science for a changing world

# Seepage Investigation of the Rio Grande From Below Leasburg Dam, Leasburg, New Mexico, to Above American Dam, El Paso, Texas, 2014

Scientific Investigations Report 2016–5010

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

**Cover,** South-oriented view of the Rio Grande near Radium Springs, New Mexico, February 4, 2014 (photograph by Andrew J. Robertson).

# Seepage Investigation of the Rio Grande From Below Leasburg Dam, Leasburg, New Mexico, to Above American Dam, El Paso, Texas, 2014

By Alyse C. Briody, Andrew J. Robertson, and Nicole Thomas

Scientific Investigations Report 2016–5010

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

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

**U.S. Geological Survey**
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod/.



Suggested citation:
Briody, A.C., Robertson, A.J., and Thomas, Nicole, 2016, Seepage investigation of the Rio Grande from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2014: U.S. Geological Survey Scientific Investigations Report 2016–5010, 15 p., http://dx.doi.org/10.3133/sir20165010.

ISSN 2328-0328 (online)

# Acknowledgments

The authors gratefully acknowledge the Bureau of Reclamation, New Mexico Environment Department, New Mexico Office of the State Engineer, Las Cruces Utilities (LCU), New Mexico Interstate Stream Commission, International Boundary and Water Commission–U.S. Section, and New Mexico State University for their cooperation and continued support of this project.

# Contents



# Figures



# Tables

# Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| mile (mi) | 1.609 | kilometer (km) |
| | Flow rate | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |

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

°F=(1.8×°C)+32.

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

°C=(°F-32)/1.8.

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

# Seepage Investigation of the Rio Grande From Below Leasburg Dam, Leasburg, New Mexico, to Above American Dam, El Paso, Texas, 2014

By Alyse C. Briody, Andrew J. Robertson, and Nicole Thomas

## Abstract

Seepage investigations have been conducted annually by the U.S. Geological Survey from 1988 to 1998 and from 2004 to the present (2014) along a 64-mile reach of the Rio Grande from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, as part of the Mesilla Basin monitoring program. Results of the investigation conducted in 2014 are presented in this report. The 2014 seepage investigation was conducted on February 11, 2014, during the low-flow conditions of the non-irrigation season. During the 2014 investigation, discharge was measured at 23 sites along the main-stem Rio Grande and 19 inflow sites within the study reach. Because of extended drought conditions affecting the basin, many sites along the Rio Grande (17 main-stem and 9 inflow) were observed to be dry in February 2014. Water-quality samples were collected during the seepage investigation at sites with flowing water as part of a long-term monitoring effort in the region.

Net seepage gain or loss was computed for each subreach (the interval between two adjacent measurement locations along the river) by subtracting the discharge measured at the upstream location from the discharge measured at the closest downstream location along the river and then subtracting any inflow to the river within the subreach. An estimated gain or loss was determined to be meaningful when it exceeded the cumulative measurement uncertainty associated with the net seepage computation. The cumulative seepage loss in the 64-mile study reach in 2014 was 16.0 plus or minus 2.9 cubic feet per second.

## Introduction

Increasing water demand, as well as multiyear drought conditions (National Drought Mitigation Center, 2014) within the Mesilla Basin and adjacent areas (fig. 1), has resulted in diminished surface-water supplies and increased groundwater withdrawals in the basin. In 1987, the U.S. Geological Survey (USGS) established the Mesilla Basin monitoring program (http://nm.water.usgs.gov/projects/mesilla) in cooperation with several Federal, State, and local agencies to document and identify trends in groundwater conditions and stream/aquifer relations. The monitoring program has continued through the present (2014) in cooperation with a variety of entities with an interest in the Mesilla Basin. Cooperating agencies include the Bureau of Reclamation, New Mexico Environment Department, New Mexico Office of the State Engineer, Las Cruces Utilities (LCU), New Mexico Interstate Stream Commission, International Boundary and Water Commission–U.S. Section, and New Mexico State University.

Seepage investigations on the Rio Grande from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, have been a component of the Mesilla Basin monitoring program since 1988. Seepage gain or loss is the slow interstitial movement of water into or out of a body of surface or subsurface water (U.S. Geological Survey, 2013). Information on seepage gains or losses in the Rio Grande is important to water managers in the Mesilla Basin, where multiple water users rely on surface water and groundwater in a highly interconnected hydrogeologic basin (Moyer and others, 2013). Results of seepage investigations on the Rio Grande conducted annually by the USGS from 1988 to 1998 and from 2004 to 2005 as part of the Mesilla Basin monitoring program were published in USGS annual water-data reports (available at http://nm.water.usgs.gov/publications/pubswdr.html). The results of seepage investigations from 2006 to 2013 are published in Crilley and others (2013). Study design and methods presented in this report follow those in Crilley and others (2013).

### Purpose and Scope

This report describes the methods used to obtain discharge measurements and presents the results of the seepage investigation conducted along the Rio Grande from below Leasburg Dam, Leasburg, N. Mex., to above American Dam, El Paso, Tex. (hereafter referred to as the “study reach”), during February 2014. Discharge was measured at 23 river sites and 19 inflow sites, and net seepage gain to or

