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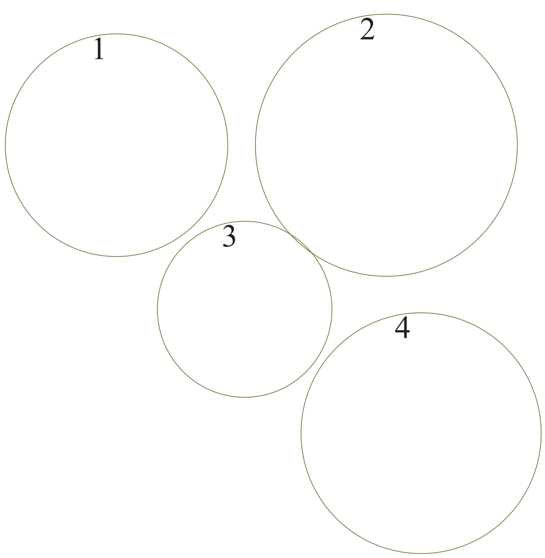
Seepage Investigation on the Rio Grande from Below Caballo Reservoir, New Mexico, to El Paso, Texas, 2012

Scientific Investigations Report 2014–5197

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



Cover.

1. View of Westside Canal at Diversion at Mesilla Diversion Dam near Mesilla, New Mexico, June 27, 2012 (photograph by Jay Cederberg, U.S. Geological Survey).
2. View of Percha Dam recreation area at Caballo Lake State Park across Arrey Canal Diversion near Arrey, New Mexico, June 26, 2013 (photograph by Jay Cederberg, U.S. Geological Survey).
3. U.S. Geological Survey hydrologist Jay Cederberg conducting discharge measurement in Pence Lateral Wasteway 34A near Canutillo, Texas, June 28, 2012 (photograph by Rachel Powell, U.S. Geological Survey).
4. View downstream at Leasburg Main Canal near Radium Springs, New Mexico, June 27, 2012 (photograph by Jay Cederberg, U.S. Geological Survey).

Seepage Investigation on the Rio Grande from Below Caballo Reservoir, New Mexico, to El Paso, Texas, 2012

By Mark A. Gunn and D. Michael Roark

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot per day (ft/d)	0.3048	meter per day (m/d)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)

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

°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Seepage Investigation on the Rio Grande from Below Caballo Reservoir, New Mexico, to El Paso, Texas, 2012

By Mark A. Gunn and D. Michael Roark

Abstract

A seepage investigation was conducted by the U.S. Geological Survey, in cooperation with the New Mexico Interstate Stream Commission, along an approximately 106-mile reach of the Rio Grande from below Caballo Reservoir, New Mexico, to El Paso, Texas, during June 26–28, 2012, to determine gain or loss of streamflow due to seepage to or from the river channel. Discharge measurements were made during the irrigation season at high flow including 5 sites along the Rio Grande, 5 diversions, and 63 inflows. The net gain or loss of flow in the river channel was computed for four reaches within the 106-mile reach of the Rio Grande. The normalized percentage difference was computed for each reach to determine the difference between discharge measured at upstream and downstream sites, and the normalized percentage uncertainty was computed to determine if a computed gain or loss exceeded cumulative uncertainty associated with measurement of discharge.

Introduction

The Rio Grande Compact (New Mexico State Annual § 75–34–3 (1953), Act of May 31, 1939, ch. 155, 53 Stat. 785), signed into law by Congress in 1938, apportions the waters of the Rio Grande above Fort Quitman, Texas, among the States of Colorado, New Mexico, and Texas and establishes water delivery obligations for Colorado and New Mexico and normal release for the Rio Grande below Elephant Butte Reservoir. The Bureau of Reclamation manages Elephant Butte and Caballo Reservoirs, located on the Rio Grande in New Mexico, for power supply and for irrigation water supply. On the Rio Grande below Caballo Reservoir, the Elephant Butte Irrigation District and El Paso County Water Improvement District No. 1 operate and maintain a system of irrigation canals and laterals that provides delivery of irrigation water to 90,640 acres of land within New Mexico and 68,000 acres within Texas (Bureau of Reclamation, 2008).

The U.S. Geological Survey (USGS), in cooperation with the New Mexico Interstate Stream Commission, conducted a seepage investigation on the Rio Grande from below Caballo Reservoir, N. Mex., to El Paso, Tex., to determine streamflow loss or gain in this approximately 106-mile reach of the Rio Grande. Increasing drought conditions have resulted in reduced water available for domestic, agricultural, and recreational uses (Crilley and others, 2013). A better understanding of the spatial distribution of streamflow gains and losses during high flow conditions in this reach of the Rio Grande is needed to better manage the available water.

The intent of the investigation was to determine gains and losses from the river during a period of flows associated with irrigation deliveries along the Rio Grande during the summer of 2012 and to determine the component of those gains and losses associated with surface-water/groundwater interaction. Previous seepage investigations were conducted along portions of the study area during winter months by measuring periods of base flow in the Rio Grande (Crilley and others, 2013).

Purpose and Scope

This report describes the methods used to obtain flow measurements and presents the results of the seepage investigation conducted on the Rio Grande between Caballo Reservoir, N. Mex., and El Paso, Tex., during June 26–28, 2012. Discharge measurements at 73 sites, which include 5 river sites, 5 irrigation diversions, and 63 inflow sites (50 irrigation return flows to the river, 8 drains, and 5 wastewater treatment outfalls) are presented. The calculated streamflow gains and losses attributed to interactions with groundwater along four reaches of the Rio Grande are also presented. Field measurements and observations recorded at discharge measurement locations are presented and include water temperature, specific conductance, instantaneous discharge measurement, discharge measurement type, and discharge rating related to each site.

Description of the Study Area and Measurement Locations

The Rio Grande flows for 1,896 miles from southwestern Colorado south through New Mexico, forming the international boundary between Texas and Mexico outside the study area below El Paso, Tex. The study area encompasses the lower third of the Rio Grande in New Mexico, a 106-mile reach from below Caballo Reservoir, N. Mex., to El Paso, Tex. (fig. 1).

Measurement locations included sites along the river and all diversion and inflow locations that provided potential gain or loss of streamflow to the river system. The river system includes the main channel, tributaries, and manmade features such as diversions and canals. River miles are referenced upstream from site 69, at USGS streamgage Rio Grande at El Paso, which is designated as river mile 1,249.9 (Hendricks, 1964). The relative locations of measurement sites are shown in figure 2, and associated river miles are presented in table 1.

Methods

The seepage investigation was conducted over a 3-day period in June 2012 during the irrigation season at high flow. Instantaneous discharge was measured at sites along the river channel, at points of diversion, and at inflows along each study reach. The net gain or loss of flow in the river channel was computed for four reaches along the Rio Grande (fig. 1). A reach is defined as the interval between two adjacent river discharge-measurement locations. The reaches were designated as follows: Reach 1, Rio Grande below Caballo Reservoir (site 1, river mile 1,355.6) to Rio Grande at Haynor Bridge (site 22, river mile 1,322.5); Reach 2, Rio Grande at Haynor Bridge (site 22, river mile 1,322.5) to Rio Grande below Mesilla Diversion Dam (site 41, river mile 1,285.7); Reach 3, Rio Grande below Mesilla Diversion Dam (site 41, river mile 1,285.7) to Rio Grande at Anthony–EP no. 1 (site 59, river mile 1,265.9); and Reach 4, Rio Grande at Anthony–EP no. 1 (site 59, river mile 1,265.9) to Rio Grande at El Paso (site 69, river mile 1,249.9) (figs. 1 and 2; table 1).

