge measurement made on diversion; A, discharge measurement made on main canal upstream from diversion; B, discharge measurement made on main canal downstream from diversion; SO, Enlarged Southside Canal; SS, Enlarged Southside Canal Sandoval Extension; SSS, Enlarged Southside Canal Split; SP, Enlarged Southside Canal Palaski Extension; SW, Enlarged Southside Canal Wagner Extension; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 9–11, 2000			May 22–23, 2001			June 27, 2001			June 8–9, 2004		
	Main canal discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main canal discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main canal discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)	Main canal discharge (ft³/s)	Diversion discharge (ft³/s)	Leakage (ft³/s)
Sandoval Extension												
SSS1-SS (LF)	50.0			45			64.7			64.9		
SS01-A	49.6			46.7			--			64.8		
SS01-Div		9.2			7.2			9.6			10[2]	
SS01-B	44.2			--			--			54.8		
SS02-Div		5			7.4			10			10.7	
SS03-Div		3.5			2.7			2.8			2.5	
SS04-Div		1.1			0.9e			0.9			1.2	
SSS2-MAIN	35.8			26.3			35.7			--		
SSS2-Wag(LF)		27.5			18.9			28.5			32.2	
SSS2-Sand(RT)	4.6			5.5			8.8			11.2		
SS05-A	4.7											
SS05-Div		0.9			1.1			--			1.4	
SS05-B	3.4						--			--		
SS06-A				3.9			--			9		
SS06-Div		1.5			1.5[2]			--			3.0[2]	
SS06-B							--			6		
SS07-A	2.4			2.1			--			6.1		
SS07-Div		1.9			0.8[2]			--			4.3[2]	
SS07-B	--			1.3			--			1.8		
SS08-A	--			1.1			--			2.1		
SS08-Div		0.8			--			--			--	
SSS3-MAIN	29.6			19.1			21.9			32.2		
SW01-Div		4.8			--			4.6			5.8	
SSS3-South		9.2			--			7.8			9.8	
SSS3-North		12.9			--			12.7			16.5	

Table A4. Summary of loss and gain measurements made along Enlarged Southside Canal, 2000–2004.—Continued

[ft^3/s, cubic feet per second; SSHG, Enlarged Southside Canal headgate; Div, discharge measurement made on diversion; A, discharge measurement made on main canal upstream from diversion; B, discharge measurement made on main canal downstream from diversion; SO, Enlarged Southside Canal; SS, Enlarged Southside Canal Sandoval Extension; SSS, Enlarged Southside Canal Split; SP, Enlarged Southside Canal Palaski Extension; SW, Enlarged Southside Canal Wagner Extension; --, no measurement made; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 9–11, 2000			May 22–23, 2001			June 27, 2001			June 8–9, 2004		
	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
South Wagner Extension												
SSS3-South	9.2			--			7.8			9.8		
SW02-A	9.1			--			--			--		
SW02-Div		1.4			--			1.6			1.9	
SW03-A	4.3			--			--			7.8		
SW03-Div		2.0			--			1.9			2.3[2]	
SW03-B										5.5		
SW04-Div		Closed	0.1		--			2.0			1.9	
SW05-A (END N Wag)	4.5			--			2.5			3.3		
SW05-Left		2.7			--			--			--	
SW05-Right		1.8			--			--			--	
North Wagner Extension												
SSS3-North	12.9			--			12.7			16.5		
SW06-Div		Closed	0		--			Closed	0		Closed	0
SW07-A	14.3			--			--			--		
SW07-Div		4.3			--			2.0			5.7	
SW07-B	8.8			--			--			--		
SW08-Div		1.2			--			1.1			1.1	
SW09-Div		2.2			--			2.6			2.5	
SW10-Div		0.8			--			0.6			0.8	
SW11-Div		Closed	0		--			1.5			1.5	
SW12-A	5.2			--			4.5			3.4		
SW12-Div		2.0			--			--				
SW12-B	3			--			--					

[1]Gate open but no flow in channel.

[2]Diversion discharge calculated by subtracting the discharge in the main canal downstream from the diversion from the discharge in the main canal upstream from the diversion.

Table A5. Summary of loss and gain measurements made along Model Canal, 2000–2004.