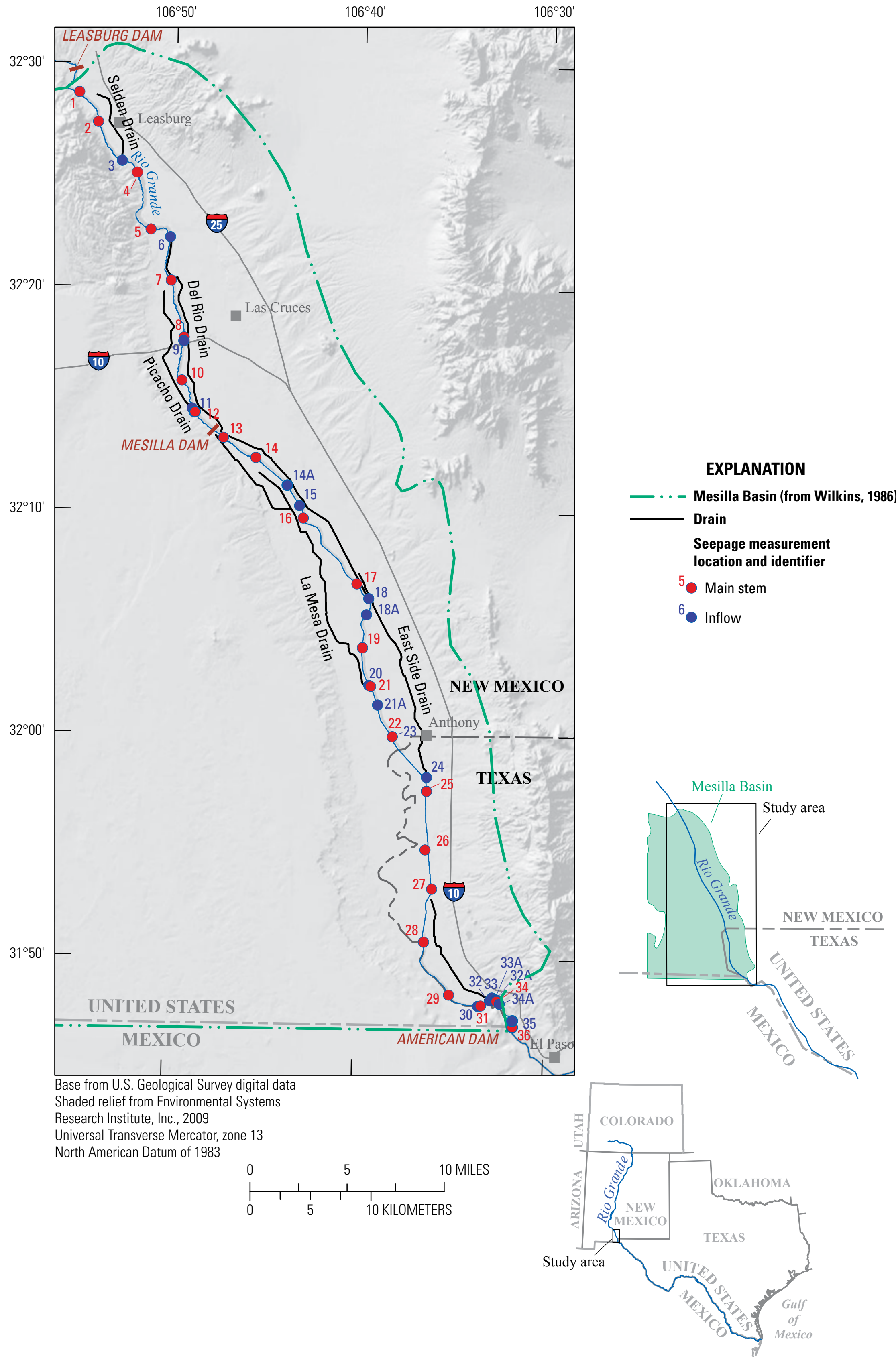



**Figure 1.** Location of U.S. Geological Survey Rio Grande seepage investigation measurements from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2014.

loss from the river was computed on the basis of discharge measurements for 22 subreaches within the study reach. Select field measurements and observations recorded at measurement locations are compiled in appendix 1, along with associated water temperature, specific conductance, dissolved oxygen, pH, discharge measurement, discharge-measurement type, discharge accuracy rating, and remarks on streamflow and channel conditions.

## Description of Study Reach and Measurement Locations

The study reach is a 64-mile section of the Rio Grande from below Leasburg Dam, Leasburg, N. Mex., to above American Dam, El Paso, Tex. (fig. 1). Measurement locations followed those established in previous seepage investigations (1988–98 and 2004–13) (table 1), with modifications to accommodate site-specific conditions. Sites included locations along the river and at points of inflow to the river (figs. 1 and 2, table 1); points of outflow from the river were not included because no diversions occurred within the study reach during the 2014 seepage investigation. River miles are referenced upstream from the Rio Grande confluence with the Gulf of Mexico; for example, site 34, Rio Grande at El Paso, Tex., is designated as river mile 1,249.9 (Hendricks, 1964) (fig. 2, table 1).

Inflows to the river included municipal and industrial discharge of effluent, agricultural drains, water from reservoirs, and discharge of water from other sources. Outfall from wastewater treatment plants (WWTPs) discharged to the river at five locations (sites 9, 18A, 21A, 30, and 35) (table 1). Drains, which collect groundwater return flow at locations where the water table is at a higher elevation than the bottom of the river channel, discharged to the river at seven locations (sites 3, 11, 15, 18, 20, 24, and 32) (table 1). Water from Keystone Reservoir, El Paso, Tex., entered the river at one location (site 33) (table 1). Inflows from other sources included stormwater inflows, unspecified pipe inflows, and other sources within the study reach (sites 6, 14A, 23, 32A, 33A, and 34A) (table 1).

# Methods

From 1988 to 1998 and 2004 to present (2014), seepage investigations were conducted over a period of 1–2 days in February of each year, during low-flow conditions in the non-irrigation season (Crilley and others, 2013). During each seepage investigation, discharge was measured at sites along the river and at locations where inflows to the river occurred. Although outflows from the river were not observed during previous or current seepage investigations, the outflow term is retained in the presentation of seepage computation equations for completeness of discussion. Measurement locations have remained fairly consistent from year to year (table 1), with minor site additions or removals based on conditions observed in the field. Discharge measurements were collected over an approximate 7-hour period beginning at about 9 a.m. and ending about 4 p.m. Net seepage gain or loss was computed for each subreach by subtracting the discharge measured at the upstream location from the discharge measured at the closest downstream location along the river and then subtracting any inflow to the river within the subreach (a subreach is defined as the interval between two adjacent measurement locations along the river). Inflows to the river were considered discrete contributions to flow and not seepage gains. Seepage gain or loss was considered to be meaningful for subreaches where the computed net seepage gain or loss exceeded the cumulative measurement uncertainty for the computation (see section “Seepage Computation”).

Gains or losses in discharge can result from seepage in the streambed or from bank storage, evaporation from the water surface, and transpiration by vegetation along the river banks. Streamflow in this reach of the Rio Grande is largely controlled by irrigation releases from Elephant Butte Dam, located on the Rio Grande about 70 miles upstream from Leasburg, N. Mex. (Moyer and others, 2013), and irrigation releases generally occur during the irrigation season of March through October of each year. Streamflow in this reach of the Rio Grande during the non-irrigation season is low and steady relative to streamflow during the irrigation season (U.S. Geological Survey, 2014), and contributions to streamflow from bank storage are considered minimal. Average air temperature during the 2014 seepage investigation was 47.5 degrees Fahrenheit (National Climatic Data Center, 2014). The seepage investigation was conducted during February, when losses to evaporation from the water surface and transpiration by vegetation are considered minimal relative to summer losses. The effects of bank storage, evaporation, and transpiration on streamflow at this time of year are considered minimal. For the seepage investigation presented in this report, computed gains or losses in discharge, therefore, are assumed to be caused by seepage to or from the streambed resulting from the interchange of surface water and groundwater.