Gains or losses in the river can result from seepage to or from the streambed, bank storage, or evaporation from the water surface. Releases from Caballo Reservoir were maintained at a constant rate during the study to minimize gains or losses from bank storage (Jay Powell, Bureau of Reclamation, oral commun., May 24, 2012).

Measurement of Surface-Water Discharge

Discharge measurements at the sites during the seepage investigation were derived from field discharge measurements following standard USGS protocols (Rantz and others, 1982; Kilpatrick and Schneider, 1983; Nolan and Shields, 2000; Oberg and others, 2005; Turnipseed and Sauer, 2010) and from reported values from wastewater treatment plants. Surface-water depth and velocity were determined primarily through the use of an acoustic Doppler current profiler (ADCP) or an acoustic Doppler velocimeter (ADV) depending on site characteristics. The ADCP provides a continuous series of data throughout the cross section of a channel, whereas the ADV measures point velocities at 25–30 vertical sections that subdivide the channel such that no section contains more than 5 percent of the total cross-sectional discharge (Oberg and others, 2005). Discharge measurements were assigned a qualitative measurement uncertainty on the basis of field assessment of flow and measurement conditions of excellent (less than or equal to 2 percent), good (less than or equal to 5 percent), fair (less than or equal to 8 percent), or poor (greater than 8 percent) (Turnipseed and Sauer, 2010).

Multiple instantaneous discharge measurements were made at river sites 1, 22, 41, 59, and 69 (table 2) throughout the duration of the investigation to monitor stability of flow within the Rio Grande. Average values for each day and reach were computed and used to calculate gain or loss within the respective reach.

Effluent from wastewater treatment plants that discharged to the Rio Grande was reported as the daily mean discharge computed from the total discharge for the day metered by the plant (reported-MDI) (table 2). Discharge data for all effluent sites are designated as “reported-MDI” with an uncertainty in measurement greater than or equal to 8 percent, with the exception of site 10, which had no discharge during this investigation.

Specific conductance and water temperature were measured at all sites with multiparameter water-quality meters calibrated according to standard USGS protocols (Wilde and Radtke, variously dated) and are reported in table 2. Water temperature at site 69 was averaged for four measurements, each consisting of six cross-sectional transits of the channel (table 2). Specific conductance at site 69 was averaged for five measurements, each consisting of six cross-sectional transits of the channel. Water quality parameters were collected to verify field conditions to enable ADCPs and ADVs to compute the speed of sound correctly to accurately measure velocities, depths, and compute discharge (Rantz and others, 1982).

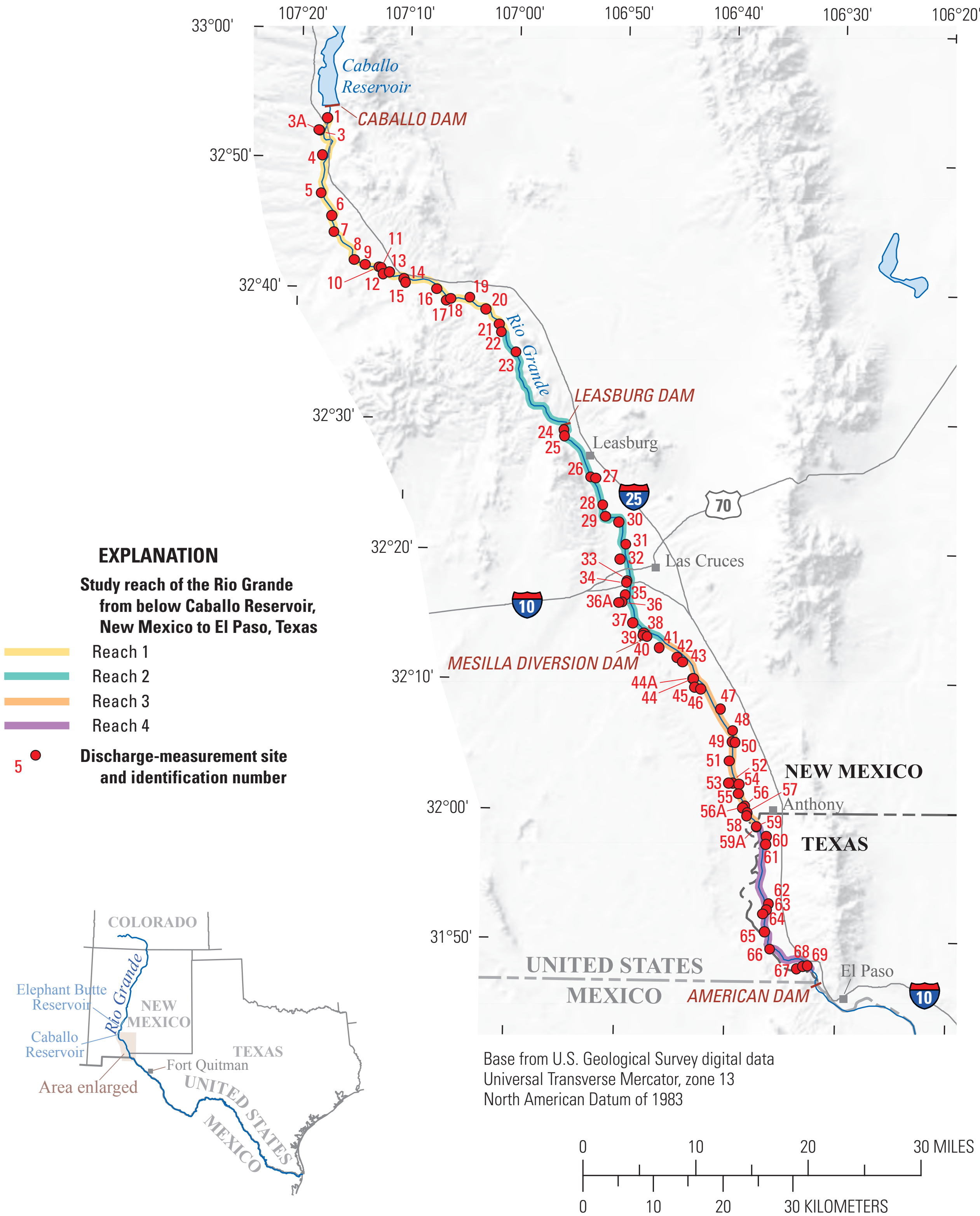

Figure 1. Locations of U.S. Geological Survey Rio Grande discharge-measurement sites from below Caballo Reservoir, New Mexico, to El Paso, Texas, June 26–28, 2012.