[ft³/s, cubic feet per second; MO, Model Canal; HG, headgate; JF, John Flood Canal; Div, discharge measurement made on diversion; A, discharge measurement made on main canal upstream from diversions; --, no measurement made; e, estimated value; blw, discharge measurement made on diversion downstream from splitter; gray shading indicates diversion gate closed]

Site ID	May 18, 2001			May 21, 2001			June 26, 2001			June 11, 2004		
	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
MOHG	55.5			56.1			--			58.1		
JF00-Div		0.7			0.3			--			1.0e	
JFHG		23.6			26			--			18.5e	
MOT0	--			29.1			--			--		
MOT1	30.5			--			--			--		
MOT2	31.2			33.1			--			39.2		
MOT3	29.3			31			--			37.3		
MOEND	--			--			--			36.3		
M2HG	--			--			38.1			30		
MO01		--			--			Closed	0		Closed	0
M3WG		--			--			No documentation			Closed—minor leakage	
M3HG	--			--			26.6			12.4		
MO02-Div		--			--			16.93			Closed—minor leakage	
MO03-A	--			--			10.1					
MO03-left blw	--			--				9.8		18.4		
MO03-right blw		--			--			Closed	0.4		Closed—minor leakage	

Table A6. Summary of loss and gain measurements made along John Flood Canal, 2000–2004.

[ft^3/s, cubic feet per second; JF, John Flood Canal; HG, headgate; WG, wastegate; A, discharge measurement made on main canal upstream from diversions; B, discharge measurement made on main canal downstream from diversions; JFRF, John Flood Canal diversion installed in 2004 used to return flow to the Purgatoire River; --, no measurement made; NA, not applicable; e, estimated value; gray shading indicates diversion gate closed]

Site ID	August 8, 2000			May 24, 2001			June 17, 2003			June 15, 2004		
	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main canal discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
JFHG	24.0			23.7			30.0			18.3		
JF01		0.7			0.9			0.8			Closed	0
JF02		1.7			1.5			2.0			1.4	
JF03		0.3			0.3			Closed	0		0.1	
JF04		1.9			1.4			1.6			1.0	
JF05		1.1			Closed	0		0.8			0.9e	
JF06		1.0			1.9			1.3			1.6	
JFWG-A	20.4			--			--			--		
JFWG		Closed with leakage?			Not noted			Closed	0		Closed	0
JFWG-B	--			22.5			--			14.1		
JF07A								Closed	0.08e		Closed—minor leakage	
JF07		Closed	0.06e		1.7			Closed	0.05e		0.6e	
JF08		Closed	0		Closed	0		Closed	0		Closed—minor leakage	
JF09		Closed	0.05e		Closed	.004e		Closed	0		Closed—minor leakage	
JF10		Closed	0.01e		0.6			0.5			0.8	
JF11		0.6			Closed—minor leakage			Closed	0.1e		Closed	0
JF12		2.2e			2.2			1.8			1.3e	
JF13		1.9			1.6			2.0			1.0	
JF14		0.8			0.4			0.3			Closed	0
JF15		Closed	0		Closed—minor leakage			Closed	0		3.0	
JF16		2.2			2.0			2.4			Closed	0.02
JF16-B				12.9			--			7.3		
JF17-A	17.2			12.3			--			--		
JF17		0.9			0.9			0.4			0.2	
JF18		0.9			0.7			0.9			1.1	
JF19		2.3			0.9			0.7			0.8	
JF20		1.0			1.5			1.5			1.2	
JF21		2.1			1.6			3.4			0.2	
JF22		2.4			2.6			3.3			Closed	0
JFRF		NA			NA			NA			1.8	
JF23		2.1			1.6			1.4			Closed—minor leakage	
JF24		Closed	0		2.1			Closed	0.05e		Closed—minor leakage	
JF25		0.4			Closed	0.04		2.0			1.1	

Table A7. Summary of loss and gain measurements made along Hoehne Canal, 2000–2003.

[ft^3/s, cubic feet per second; HO, Hoehne Canal; HG, headgate; MAIN, main canal measurement site; NA, not applicable because diversion not constructed until 2003; e, estimated value]

Site ID	July 31, 2000			May 15, 2001			June 16, 2003			June 18, 2003		
	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)	Main channel discharge (ft^3/s)	Diversion discharge (ft^3/s)	Leakage (ft^3/s)
HOHG	24			25.0			23.2			23.4e		
HO1-MAIN	21.1			24.3			20.4			21.7		
HO1-Right(MAIN)		13.7			20.7			13.4			15.4	
HO1-Middle		4.4			4.5			5.3			5	
HO1-Left		1.8			1.8			1.7			1.3	
HO2-MAIN	14			19.1			15.5			17.2		
HO2-Right		0.2			2.1			0			0	
HO2-Middle(MAIN)		7.6			11.8			11.4			12.4	
HO2-Left		5.6			6.2			4.1			4.8	
HO2A-MAIN	NA			NA			10.9			10.6		
HO2A-Right(MAIN)		NA			NA			7.7			7.8	
HO2A-Left		NA			NA			3.2			2.9	
HO3-MAIN	8.9			9.9			7.3			7.3		
HO3-Right(MAIN)		3.8			4.3			3.4			3.5	
HO3-Left		4.6			4.3			4			3.8	
HO4-MAIN	1.0			4.2			4.5			5.0		
HO4-Right		1.0			1.7			2.7			3.9	
HO4-Left		0.1			2.7			1.8			1.1	