## Data Collection

Data collected during the 2014 seepage investigation included surface-water discharge measurements and water-quality samples. The surface-water discharge measurements are used to compute seepage for subreaches and the cumulative 64-mile study reach. Water-quality field measurements are presented in appendix 1, and laboratory analyses of water-quality samples can be accessed through the USGS National Water Information System (NWIS database) at http://qwwebservices.usgs.gov/.

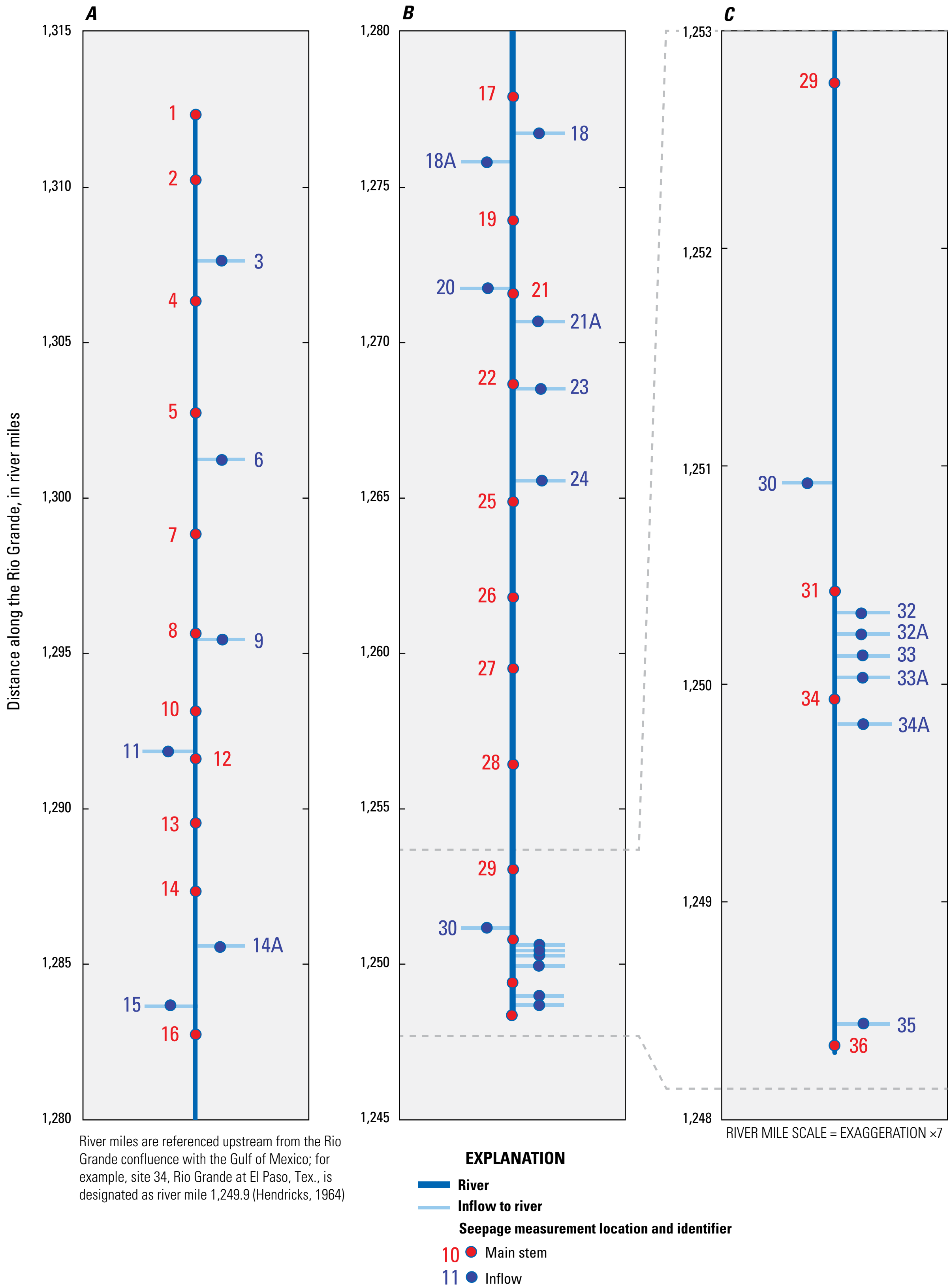



**Figure 2.** Location of U.S. Geological Survey Rio Grande seepage investigation measurements from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2014, and the location of inflows to the river within the study reach. *A*, Location of measurement sites 1–16. *B*, Location of measurement sites 17–36. *C*, Expanded view of the location of measurement sites 29–36.

**Table 1.** Location of U.S. Geological Survey Rio Grande seepage investigation measurements from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2014.

[ID, identifier; USGS, U.S. Geological Survey; NAD 27, North American Datum of 1927; NM, New Mexico; WWTP, wastewater treatment plant; TX, Texas]