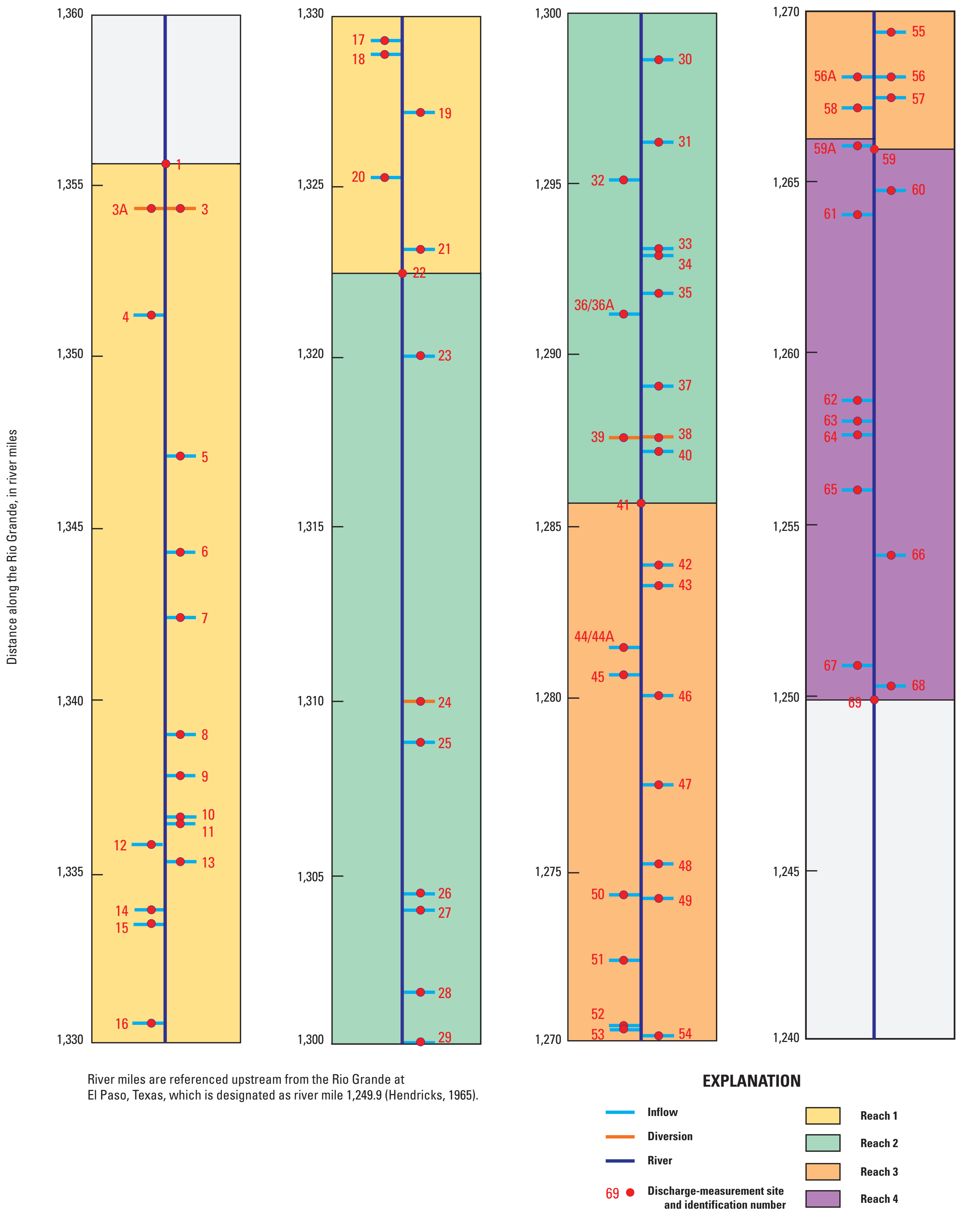

Figure 2. Locations of U.S. Geological Survey Rio Grande discharge-measurement sites from below Caballo Reservoir, New Mexico, to El Paso, Texas, June 26–28, 2012, and the relation of diversions, drains, and inflows to the river channel along the study reach.

Table 1. Locations of U.S. Geological Survey Rio Grande discharge-measurement sites from below Caballo Reservoir, New Mexico, to El Paso, Texas, June 26–28, 2012.

[ID, identification number; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; WW, wasteway]

Site ID	USGS station ID	Station name	Latitude (NAD 83)	Longitude (NAD 83)	River mile[1]
1	8362500	Rio Grande below Caballo Dam	32.88492	-107.29269	1,355.6
3	325205107181110	Percha Lateral Diversion	32.86811	-107.30308	1,354.5
3A	325208107181810	Arrey Canal Diversion	32.86900	-107.30514	1,354.3
4	325011107175710	Trujillo Lateral WW	32.83636	-107.29906	1,351.2
5	324714107175610	Vega Lateral WW 3B	32.78722	-107.29889	1,347.1
6	324531107165810	Gonzales Lateral WW 3	32.75858	-107.28269	1,344.3
7	324416107164310	Palmer Lateral WW 4	32.73778	-107.27853	1,342.4
8	324208107144910	Garfield/Hatch Canal WW 5	32.70222	-107.24700	1,339.0
9	324147107134910	WW6A	32.69631	-107.23033	1,337.8
10	324137107123310	Dona Anna Sewage Outfall	32.69369	-107.20906	1,336.6
11	324133107122010	Unnamed WW	32.69253	-107.20558	1,336.4
12	324106107120810	Unnamed WW (A)	32.68503	-107.20222	1,335.8
13	324115107113710	Garfield Drain	32.68758	-107.19353	1,335.3
14	324047107101610	H-2 Lateral	32.67972	-107.17097	1,333.9
15	324028107100310	Hatch Canal WW 13	32.67447	-107.16739	1,333.5
16	324000107071410	Hatch Canal WW 16	32.66678	-107.12053	1,330.6
17	323910107062010	Hatch Drain	32.65275	-107.10542	1,329.3
18	323916107055710	Angostura Lateral WW 14	32.65458	-107.09914	1,328.9
19	323926107040910	WW17	32.65714	-107.06922	1,327.2
20	323832107024210	Angostura Lateral WW 15	32.64225	-107.04492	1,325.3
21	323723107012810	Rincon Canal WW 18	32.62317	-107.02453	1,323.2
22	323649107011410	Rio Grande at Haynor Bridge	32.61344	-107.02053	1,322.5
23	323516106595110	Tonuco Intercepting Drain	32.58769	-106.99764	1,320.1
24	322920106552010	Leasburg Main Canal Diversion	32.48897	-106.92219	1,310.0
25	322850106551510	Leasburg Lateral WW 1	32.48067	-106.92094	1,300.0
26	322541106525210	Selden Drain	32.42800	-106.88097	1,308.8
27	322536106522210	American Bend Lateral WW 2	32.42658	-106.87278	1,304.4
28	322334106514010	Hill Lateral WW 2A	32.39281	-106.86114	1,303.9
29	322241106512810	Picacho WW 3	32.37808	-106.85764	1,301.5
30	322215106501410	Leasburg Lateral WW 5	32.37075	-106.83722	1,298.6
31	322032106493110	Leasburg Extension Lateral WW 8	32.34208	-106.82528	1,296.2
32	321923106500410	Picacho A Lateral WW 39A	32.32308	-106.83458	1,295.1
33	321744106492310	Mesilla Lateral WW 11	32.29567	-106.82294	1,293.1
34	321736106492410	City of Las Cruces Wastwater	32.29325	-106.82328	1,292.9
35	321639106493010	WW12	32.27750	-106.82508	1,291.8
36	321605106494710	Picacho Lateral WW 40	32.26814	-106.82978	1,291.2
36A	321603106500610	Picacho Drain	32.26747	-106.83497	1,291.2
37	321431106484710	California Lateral WW 13	32.24183	-106.81294	1,289.1
38	321342106474610	Eastside Canal at Diversion	32.22842	-106.79617	1,287.6
39	321332106474910	Westside Canal at Diversion	32.22564	-106.79706	1,287.6
40	321327106472610	Del Rio Lateral WW 14A	32.22406	-106.79047	1,287.2
41	321237106462010	Rio Grande below Mesilla Diversion Dam	32.21028	-106.77186	1,285.7

Table 1. Locations of U.S. Geological Survey Rio Grande discharge-measurement sites from below Caballo Reservoir, New Mexico, to El Paso, Texas, June 26–28, 2012.—Continued

[ID, identification number; USGS, U.S. Geological Survey; NAD 83, North American Datum of 1983; WW, wasteway]

Site ID	USGS station ID	Station name	Latitude (NAD 83)	Longitude (NAD 83)	River mile[1]
42	321151106444310	Del Rio Lateral WW 14B	32.19756	-106.74533	1,283.9
43	321132106441310	Eastside Lateral WW 15	32.19219	-106.73703	1,283.3
44	321016106431310	Santo Tomas River Drain	32.17108	-106.72033	1,281.5
44A	321014106431210	Santa Tomas River Lateral WW 25 or 14	32.17069	-106.72014	1,281.5
45	320936106430310	Wasteway 26	32.16014	-106.71761	1,280.7
46	320928106423010	Brazito River Lateral WW 16B	32.15767	-106.70831	1,280.1
47	320757106403910	WW 18	32.13250	-106.67758	1,277.5
48	320615106393310	Del Rio Drain	32.10414	-106.65914	1,275.2
49	320525106393610	Dona Ana County Wastewater	32.09031	-106.65994	1,274.3
50	320523106391710	Three Saints Main Canal WW 19	32.08983	-106.65461	1,274.2
51	320354106395010	Chamberino East Lateral WW 30	32.06511	-106.66397	1,272.4
52	320214106392810	La Mesa Drain	32.03722	-106.65769	1,270.5
53	320215106395110	La Union Main Canal WW 31	32.03739	-106.66406	1,270.4
54	320210106385510	Three Saints West Lateral WW 20	32.03611	-106.64856	1,270.2
55	320122106385610	Anthony Wastewater	32.02289	-106.64878	1,269.3
56	320027106381810	Three Saints West Lateral WW 21	32.00744	-106.63847	1,268.0
56A	320019106383410	Jiminez Lateral WW 31B	32.00519	-106.64281	1,268.0
57	315957106380610	Pipe inflow at NM-225 Bridge	31.99928	-106.63531	1,267.4
58	315942106380810	La Union East Lateral WW 32	31.99508	-106.63561	1,267.1
59	315853106371510	Rio Grande at Anthony-EP no. 1	31.98153	-106.62106	1,265.9
59A	315849106371610	Rowley Lateral	31.98036	-106.62122	1,265.9
60	315808106362010	Texas Lateral WW 23A	31.96897	-106.60556	1,264.7
61	315733106362310	Vinton Cut-off Lateral WW 32B	31.95917	-106.60642	1,264.0
62	315256106360310	Canutillo Lateral WW 34	31.88225	-106.60078	1,258.6
63	315229106361610	Pence Lateral WW 34A	31.87472	-106.60453	1,258.0
64	315208106363410	La Union East Lateral	31.86900	-106.60956	1,257.6
65	315047106362410	Schultz Lateral WW 35C	31.84631	-106.60669	1,256.0
66	314924106355410	Montoya A Lateral WW 36	31.82319	-106.59833	1,254.1
67	314755106332510	Sunland Park Wastewater	31.79867	-106.55703	1,250.9
68	314808106325310	Montoya Drain	31.80233	-106.54800	1,250.3
69	08364000	Rio Grande at El Paso	31.80289	-106.54083	1,249.9

[1]River miles are referenced upstream from the Rio Grande at El Paso, Texas, which is designated as river mile 1,249.9 (Hendricks, 1964).

Table 2. Field measurements and observations, Rio Grande seepage investigation, June 26–28, 2012.

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. °C, degrees Celsius; µS/cm, microsiemens per centimeter; ft³/s, cubic foot per second ; —, not applicable; ADCP, acoustic Doppler current meter; ADV, acoustic Doppler velocimeter; EST, estimate; reported-MDI, instantaneous discharge computed from the reported mean daily total discharge; E, excellent (within 2 percent); G, good (within 5 percent); F, fair (within 8 percent); P, poor (greater than 8 percent); U, unspecified (rated as fair, within 8 percent); LB, left bank; RB, right bank; Av, measurement average]

Site ID	Sample date	Sample time (military)	Water temperature (°C)	Specific conductance at 25 °C (µS/cm)	Instantaneous discharge measurement (ft³/s)	Discharge measurement type	Discharge rating
1	6/26/2012	1037	23.1	—	1,680	ADCP	G
1	6/26/2012	1146	24.1	—	1,670	ADCP	G
1	6/26/2012	1251	24.1	—	1,660	ADCP	G
3	6/26/2012	0900	—	—	—	—	E
3	6/26/2012	1047	—	—	—	—	E
3A	6/26/2012	0921	22.7	—	187	ADCP	G
3A	6/26/2012	1014	—	—	192	ADCP	G
4	6/26/2012	1000	—	—	—	—	E
5	6/26/2012	1015		—	—	—	E
6	6/26/2012	1025	24.5	752	0.08	EST	F
7	6/26/2012	1035	21.8	1,310	0.01	EST	F
8	6/26/2012	1045	24.9	746	0.55	EST	P
9	6/26/2012	1100	—	—	—	—	E
10	6/26/2012	1105	—	—	—	—	E
11	6/26/2012	1113	—	—	—	—	E
12	6/26/2012	1108	—	—	—	—	E
13	6/26/2012	1111	—	—	—	—	E
14	6/26/2012	1117	—	—	—	—	E
15	6/26/2012	1145	25.8	723	4.76	ADV	F
16	6/26/2012	1210	26.2	745	0.10	ADV	F
17	6/26/2012	1221	—	—	—	—	E
18	6/26/2012	1225	—	—	—	—	E
19	6/26/2012	1222	—	—	—	—	E
20	6/26/2012	1230	—	—	—	—	E
21	6/26/2012	1224	—	—	0.25	EST	P
22	6/26/2012	0951	24.0	738	1,420	ADCP	G
22	6/26/2012	1059	24.3	732	1,410	ADCP	G
22	6/26/2012	1142	—	—	1,420	ADCP	G
22	6/26/2012	1209	24.8	735	1,410	ADCP	G
22	6/26/2012	1301	—	—	1,430	ADCP	G
22	6/27/2012	0859	23.4	738	1,390	ADCP	F
22	6/27/2012	0944	23.5	735	1,420	ADCP	G
22	6/27/2012	1027	23.8	721	1,390	ADCP	G
22	6/27/2012	1115	24.1	732	1,390	ADCP	G
22	6/27/2012	1208	24.4	731	1,420	ADCP	G
22	6/27/2012	1251	24.7	731	1,400	ADCP	G
22	6/27/2012	1328	25.1	726	1,400	ADCP	G
22	6/27/2012	1402	25.3	726	1,400	ADCP	G