| Site ID (see fig. 1) | USGS station ID | Station name | Latitude (NAD 27) | Longitude (NAD 27) | River mile | Years of site inclusion in seepage investigation during 2006–14 |
|---|---|---|---|---|---|---|
| 1 | 322841106551010 | Rio Grande below Leasburg Dam, NM | 32.4769 | -106.9197 | 1,312.3 | 2006–09, 2012–14 |
| 2 | 322721106540810 | Rio Grande near Leasburg, NM | 32.4544 | -106.9017 | 1,310.2 | 2006–09, 2012–14 |
| 3 | 322541106525110 | Selden Drain at Levee Road near Leasburg, NM | 32.4281 | -106.8814 | 1,307.6 | 2006–09, 2012–14 |
| 4 | 322505106520110 | Rio Grande near Hill, NM | 32.4186 | -106.8672 | 1,306.3 | 2006–09, 2012–14 |
| 5 | 322234106511710 | Rio Grande at Shalem Bridge near Dona Ana, NM | 32.3762 | -106.8553 | 1,302.7 | 2006–09, 2012–14 |
| 6 | 322214106501410 | Spillway Number 5 near Dona Ana, NM | 32.3703 | -106.8381 | 1,301.2 | 2006–09, 2012–14 |
| 7 | 322018106500910 | Rio Grande near Picacho, NM | 32.3383 | -106.8367 | 1,298.8 | 2006–09, 2012–14 |
| 8 | 321745106492510 | Rio Grande below Picacho Bridge near Las Cruces, NM | 32.2964 | -106.8242 | 1,295.6 | 2006–09, 2012–14 |
| 9 | 321735106492610 | Las Cruces WWTP Outfall, Las Cruces, NM | 32.2928 | -106.8247 | 1,295.4 | 2006–09, 2012–14 |
| 10 | 321549106492910 | Rio Grande at NM-359 Bridge near Mesilla, NM | 32.2637 | -106.8253 | 1,293.1 | 2006–09, 2012–14 |
| 11 | 321434106485610 | Picacho Drain above Mesilla Dam, NM | 32.2422 | -106.8153 | 1,291.8 | 2006–09, 2012–14 |
| 12 | 321430106484910 | Rio Grande below Picacho Drain, NM | 32.2419 | -106.8142 | 1,291.7 | 2006–09, 2012–14 |
| 13 | 321317106471510 | Rio Grande below Mesilla Dam near Santo Tomas, NM | 32.2211 | -106.7886 | 1,289.5 | 2006–09, 2012–14 |
| 14 | 321224106453210 | Rio Grande at NM-28 Bridge near San Pablo, NM | 32.2067 | -106.7597 | 1,287.3 | 2006–09, 2012–14 |
| 14A | 321131106441410 | Wasteway below NM-28 | 32.1919 | -106.7372 | 1,287.3 | 2014 |
| 15 | 321014106431410 | Santo Tomas River Drain at Levee Road near San Miguel, NM | 32.1707 | -106.7211 | 1,283.6 | 2006–09, 2012–14 |
| 16 | 320943106425810 | Rio Grande NM-192 Bridge near San Miguel, NM | 32.1620 | -106.7167 | 1,282.7 | 2006–09, 2012–14 |
| 17 | 320648106400510 | Rio Grande at NM-189 Bridge near Vado, NM | 32.1136 | -106.6689 | 1,277.8 | 2006–09, 2012–14 |
| 18 | 320610106393110 | Del Rio Drain at Levee Road near Vado, NM | 32.1029 | -106.6592 | 1,276.6 | 2006–09, 2012–14 |
| 18A | 320525106393410 | Dona Ana Co South Central WWTP Outfall near Vado, NM | 32.0903 | -106.6600 | 1,275.7 | 2006–09, 2012–14 |
| 19 | 320356106394510 | Rio Grande at NM-226 Bridge near Berino, NM | 32.0656 | -106.6633 | 1,273.8 | 2006–09, 2012–14 |
| 20 | 320214106392510 | La Mesa Drain at Levee Road near Chamberino, NM | 32.0373 | -106.6575 | 1,271.6 | 2006–09, 2012–14 |
| 21 | 320212106391810 | Rio Grande below La Mesa Drain near Chamberino, NM | 32.0369 | -106.6561 | 1,271.5 | 2006–09, 2012–14 |
| 21A | 320122106385610 | Anthony WWTP Outfall at NM-186 Bridge near Anthony, NM | 32.0228 | -106.6489 | 1,270.5 | 2009, 2012–14 |
| 22 | 315958106380710 | Rio Grande at NM-225 Bridge near Anthony, NM | 31.9994 | -106.6361 | 1,268.5 | 2006–14 |
| 23 | 315957106380610 | Pipe Inflow at NM-225 Bridge near Anthony, NM | 31.9992 | -106.6353 | 1,268.4 | 2006–14 |
| 24 | 315807106361910 | East Side Drain at Levee Road near Anthony, TX | 31.9687 | -106.6058 | 1,265.4 | 2006–14 |
| 25 | 315733106361610 | Rio Grande at Vinton Bridge near Vinton, TX | 31.9594 | -106.6050 | 1,264.7 | 2006–14 |
| 26 | 315454106360610 | Rio Grande at TX-259 Bridge, Canutillo, TX | 31.9153 | -106.6022 | 1,261.6 | 2006–14 |
| 27 | 315309106355510 | Rio Grande at Borderland Bridge near Borderland, TX | 31.8861 | -106.5989 | 1,259.3 | 2006–14 |

**Table 1.** Location of U.S. Geological Survey Rio Grande seepage investigation measurements from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2014.—Continued

[ID, identifier; USGS, U.S. Geological Survey; NAD 27, North American Datum of 1927; NM, New Mexico; WWTP, wastewater treatment plant; TX, Texas]

| Site ID (see fig. 1) | USGS station ID | Station name | Latitude (NAD 27) | Longitude (NAD 27) | River mile | Years of site inclusion in seepage investigation during 2006–14 |
|---|---|---|---|---|---|---|
| 28 | 315046106361810 | Rio Grande at TX-260 Bridge near Santa Teresa, NM | 31.8464 | -106.6058 | 1,256.2 | 2006−14 |
| 29 | 314824106345710 | Rio Grande near Sunland Park, NM | 31.8067 | -106.5828 | 1,252.8 | 2006−14 |
| 30 | 314755106332510 | Sunland Park WWTP Outfall, Sunland Park, NM | 31.7986 | -106.5575 | 1,250.9 | 2006−14 |
| 31 | 314756106331610 | Rio Grande at Sunland Park Bridge, Sunland Park, NM | 31.7989 | -106.5550 | 1,250.3 | 2006−14 |
| 32 | 314810106324610 | Montoya Drain at Sunland Park, NM | 31.8029 | -106.5467 | 1,250.3 | 2006−14 |
| 32A | 314812106324410 | El Paso Electric Plant Wastewater Outfall, Sunland Park, NM | 31.8036 | -106.5461 | 1,250.2 | 2006−14 |
| 33 | 314818106323910 | Keystone Reservoir Inlet, El Paso, TX | 31.8050 | -106.5444 | 1,250.1 | 2006−14 |
| 33A | 314813106322810 | Side-Channel Inlet above Courchesne Bridge, El Paso, TX | 31.8036 | -106.5417 | 1,250.0 | 2006−14 |
| 34 | 08364000 | Rio Grande at El Paso, TX | 31.8029 | -106.5408 | 1,249.9 | 2006−14 |
| 34A | 314802106321710 | Side-Channel Inlet below Courchesne Bridge, El Paso, TX | 31.8007 | -106.5386 | 1,249.7 | 2006−14 |
| 35 | 314718106313410 | EPWU-Northwest WWTP Outfall, El Paso, TX | 31.7884 | -106.5267 | 1,248.4 | 2010−14 |
| 36 | 314713106313610 | Rio Grande above American Dam, El Paso, TX | 31.7871 | -106.5272 | 1,248.3 | 2010−14 |

[1]River miles are referenced upstream from the Rio Grande confluence with the Gulf of Mexico.

## Measurement of Surface-Water Discharge

Discharge measurements used in the 2014 seepage computation were collected by USGS personnel using a variety of measurement techniques, depending on site characteristics, or were reported from other sources. Instantaneous discharge was measured by using an acoustic Doppler velocimeter (ADV), a portable 3-inch Parshall flume, or a volumetric flow container (standard USGS protocols as described in Rantz and others, 1982; Kilpatrick and Schneider, 1983; Nolan and Shields, 2000; Turnipseed and Sauer, 2010). Midsection measurements were made by using the ADV when possible. A Parshall flume was used when surface-water depths were too shallow and velocities were too low to measure discharge by using an ADV, and a volumetric flow container was used to measure discharge entering the river from pipes (Kilpatrick and Schneider, 1983). Discharge measurements are reported in cubic feet per second and assigned a qualitative accuracy rating, on the basis of a field assessment of the uncertainty of the discharge measurement and channel 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) (app. 1).

Effluent from municipal and industrial WWTPs is discharged to the river in one of three ways: (1) as a discrete variable-flow (batch) release, (2) as a continuous equalized-flow (equalized) release, or (3) as a continuous variable-flow (unequalized) release. Discharge from a WWTP was reported as either the instantaneous metered discharge reported by the plant (Reported-I) or as the mean daily discharge computed from the reported total daily discharge (Reported-MDI) (app. 1); these two discharge measurements can be substantially different for WWTPs that batch release effluent. For the five WWTPs that discharged effluent to the river (sites 9, 18A, 21A, 30, and 35), the most appropriate methods of reporting discharge and the associated uncertainty in the reported measurement were assessed on a site-by-site basis. The assessment was based on the way in which effluent was released from the plant, as well as data availability. Of the five WWTPs included in the seepage investigation, one was a batch-release plant (site 18A), one was an equalized-release plant (site 9), and three were unequalized-release plants (sites 21A, 30, and 35). Discharge data for sites 18A and 30 were provided by the plants and are designated as Reported-MDI with a measurement uncertainty greater than 8 percent (poor). Discharge data for site 9 was provided by the plant and is designated as Reported-I with a measurement uncertainty less than or equal to 8 percent (fair). Discharge of plant effluent at site 35 was measured at the riverside outfall and assigned a measurement uncertainty of less than or equal to 8 percent (fair) on the basis of the continuous but unequalized release of discharge from the plant. Discharge at site 21A was measured with a volumetric container and designated as Q-Volm with a measurement uncertainty greater than 8 percent (poor) because of the high flow rate.

## Measurement of Surface-Water Quality

Water-quality samples were collected at select sites (app. 1) during the 2014 seepage investigation using USGS collection protocols for water-quality samples and the USGS equal-width increment (EWI) sampling method where applicable (U.S. Geological Survey, 2006). Low-flow conditions necessitated non-isokinetic (dip) sampling at 9 of 16 sampling locations. Field measurements were made with multiparameter water-quality meters calibrated according to standard USGS protocols (Wilde and Radtke, 2008). Field measurements at the water-quality sites included water temperature, specific conductance, dissolved oxygen, and pH (app. 1). Laboratory measurements included the analysis of nutrients, total dissolved solids, and select major and trace dissolved ion concentrations. Water-quality samples were collected as part of the long-term monitoring effort and have been used in complementary studies in this region, such as salinity assessments and load calculations. Terrigenic helium and radon sampling was conducted in conjunction with this seepage investigation, but the majority of samples were collected from nearby well and drain sites and thus are beyond the scope of this report. Water-quality data for samples analyzed by the USGS National Water Quality Laboratory in Denver, Colorado, from select seepage investigation sites can be accessed at http://qwwebservices.usgs.gov/.

# Seepage Computation

Computations presented as part of the seepage investigations include net seepage gain or loss, estimation of uncertainty for each measurement, and determination of meaningful computed seepage gain or loss.

## Net Seepage Gain or Loss

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

$$Q_S = Q_{ds} - Q_{us} - Q_{in} + Q_{out}, \qquad (1)$$

where

$Q_S$ is the net seepage gain or loss for a subreach, in cubic feet per second;

$Q_{ds}$ is the discharge measured at the downstream end of the subreach, in cubic feet per second;

$Q_{us}$ is the discharge measured at the upstream end of the subreach, in cubic feet per second;

$Q_{in}$ is the sum of inflows, in cubic feet per second; and

$Q_{out}$ is the sum of outflows, in cubic feet per second.

The result is the estimated net flux of water gained or lost from the streambed for the subreach. If $Q_{ds}$ is less than $Q_{us}$ plus $Q_{in}$—that is, if less discharge was measured at the downstream section of the subreach than was measured at the upstream section plus any inflow to that subreach (equation 1)—then the algebraic sign of the net seepage is negative (-),which signifies a loss in discharge for the subreach. Conversely, if $Q_{ds}$ is greater than $Q_{us}$ plus $Q_{in}$, then the algebraic sign of the net seepage is positive (+), which signifies a gain in discharge for that subreach. $Q_{out}$ is zero in the calculations in this report because no diversions or outflows occurred within the study reach during this seepage investigation. For example, in the 2014 investigation, the net seepage gain or loss for the subreach "8 to 10" was computed as -7.8 cubic feet per second ($ft^3/s$) ($Q_S$), which is the difference between the measured discharge of 4.23 $ft^3/s$ at site 10 ($Q_{ds}$) and the measured discharge of 0 $ft^3/s$ at site 8 ($Q_{us}$), minus the measured inflow of 12.0 $ft^3/s$ at site 9 ($Q_{in}$) (table 2).