Table 2. Field measurements and observations, Rio Grande seepage investigation, June 26–28, 2012.—Continued

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. °C, degrees Celsius; µS/cm, microsiemens per centimeter; ft^3/s, cubic foot per second ; —, not applicable; ADCP, acoustic Doppler current meter; ADV, acoustic Doppler velocimeter; EST, estimate; reported-MDI, instantaneous discharge computed from the reported mean daily total discharge; E, excellent (within 2 percent); G, good (within 5 percent); F, fair (within 8 percent); P, poor (greater than 8 percent); U, unspecified (rated as fair, within 8 percent); LB, left bank; RB, right bank; Av, measurement average]

Site ID	Sample date	Sample time (military)	Water temperature (°C)	Specific conductance at 25 °C (µS/cm)	Instantaneous discharge measurement (ft^3/s)	Discharge measurement type	Discharge rating
22	6/27/2012	1440	25.6	729	1,400	ADCP	G
22	6/27/2012	1512	25.8	731	1,410	ADCP	G
22	6/27/2012	1550	26.1	732	1,410	ADCP	G
22	6/27/2012	1632	26.3	734	1,390	ADCP	G
23	6/27/2012	0900	19.1	1,933	2.46	EST	P
24	6/27/2012	1135	24.9	730	193	ADCP	G
25	6/27/2012	1128	—	—	—	—	E
26	6/27/2012	1222	—	—	—	—	P
27	6/27/2012	1230	—	—	—	—	E
28	6/27/2012	1240	28.2	701	0.34	EST	F
29	6/27/2012	1128	25.0	744	4.64	ADV	P
30	6/27/2012	1320	—	—	—	—	E
31	6/27/2012	1333	27.0	753	1.36	ADV	P
32	6/27/2012	1400	—	—	—	—	E
33	6/27/2012	1405	—	—	—	—	E
34	6/27/2012	1410	28.7	1,305	7.00	EST	P
35	6/27/2012	1420	27.8	750	0.25	EST	P
36	6/27/2012	1431	26.6	1,033	5.32	ADV	F
36A	6/27/2012	1510	—	—	—	—	E
37	6/27/2012	1242	—	—	—	—	E
38	6/27/2012	1317	27.0	—	172	ADCP	G
39	6/27/2012	1624	28.7	732	437	ADCP	G
40	6/28/2012	0957	—	—	—	—	E
41	6/27/2012	1027	24.8	750	364	ADCP	P
41	6/27/2012	1128	25.6	751	408	ADCP	P
41	6/27/2012	1250	26.7	754	404	ADCP	P
41	6/27/2012	1414	28.1	753	366	ADCP	P
41	6/27/2012	1630	28.7	754	382	ADCP	P
41	6/28/2012	0953	24.8	757	353	ADCP	F
41	6/28/2012	1050	25.5	753	351	ADCP	F
41	6/28/2012	1146	26.3	754	354	ADCP	F
41	6/28/2012	1256	27.0	757	352	ADCP	F
41	6/28/2012	1344	27.8	754	361	ADCP	F
41	6/28/2012	1449	28.7	753	334	ADCP	F
41	6/28/2012	1549	29.5	751	334	ADCP	F
41	6/28/2012	1642	29.8	755	318	ADCP	F
42	6/28/2012	1006	—	—	—	EST	E
43	6/28/2012	1010	24.5	776	0.25	EST	P
44	6/28/2012	1023	—	—	—	EST	E
44A	6/28/2012	1022	22.9	728	0.12	EST	P

Site ID	Sample date	Sample time (military)	Water temperature (°C)	Specific conductance at 25 °C (µS/cm)	Instantaneous discharge measurement (ft^3/s)	Discharge measurement type	Discharge rating
45	6/28/2012	1028	25.5	759	0.42	EST	P
46	6/28/2012	1036	25.6	772	1.00	EST	P
47	6/28/2012	1045	26.3	713	0.25	EST	P
48	6/28/2012	1053	—	—	—	—	E
49	6/28/2012	1106	29.1	1,340	6.00	Reported-MDI	P
50	6/28/2012	1120	26.9	775	0.03	EST	P
51	6/28/2012	1115	—	—	—	—	E
52	6/28/2012	1135	—	—	—	—	E
53	6/28/2012	1138	—	—	—	—	E
54	6/28/2012	1145	26.6	782	0.01	EST	P
55	6/28/2012	1150	29.2	2,094	1.50	Reported-MDI	P
56	6/28/2012	1156	—	—	—	—	E
56A	6/28/2012	1210	22.9	769	0.02	EST	P
57	6/28/2012	1132	29.3	66	0.01	EST	P
58	6/28/2012	1013	26.4	745	9.39	ADV	G
59	6/28/2012	1149	27.8	738	395	ADCP	F
59	6/28/2012	1231	28.3	771	394	ADCP	F
59	6/28/2012	1302	29.0	760	397	ADCP	F
59	6/28/2012	1335	29.6	760	385	ADCP	F
59	6/28/2012	1409	30.2	767	393	ADCP	F
59	6/28/2012	1442	30.7	770	396	ADCP	F
59	6/28/2012	1519	31.3	771	392	ADCP	F
59	6/28/2012	1559	31.7	772	399	ADCP	F
59	6/28/2012	1632	31.9	776	405	ADCP	F
59	6/28/2012	1709	32.0	779	413	ADCP	F
59A	6/28/2012	1009	—	—	—	—	E
60	6/28/2012	1201	28.7	725	3.21	ADV	G
61	6/28/2012	1257	—	—	—	—	E
62	6/28/2012	1305	27.4	741	3.66	ADV	G
63	6/28/2012	1315	28.2	742	3.62	ADV	G
64	6/28/2012	1416	26.7	823	11.0	ADV	G
65	6/28/2012	1433	—	—	—	—	E
66	6/28/2012	1445	28.6	789	6.36	ADV	P
67	6/28/2012	1500	—	—	—	—	E
68	6/28/2012	1700	31.2	345	8.88	ADCP	P
69	6/28/2012	1020	25.4 (Av)	822 (Av)	399	ADCP	F
69	6/28/2012	1125	26.3 (Av)	814 (Av)	393	ADCP	F
69	6/28/2012	1203	26.0	875	388	ADCP	F
69	6/28/2012	1232	28.4	873	385	ADCP	F
69	6/28/2012	1334	29.4	781 (Av)	385	ADCP	F
69	6/28/2012	1417	30.0	900	383	ADCP	F
69	6/28/2012	1526	30.5 (Av)	746 (Av)	376	ADCP	F
69	6/28/2012	1619	30.5 (Av)	796 (Av)	370	ADCP	F
69	6/28/2012	1656	30.8	872	370	ADCP	F

Seepage Computation

The mass balance equation used for calculating net seepage gain or loss in a reach is as follows (Simonds and Sinclair, 2002):

$$Q_G = Q_{ds} - Q_{in} - Q_{us} + Q_{out} \tag{1}$$

where

- Q_G is the net seepage gain or loss for a reach, in cubic feet per second;
- Q_{ds} is the discharge measured at the downstream end of the reach, in cubic feet per second;
- Q_{in} is the sum of inflows, in cubic feet per second;
- Q_{us} is the discharge measured at the upstream end of the reach, in cubic feet per second; and
- Q_{out} is the sum of the outflows, in cubic feet per second.