## Estimation of Uncertainty

Individual discharge measurements were assigned a qualitative accuracy rating that represents the percentage of uncertainty in an individual measurement. The percentage of uncertainty was based on a subjective evaluation of the measurement uncertainty made by the hydrographer on the basis of multiple factors that could affect the quality of the measurement (Sauer and Meyer, 1992). These factors include the instrumentation used, number and distribution of vertical sections where velocity is measured, estimation of average velocity, uniformity of streamflow, 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 streamflow that could affect the ability of the meter to accurately measure the streamflow velocity (Wilberg and Stolp, 2005). The uncertainty in the discharge measurement was assigned a numerical value, derived from the qualitative accuracy rating, as follows: excellent, 2 percent; good, 5 percent; fair, 8 percent; and poor, 10 percent. If there was no measurable discharge at a site, then the uncertainty for the individual measurement was zero, and the individual uncertainty did not contribute numerically to the cumulative uncertainty estimation of the seepage computation for the subreach.

**Table 2.** Summary of measured discharge and the computed net seepage gain or loss in streamflow in main-stem subreaches, Rio Grande seepage investigation, February 11, 2014.

[Site number: See table 1 and figures 1 and 2 for location of sites; $Q_{us}$, discharge measured at the upstream end of the subreach; ft³/s, cubic foot per second; ±, plus or minus; $Q_{inx}$, discharge measured at inflow site (individual subreaches had between 0 and 4 inflows; subscript number, $x$, indicates inflow site 1, 2, 3, or 4, ordered upstream to downstream); $Q_{ds}$, discharge measured at the downstream end of the subreach; $Q_S$, net seepage gain or loss for a subreach. See text for equations and description of cumulative uncertainty computation; $N_d$%, percentage of normalized seepage 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; $N_e$%, percentage of normalized cumulative uncertainty, 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; Y, yes; N, no; %, percentage; —, not applicable]

| Subreach[1] | Sites included in subreach[1] | Distance (miles) | Sample date | $Q_{us}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_{in1}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_{in2}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_{in3}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_{in4}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_{ds}$ with percentage of measurement uncertainty in parentheses (ft³/s) | $Q_S$ (ft³/s) | $N_d$% | $N_e$% | $N_d$% ≥ $N_e$% (Y or N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 to 2 | 1, 2 | 2.1 | 2/11/2014 | 1.06 (10%) | — | — | — | — | 0.563 (10%) | -0.50 ± 0.12 | 47 | 11 | Y |
| 2 to 4 | 2, 3, 4 | 3.9 | 2/11/2014 | 0.563 (10%) | 0 (0%) | — | — | — | 0 (0%) | -0.563 ± 0.056 | 100 | 10 | Y |
| 4 to 5 | 4, 5 | 3.6 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 5 to 7 | 5, 6, 7 | 3.9 | 2/11/2014 | 0 (0%) | 0 (0%) | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 7 to 8 | 7, 8 | 3.2 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 8 to 10 | 8, 9, 10 | 2.5 | 2/11/2014 | 0 (0%) | 12.0 (8%) | — | — | — | 4.23 (10%) | -7.8 ± 1.1 | 65 | 9 | Y |
| 10 to 12 | 10, 11, 12 | 1.4 | 2/11/2014 | 4.23 (10%) | 0 (0%) | — | — | — | 0 (0%) | -4.23 ± 0.42 | 100 | 10 | Y |
| 12 to 13 | 12, 13 | 2.2 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 13 to 14 | 13, 14 | 2.2 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 14 to 16 | 14, 14A, 15, 16 | 4.6 | 2/11/2014 | 0 (0%) | 0 (0%) | 0 (0%) | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 16 to 17 | 16, 17 | 4.9 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 17 to 19 | 17, 18, 18A, 19 | 4.0 | 2/11/2014 | 0 (0%) | 0 (0%) | 0.616 (10%) | — | — | 0 (0%) | -0.616 ± 0.062 | 100 | 10 | Y |
| 19 to 21 | 19, 20, 21 | 2.3 | 2/11/2014 | 0 (0%) | 0 (0%) | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 21 to 22 | 21, 21A, 22 | 3.0 | 2/11/2014 | 0 (0%) | 0.788 (10%) | — | — | — | 0 (0%) | -0.788 ± 0.079 | 100 | 10 | Y |
| 22 to 25 | 22, 23, 24, 25 | 3.8 | 2/11/2014 | 0 (0%) | 0.051 (2%) | 0 (0%) | — | — | 0 (0%) | -0.051 ± 0.001 | 100 | 2 | Y |
| 25 to 26 | 25, 26 | 3.1 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 26 to 27 | 26, 27 | 2.3 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 27 to 28 | 27, 28 | 3.1 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 28 to 29 | 28, 29 | 3.4 | 2/11/2014 | 0 (0%) | — | — | — | — | 0 (0%) | 0 ± 0 | — | — | — |
| 29 to 31 | 29, 30, 31 | 2.5 | 2/11/2014 | 0 (0%) | 2.16 (10%) | — | — | — | 3.20 (8%) | 1.04 ± 0.34 | 33 | 10 | Y |
| 31 to 34 | 31, 32, 32A, 33, 33A, 34 | 0.4 | 2/11/2014 | 3.20 (8%) | 8.59 (8%) | 0 (0%) | 0.711 (8%) | 0.010 (8%) | 12.9 (8%) | 0.4 ± 1.3 | 3 | 10 | N |
| 34 to 36 | 34, 34A, 35, 36 | 1.6 | 2/11/2014 | 12.9 (8%) | 0.097 (8%) | 15.0 (8%) | — | — | 25.1 (8%) | -2.9 ± 2.6 | 10 | 9 | Y |

[1]Subreach is defined as the interval between two adjacent main-stem dischage-measurement locations.

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

$$\delta Q_s = \sqrt{\left(a_1 Q_1\right)^2 + (a_2 Q_2)^2 \ldots + (a_n Q_n)^2}\ , \qquad (2)$$

where

$\delta Q_s$ is the cumulative uncertainty in the computation of net seepage gain or loss, in cubic feet per second;

$a_n$ is the uncertainty of a measurement, in percent; and

$Q_n$ is the measured discharge, in cubic feet per second.