The result is the estimated net flux of water gained or lost from the river for the reach. Positive values indicate a gaining reach, and negative values indicate a losing reach. If Q_{ds} is greater than Q_{us} plus Q_{in} minus Q_{out}, then the algebraic sign of the estimated flux is positive (+), which signifies a gain for that reach. Conversely, if Q_{ds} is less than Q_{us} plus Q_{in} minus Q_{out} (that is, if less discharge was measured at the downstream section of the reach than was measured at the upstream section plus any inflow to that reach and minus any outflows [equation 1]), then the algebraic sign of the estimated flux in equation 1 is negative (-), which signifies a loss.

Estimation of Uncertainty

The percentage of uncertainty for individual discharge measurements was determined by a qualitative evaluation of the measurement uncertainty and a subjective evaluation by the hydrographer considering objective factors that could affect measurement quality (Sauer and Meyer, 1992). These factors include number and distribution of vertical sections where velocity is measured, average velocity, uniformity of flow, regularity and firmness of channel bottom, steadiness of stage and discharge during the measurement, and presence or absence of ice, wind, or debris in the flow that could affect the ability of the current meter to accurately measure the current velocity (Wilberg and Stolp, 2005). If a site had zero flow (dry channel), then the uncertainty for that individual measurement was 0, and the uncertainty for that measurement did not contribute numerically to the cumulative uncertainty estimation for the reach. For purposes of computation, the uncertainty in the measurement of discharge was assigned a numerical value as follows: dry channel, 0 percent; excellent, 2 percent; good, 5 percent; fair, 8 percent; and poor, 10 percent.

The cumulative measurement uncertainty estimation associated with the computed net seepage gain or loss for a reach was determined by the following equation (Wheeler and Eddy-Miller, 2005):

$$\delta Q_G = \left| \sqrt{\left(\pm a_1 \cdot Q_1\right)^2 + \left(\pm a_2 \cdot Q_2\right)^2 \ldots + \left(\pm a_n \cdot Q_n\right)^2} \right| \tag{2}$$

where

- δQ_G is the absolute value of the cumulative measurement uncertainty in the computation of seepage gain or loss, in cubic feet per second;
- $a_1, a_2, \ldots a_n$ is measurement uncertainty, in percent; and
- $Q_1, Q_2, \ldots Q_n$ is the measured discharge, in cubic feet per second.

A gain or loss was determined to be substantial when it exceeded the cumulative uncertainty associated with the net seepage computation.

Net Seepage Gain or Loss and Estimation of Uncertainty

Wilberg and others (2001) developed a technique used to determine if the difference between discharge measured at upstream and downstream sites in a specified reach exceeded the cumulative measurement uncertainty at those sites. Each reach was normalized to the maximum discharge within that reach to allow for comparison between reaches with varying discharges. These computations, as modified from Wilberg and Stolp (2005), are as follows:

$$N_d = \frac{Q_G}{MaxQ_{\left[(Q_{us}+Q_{in}),\,(Q_{ds}+Q_{out})\right]}} \times 100 \tag{3}$$

where

- N_d is the normalized seepage difference, in percent; and
- $MaxQ$ is the maximum discharge measured along a reach as either the downstream discharge plus any outflow or the upstream discharge plus any inflow, in cubic feet per second.

$$N_e = \pm \frac{\delta Q_G}{MaxQ_{\left[(Q_{us}+Q_{in}),\,(Q_{ds}+Q_{out})\right]}} \times 100 \tag{4}$$

where

- N_e is the normalized cumulative uncertainty, in percent.

A computed loss or gain for a reach is considered substantial if the normalized percentage difference (N_d%) was greater than or equal to the normalized percentage uncertainty (N_e%).

Results of Seepage Investigation on the Rio Grande from Below Caballo Reservoir, New Mexico, to El Paso, Texas

The seepage investigation focused on a 106-mile reach of the Rio Grande and included 73 measurement locations from site 1 below Caballo Reservoir, N. Mex., to site 69, the Rio Grande at El Paso streamgage, in Texas (fig. 1; table 1). Releases and diversions were coordinated with the Bureau of Reclamation, Elephant Butte Irrigation District, and El Paso County Water Improvement District No. 1 to provide stable flow conditions during the course of the investigation. Of the 73 measurement locations, a total of 39 sites had measurable discharge (5 river sites, 4 diversions, and 30 inflow sites), with specific conductance and water temperature measured at each site (table 2). The averages of multiple instantaneous discharge measurements at main-stem sites 1, 22, 41, 59, and 69 (table 2) on days of data collection for a specific reach were used for the instantaneous discharge measurement values that are used in the computation of gain and loss.

Reach 1, Rio Grande Below Caballo Reservoir (Site 1) to Rio Grande at Haynor Bridge (Site 22)

Reach 1 consists of 31.1 miles along the Rio Grande from site 1 below Caballo Reservoir to site 22 at Haynor Bridge (fig. 1). Of the 22 measurement locations, a total of 9 sites had measurable discharge (2 river, 1 diversion, and 6 inflow sites; table 3), with specific conductance and water temperature measured at each site (table 2). Zero flow was observed at 1 diversion and 12 inflow sites.

Uncertainty in the measurement of discharge was good at sites 1, 3A, and 22 (table 2). All measured inflow sites were rated fair to poor. The discharge measurement at site 15 was not assigned any measurement uncertainty at the time of collection and was categorized as unspecified; a rating of fair was assigned for the purpose of analysis on the basis of the discharge and channel conditions. Discharge measured on June 26 at site 1 (average of 1,670 cubic feet per second [ft^3/s]) and site 22 (average of 1,420 ft^3/s) indicated stable flow conditions on the basis of variability of multiple measurements at each site (tables 2 and 3). The computed net seepage gain or loss was less than the cumulative uncertainty, indicating that the estimated gain or loss within Reach 1 cannot be considered substantial. The sum of seepage gains and losses within the reach was a loss of 66.8 ft^3/s (table 3).

Reach 2, Rio Grande at Haynor Bridge (Site 22) to Rio Grande Below Mesilla Diversion Dam (Site 41)

Reach 2 consists of 36.8 miles along the Rio Grande and includes sites 22 to 41 beginning at Haynor Bridge and ending below Mesilla Diversion Dam (fig. 1). Of the 21 measurement locations, a total of 12 sites had measurable discharge (2 river, 3 diversion, and 7 inflow sites; table 4), with specific conductance and water temperature measured at each site (table 2). Zero flow was observed at 9 inflow sites.

Uncertainty in the measurement of discharge was good at sites 22, 24, 38, and 39 (table 2). All measured inflow sites were rated fair to poor. Site 28 was not assigned any measurement uncertainty at the time of collection and was categorized as unspecified; site 28 was categorized as fair for the purpose of analysis on the basis of the discharge and channel conditions. Discharge measured on June 27 at site 22 (average of 1,400 ft^3/s) and site 41 (average of 385 ft^3/s) indicated stable flow conditions on the basis of variability of multiple measurements at each site (tables 2 and 4). The computed net seepage gain or loss was greater than the cumulative uncertainty, indicating that seepage losses across the reach were substantial. The sum of seepage gains and losses within the reach was a loss of 234 ft^3/s (table 4).