For example, in this investigation, the measurement uncertainty of the individual discharge measurement for site 34 was plus or minus (±) 1.0 ft³/s ($a_1Q_1$), computed as the product of the discharge measurement of 12.9 ft³/s ($Q_1$) and the discharge-measurement accuracy rating of 8 percent, expressed as the fractional equivalent, 0.08 ($a_1$) (table 2). The cumulative measurement uncertainty associated with the net seepage gain or loss for the subreach “34 to 36” was ± 2.6 ft³/s ($\delta Q_S$), computed as the square root of the sum of the squares of the measurement uncertainties for site 34, ± 1.0 ft³/s ($a_1Q_1$); site 34A, ± 0.008 ft³/s ($a_2Q_2$); site 35, ± 1.2 ft³/s ($a_3Q_3$); and site 36, ± 2.0 ft³/s ($a_4Q_4$) (table 2).

## Determination of Meaningful Computed Seepage Gain or Loss

Shallow water depths and poor channel conditions, particularly during dry years, can result in increased uncertainties (exceeding 8 percent) in the computation of net seepage gains and losses. In some cases, the cumulative measurement uncertainty can exceed the net seepage gain or loss computed for a subreach. For the determination of meaningful gain or loss, the net seepage gain or loss and the cumulative measurement uncertainty were normalized to allow for comparison between subreaches with varying discharges and for a particular subreach in different years. The percentage of normalized seepage gain or loss and normalized cumulative uncertainty was computed for each subreach by using the following equations modified from Wilberg and Stolp (2005):

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

where

$N_d$ is the absolute value of the percentage of normalized seepage difference, and

$MaxQ$ is the maximum discharge measured along a subreach as either the downstream discharge plus any outflow or the upstream discharge plus any inflow, in cubic feet per second.

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

where

$N_e$ is the absolute value of the percentage of normalized cumulative uncertainty.

A computed gain or loss for a subreach was considered meaningful if the percentage of normalized seepage difference ($N_d$) was greater than or equal to the percentage of normalized cumulative uncertainty ($N_e$). For example, the estimated net seepage loss ($Q_S$) for subreach “8 to 10” is -7.8 ± 1.1 ft³/s (table 2). This loss, as a percentage of the normalized seepage difference ($N_d$), is 65 percent of the maximum discharge (sum of upstream discharge and inflow) and is greater than the percentage of normalized cumulative uncertainty ($N_e$) of 9 percent, indicating that the loss is meaningful.

# Seepage Investigation

The 2014 seepage investigation was conducted on the 64-mile reach of the Rio Grande and included 42 measurement locations from site 1 in Leasburg, N. Mex., to site 36 in El Paso, Tex. (fig. 1, table 1). The sites were measured on February 11, 2014. There was measurable discharge at 16 of the 42 measurement locations (6 river sites and 10 inflow sites; app. 1); field measurements of water quality including water temperature, specific conductance, dissolved oxygen, and pH were also made (app. 1). No measurable discharge occurred at 17 main-stem and 9 inflow sites; the river was dry for at least 53 miles downstream from site 2 to upstream from site 31, except for short intervals directly below inflow sites 9 and 30 (app. 1). Uncertainty in the discharge measurements ranged from 2 to 10 percent throughout the study reach (table 2). No precipitation was recorded at El Paso International Airport during the week prior to the seepage investigation (National Climatic Data Center, 2014) or during the seepage investigation. Precipitation was therefore assumed to not affect streamflow during this seepage investigation.

Net seepage gain to or loss from the river and the associated percentage of normalized cumulative uncertainty were computed for the 10 subreaches with measurable flow (table 2). Shallow water depths and poor channel conditions resulted in increased percentage of normalized cumulative uncertainty (at least 8 percent in 9 out of 10 main-stem subreaches) in the computation of net seepage gains and losses. The percentage of normalized seepage difference was less than the percentages of normalized cumulative uncertainty at 1 of the 10 subreaches (subreach “31 to 34”), indicating that the estimated gain or loss cannot be considered meaningful within this subreach. This seepage value and corresponding error were still included, however, in the computation of the cumulative gain or loss for the entire reach. The sum of gains and losses computed for each subreach indicates a cumulative loss of 16.0 ± 2.9 $ft^3/s$ within the 64-mile study reach (table 3). The cumulative seepage losses and streamflow characteristics for this investigation (2014) are also compared with those reported by Crilley and others (2013) (table 3).

Because of recent drought conditions, a decrease in surface water flowing into the Mesilla Basin (the study reach) is evident for years 2012–14, as indicated by the discharge measured at site 1 compared to previous years (table 3). The Rio Grande in the Mesilla Basin has historically been classified as a losing reach (table 3). The cumulative seepage loss for the study reach is generally less when there are smaller inflows at site 1 (as observed in years 2012–14) because there is less water in the system to be lost. The decreased flow into the Mesilla Basin also results in fewer sites in the study area containing measurable flow (table 3). Gaining and losing reaches identified in this investigation generally correspond to seepage patterns observed in previous investigations (Crilley and others, 2013) conducted during dry years, with the gaining reaches occurring primarily at the southern (downstream) end of the basin.

**Table 3.** Summary of the cumulative gain or loss in streamflow caused by seepage along subreaches within the study reach, Rio Grande seepage investigations, 2006–14.

[$ft^3/s$, cubic foot per second; $Q_S$, net seepage gain or loss. See text for equations and description of uncertainty computation; -, minus; ±, plus or minus; —, not measured]

| Year | Length of study reach (miles) | Number of sites visited (N) | Number of sites with measurable flow ($N_1$) | Percentage of sites flowing ($N/N_1$) | Initial streamflow at site 1 ($ft^3/s$) | Cumulative sum of $Q_S$ ($ft^3/s$) |
|---|---|---|---|---|---|---|
| 2006 | 62.4 | 39 | 31 | 79.5 | 6.67 | -36.2 ± 2.7 |
| 2007 | 62.4 | 37 | 34 | 91.9 | 28.7 | -36.3 ± 6.7 |
| 2008 | 62.4 | 37 | 33 | 89.2 | 17.7 | -41.4 ± 3.5 |
| 2009 | 62.4 | 38 | 33 | 86.8 | 31.0 | -47.9 ± 8.2 |
| 2010 | 20.2 | 19 | 18 | 94.7 | — | -10.5 ± 3.4 |
| 2011 | 20.2 | 18 | 13 | 72.2 | — | -8.2 ± 3.1 |
| 2012 | 64 | 41 | 16 | 39.0 | 1.31 | -16.2 ± 2.1 |
| 2013 | 64 | 41 | 15 | 36.6 | 0.696 | -19.3 ± 2.5 |
| 2014 | 64 | 42 | 16 | 38.1 | 1.06 | -16.0 ± 2.9 |