Reach 3, Rio Grande from Below Mesilla Diversion Dam (Site 41) to Rio Grande at Anthony–EP No. 1 (Site 59)

Reach 3 consists of 19.8 miles along the Rio Grande and includes sites 41 to 59 beginning below Mesilla Diversion Dam and ending at the Rio Grande at Anthony–EP no. 1 (fig. 1). Of the 21 measurement locations, a total of 14 sites had measurable discharge (2 river and 12 inflow sites; table 5), with specific conductance and water temperature measured at each site (table 2). Zero flow conditions were observed at seven inflow sites.

Uncertainty in the measurement of discharge was good at inflow site 58 (table 2). All river sites were rated fair, and the other measured inflow sites were rated poor. Discharge measured on June 28 at site 41 (average of 345 ft^3/s) and site 59 (average of 397 ft^3/s) indicated stable flow conditions on the basis of variability of multiple measurements at each site (tables 2 and 5). The computed net gain or loss was less than the cumulative uncertainty, indicating that the estimated gain or loss in Reach 3 cannot be considered substantial. The sum of seepage gains and losses within the reach was a gain of 33.0 ft^3/s (table 5).

Table 3. Summary of measured discharge and the computed net seepage gain or loss in Reach 1, Rio Grande seepage investigation, June 26, 2012.

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. ft³/s, cubic feet per second; %, percent; Q_{ds}, discharge measured at downstream river site; Q_G, net seepage gain (+) or loss (-). See text for equations and description of cumulative uncertainty computation; N_d%, normalized percentage difference, used to determine the difference between discharge measured at upstream and downstream sites of a given subreach. See text for equations and definitions of terms; N_e%, normalized cumulative uncertainty, in percent, used to determine if a computed gain or loss exceeds errors associated with discharge measurement. See text for equations and definitions of terms; ≥, greater than or equal to; >, greater than; <, less than; Y, yes; N, no; —, not applicable; Av, daily average]

Site ID	River mile	Date	Measurement location	Instantaneous discharge measurement (ft³/s)	Discharge measurement uncertainty (%)	Q_{ds} discharge measurement uncertainty (ft³/s)	Q_G (ft³/s)	Squared % measure error	Cumulative error (+/-) for Q_G (ft³/s)	Normalized percentage difference (N_d%)	Normalized percentage error (N_e%)	N_d% ≥ N_e% (Y or N)
1	1,355.6	6/26/12	River	1,670 (Av)	5	83.5	—	6,972	—	—	—	—
3	1,354.3	6/26/12	Diversion	0	—	—	—	—	—	—	—	—
3A	1,354.3	6/26/12	Diversion	189 (Av)	5	9.45	—	89.3	—	—	—	—
4	1,351.2	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
5	1,347.1	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
6	1,344.3	6/26/12	Inflow	0.08	8	0.01	—	< 0.01	—	—	—	—
7	1,342.4	6/26/12	Inflow	0.01	8	< 0.001	—	< 0.01	—	—	—	—
8	1,339.0	6/26/12	Inflow	0.55	10	0.06	—	< 0.01	—	—	—	—
9	1,337.8	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
10	1,336.6	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
11	1,336.4	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
12	1,335.8	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
13	1,335.3	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
14	1,333.9	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
15	1,333.5	6/26/12	Inflow	4.76	8	0.38	—	0.15	—	—	—	—
16	1,330.6	6/26/12	Inflow	0.10	8	< 0.01	—	< 0.01	—	—	—	—
17	1,329.3	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
18	1,328.9	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
19	1,327.2	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
20	1,325.3	6/26/12	Inflow	0	—	—	—	—	—	—	—	—
21	1,323.2	6/26/12	Inflow	0.25	10	0.03	—	< 0.01	—	—	—	—
22	1,322.5	6/26/12	River	1,420 (Av)	5	71.0	-66.8	5,041	110	-3.98	6.56	N

Table 4. Summary of measured discharge and the computed net seepage gain or loss in Reach 2, Rio Grande seepage investigation, June 27, 2012.

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. ft³/s, cubic feet per second; %, percent; Q_{ds}, discharge measured at downstream river site; Q_G, net seepage gain (+) or loss (-). See text for equations and description of cumulative uncertainty computation; N_d%, normalized percentage difference, used to determine the difference between discharge measured at upstream and downstream sites of a given subreach. See text for equations and definitions of terms; N_e%, normalized cumulative uncertainty, in percent, used to determine if a computed gain or loss exceeds errors associated with discharge measurement. See text for equations and definitions of terms; ≥, greater than or equal to; >, greater than; <, less than; Y, yes; N, no; —, not applicable; Av, daily average]

Site ID	River mile	Date	Measurement location	Instantaneous discharge measurement (ft³/s)	Discharge measurement uncertainty (%)	Q_{ds} discharge measurement uncertainty (ft³/s)	Q_G (ft³/s)	Squared % measure error	Cumulative error (+/-) for Q_G (ft³/s)	Normalized percentage difference (N_d%)	Normalized percentage error (N_e%)	$N_d\% \geq N_e\%$ (Y or N)
22	1,322.5	6/27/12	River	1,400 (Av)	5	70.0	—	4,900	—	—	—	—
23	1,320.1	6/27/12	Inflow	2.46	10	0.25	—	0.06	—	—	—	—
24	1,310.0	6/27/12	Diversion	193	5	9.65	—	93.1	—	—	—	—
25	1,300.0	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
26	1,308.8	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
27	1,304.4	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
28	1,303.9	6/27/12	Inflow	0.34	8	0.03	—	< 0.01	—	—	—	—
29	1,301.5	6/27/12	Inflow	4.64	10	0.46	—	0.22	—	—	—	—
30	1,298.6	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
31	1,296.2	6/27/12	Inflow	1.36	10	0.14	—	0.02	—	—	—	—
32	1,295.1	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
33	1,293.1	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
34	1,292.9	6/27/12	Inflow	7.00	10	0.70	—	0.49	—	—	—	—
35	1,291.8	6/27/12	Inflow	0.25	10	0.03	—	< 0.01	—	—	—	—
36	1,291.2	6/27/12	Inflow	5.32	8	0.43	—	0.18	—	—	—	—
36A	1,291.2	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
37	1,289.1	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
38	1,287.6	6/27/12	Diversion	172	5	8.60	—	74.0	—	—	—	—
39	1,287.6	6/27/12	Diversion	437	5	21.9	—	477	—	—	—	—
40	1,287.2	6/27/12	Inflow	0	—	—	—	—	—	—	—	—
41	1,285.7	6/27/12	River	385 (Av)	10	38.5	-234	1,482	83.8	-16.5	5.90	Y

Table 5. Summary of measured discharge and the computed net seepage gain or loss in Reach 3, Rio Grande seepage investigation, June 28, 2012.

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. ft³/s, cubic feet per second; %, percent; Q_{ds}, discharge measured at downstream river site; Q_G, net seepage gain (+) or loss (-). See text for equations and description of cumulative uncertainty computation; N_d%, normalized percentage difference, used to determine the difference between discharge measured at upstream and downstream sites of a given subreach. See text for equations and definitions of terms; N_e%, normalized cumulative uncertainty, in percent, used to determine if a computed gain or loss exceeds errors associated with discharge measurement. See text for equations and definitions of terms; ≥, greater than or equal to; >, greater than; <, less than; Y, yes; N, no; —, not applicable; Av, daily average]

Site ID	River mile	Date	Measurement location	Instantaneous discharge measurement (ft³/s)	Discharge measurement uncertainty (%)	Q_{ds} discharge measurement uncertainty (ft³/s)	Q_G (ft³/s)	Squared % measure error	Cumulative error (+/-) for Q_G (ft³/s)	Normalized percentage difference (N_d%)	Normalized percentage error (N_e%)	$N_d\% \geq N_e\%$ (Y or N)
41	1,285.7	6/28/12	River	345 (Av)	8	27.6	—	762	—	—	—	—
42	1,283.9	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
43	1,283.3	6/28/12	Inflow	0.25	10	0.03	—	< 0.01	—	—	—	—
44	1,281.5	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
44A	1,281.5	6/28/12	Inflow	0.12	10	0.01	—	< 0.01	—	—	—	—
45	1,280.7	6/28/12	Inflow	0.42	10	0.04	—	< 0.01	—	—	—	—
46	1,280.1	6/28/12	Inflow	1.00	10	0.10	—	0.01	—	—	—	—
47	1,277.5	6/28/12	Inflow	0.25	10	0.03	—	< 0.01	—	—	—	—
48	1,275.2	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
49	1,274.3	6/28/12	Inflow	6.00	10	0.60	—	0.36	—	—	—	—
50	1,274.2	6/28/12	Inflow	0.03	10	< 0.01	—	< 0.01	—	—	—	—
51	1,272.4	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
52	1,270.5	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
53	1,270.4	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
54	1,270.2	6/28/12	Inflow	0.01	10	< 0.01	—	< 0.01	—	—	—	—
55	1,269.3	6/28/12	Inflow	1.50	10	0.15	—	0.02	—	—	—	—
56	1,268.0	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
56A	1,268.0	6/28/12	Inflow	0.02	10	< 0.01	—	< 0.01	—	—	—	—
57	1,267.4	6/28/12	Inflow	0.01	10	< 0.01	—	< 0.01	—	—	—	—
58	1,267.1	6/28/12	Inflow	9.39	5	0.47	—	0.22	—	—	—	—
59	1,265.9	6/28/12	River	397 (Av)	8	31.8	33.0	1,009	42.1	8.31	10.6	N

Reach 4, Rio Grande at Anthony–EP No. 1 (Site 59) to Rio Grande at El Paso (Site 69)

Reach 4 consists of 16.0 miles along the Rio Grande and includes sites 59 to 69 beginning at the Rio Grande at Anthony–EP no. 1 and ending at the Rio Grande at El Paso (fig. 1). Of the 12 measurement locations, a total of 8 sites had measurable discharge (2 river and 6 inflow sites; table 6), with specific conductance and water temperature measured at each site (table 2). Zero flow conditions were observed at four inflow sites.

Uncertainty in the measurement of discharge was good at sites 60, 62, 63, and 64 (table 2). All river sites were rated fair, and measured inflow sites were rated good or poor. Discharge measured on June 28 at site 59 (average of 397 ft^3/s) and site 69 (average of 383 ft^3/s) indicated stable flow conditions on the basis of variability of multiple measurements at each site (table 6). The computed net seepage gain or loss was greater than the cumulative uncertainty, indicating that losses occurred across the reach and were substantial compared to the uncertainties associated with measuring streamflow. The sum of gains and losses within the reach was a loss of 50.7 ft^3/s (table 6).

Table 6. Summary of measured discharge and the computed net seepage gain or loss in Reach 4, Rio Grande seepage investigation, June 28, 2012.

[ID, identification number; site ID: see table 1 and figures 1 and 2 for location of sites. ft³/s, cubic feet per second; %, percent; Q_{ds}, discharge measured at downstream river site; Q_G, net seepage gain (+) or loss (-). See text for equations and description of cumulative uncertainty computation; N_d%, normalized percentage difference, used to determine the difference between discharge measured at upstream and downstream sites of a given subreach. See text for equations and definitions of terms; N_e%, normalized cumulative uncertainty, in percent, used to determine if a computed gain or loss exceeds errors associated with discharge measurement. See text for equations and definitions of terms; ≥, greater than or equal to; >, greater than; <, less than; Y, yes; N, no; —, not applicable; Av, daily average]

Site ID	River mile	Date	Measurement location	Instantaneous discharge measurement (ft³/s)	Discharge measurement uncertainty (%)	Q_{ds} discharge measurement uncertainty (ft³/s)	Q_G (ft³/s)	Squared % measure error	Cumulative error (+/-) for Q_G (ft³/s)	Normalized percentage difference (N_d%)	Normalized percentage error (N_e%)	$N_d\% \geq N_e\%$ (Y or N)
59	1,265.9	6/28/12	River	397 (Av)	8	31.8	—	1,009	—	—	—	—
59A	1,265.9	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
60	1,264.7	6/28/12	Inflow	3.21	5	0.16	—	0.03	—	—	—	—
61	1,264.0	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
62	1,258.6	6/28/12	Inflow	3.66	5	0.18	—	0.03	—	—	—	—
63	1,258.0	6/28/12	Inflow	3.62	5	0.18	—	0.03	—	—	—	—
64	1,257.6	6/28/12	Inflow	11.0	5	0.55	—	0.30	—	—	—	—
65	1,256.0	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
66	1,254.1	6/28/12	Inflow	6.36	10	0.64	—	0.40	—	—	—	—
67	1,250.9	6/28/12	Inflow	0	—	—	—	—	—	—	—	—
68	1,250.3	6/28/12	Inflow	8.88	10	0.89	—	0.79	—	—	—	—
69	1,249.9	6/28/12	River	383 (Av)	8	30.6	-50.7	939	44.1	-11.7	10.2	Y

Summary

A seepage investigation was conducted in 2012 on the Rio Grande from below Caballo Reservoir, New Mexico, to El Paso, Texas, by the U.S. Geological Survey, in cooperation with the New Mexico Interstate Stream Commission. A total of 73 sites including river channel, diversions, and inflows associated with irrigation systems were selected for four reaches on the Rio Grande. The most upstream site was located immediately below Caballo Reservoir, and the most downstream site was located at the U.S. Geological Survey streamgage Rio Grande at El Paso.

Discharge was measured at 40 of the 73 sites during June 26–28, 2012, during the irrigation season at high flow. Cumulative gains or losses, which include estimated seepage gains or losses, were calculated for each of the four reaches by using the instantaneous discharge values for each site. Reach 1 had a calculated loss of 66.8 cubic feet per second (ft^3/s) that was less than the estimated measurement uncertainty. Reach 2 had a calculated loss of 234 ft^3/s that was greater than the estimated measurement uncertainty. Reach 3 had a calculated gain of 33.0 ft^3/s that was less than the estimated measurement uncertainty. Reach 4 had a calculated loss of 50.7 ft^3/s that was greater than the estimated measurement uncertainty.

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