## Summary

Increasing water demand as well as multiyear drought conditions within the Mesilla Basin and adjacent areas have resulted in diminished surface-water supplies and increased groundwater withdrawals in the basin. In 1987, the U.S. Geological Survey (USGS) established the Mesilla Basin monitoring program in cooperation with several Federal, State, and local agencies to document and identify trends in groundwater conditions and stream/aquifer relations. Seepage investigations along a 64-mile reach of the Rio Grande from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, were conducted annually from 1988 to 1998 and from 2004 to the present (2014) as part of the monitoring program.

The 2014 seepage investigation was conducted on 1 day (February 11), during low-flow conditions in the non-irrigation season, and results are presented in this report. During the seepage investigation, discharge was measured at 23 sites along the main-stem Rio Grande and 19 inflow sites. Historically, outflows from the river have not occurred during the seepage investigations, and no outflows were observed during the 2014 seepage investigation.

Computations presented for the 2014 seepage investigation include net seepage gain or loss, estimation of uncertainty for each measurement, and determination of meaningful computed seepage gain or loss. Net seepage gain or loss was computed for each subreach by subtracting the discharge measured at the upstream location from the discharge measured at the closest downstream location along the river and then subtracting any inflow to the river within the subreach. Individual discharge measurements were assigned a qualitative accuracy rating that represents the percentage of uncertainty in an individual measurement. Qualitative accuracy ratings were based on a subjective evaluation of the measurement made by the hydrographer on the basis of multiple factors that could affect the quality of the measurement. The uncertainty in the discharge measurement was assigned a numerical value, derived from the qualitative accuracy rating, as follows: excellent, 2 percent; good, 5 percent; fair, 8 percent; and poor, 10 percent. The cumulative measurement uncertainty associated with the computed net seepage gain or loss for each subreach was determined.

To allow for comparison between subreaches with varying discharges, the percentage of normalized seepage gain or loss ($N_d$) and normalized cumulative uncertainty ($N_e$) were computed for each subreach. A computed gain or loss for a subreach was considered meaningful if the percentage of normalized seepage difference was greater than or equal to the percentage of normalized cumulative uncertainty. Shallow water depths and poor channel conditions, caused by the dry conditions in 2014 (no measurable discharge occurred at 17 main-stem and 9 inflow sites), resulted in increased percentages of normalized cumulative uncertainty (at least 8 percent in 9 out of 10 main-stem subreaches) in the computation of net seepage gains and losses. The cumulative seepage loss was 16.0 plus or minus 2.9 cubic feet per second within the 64-mile study reach. Because of recent drought conditions, a decrease in surface water flowing into the Mesilla Basin (the study reach) is evident for years 2012–14, as indicated by the discharge measured at site 1 compared to previous years. This decreased flow also resulted in fewer sites in the study area containing measurable flow. Gaining and losing reaches identified in this investigation generally correspond to seepage patterns observed in previous investigations conducted during dry years, with the gaining reaches occurring primarily at the southern (downstream) end of the basin.

## References Cited

Crilley, D.M., Matherne, A.M., Thomas, Nicole, and Falk, S.E., 2013, Seepage investigations of the Rio Grande from below Leasburg Dam, Leasburg, New Mexico, to above American Dam, El Paso, Texas, 2006–13: U.S. Geological Survey Open-File Report 2013–1233, 34 p., accessed June 2015 at http://pubs.usgs.gov/of/2013/1233/.

Hendricks, E.L., 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960: U.S. Geological Survey Water-Supply Paper 1732, 574 p. [Also available at http://pubs.usgs.gov/wsp/1732/report.pdf.]

Kilpatrick, F.A., and Schneider, V.R., 1983, Use of flumes in measuring discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A14, 46 p. [Also available at http://pubs.usgs.gov/twri/twri3-a14/.]

Moyer, D.L., Anderholm, S.K., Hogan, J.F., Phillips, F.M., Hibbs, B.J., Witcher, J.C., Matherne, A.M., and Falk, S.E., 2013, Knowledge and understanding of dissolved solids in the Rio Grande–San Acacia, New Mexico, to Fort Quitman, Texas, and plan for future studies and monitoring: U.S. Geological Survey Open-File Report 2013–1190, 55 p., accessed May 2014 at http://pubs.usgs.gov/of/2013/1190/.

National Climatic Data Center, 2014, Climate Data Online—Quality controlled local climatological data, COOP station 412797, El Paso International Airport, El Paso, TX: National Oceanic and Atmospheric Administration, accessed February 2014 at http://www.ncdc.noaa.gov/cdo-web/.

National Drought Mitigation Center, 2014, United States Drought Monitor—New Mexico tabular data archive: Accessed May 2014 at http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx?NM.

Nolan, K.M., and Shields, R.R., 2000, Measurement of stream discharge by wading: U.S. Geological Survey Water-Resources Investigations Report 00–4036, CD-ROM.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, volume 1—Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p. [Also available at http://pubs.usgs.gov/wsp/wsp2175/.]

Sauer, V.B., and Meyer, R.W., 1992, Determination of error in individual discharge measurements: U.S. Geological Survey Open-File Report 92–144, 21 p. [Also available at http://pubs.usgs.gov/of/1992/ofr92-144/.]

Simonds, F.W., and Sinclair, K.A., 2002, Surface water-ground water interactions along the Lower Dungeness River and vertical hydraulic conductivity of streambed sediments, Clallam County, Washington, September 1999–July 2001: U.S. Geological Survey Water-Resources Investigations Report 02–4161, 60 p.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods, book 3, chap. A8, 87 p. [Also available at http://pubs.usgs.gov/tm/tm3-a8/.]

U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, September 2006, accessed May 22, 2013, at http://pubs.water.usgs.gov/twri9A4/.

U.S. Geological Survey, 2013, USGS Water Science School water science glossary of terms: U.S. Geological Survey, accessed June 7, 2013, at http://ga.water.usgs.gov/edu/dictionary.html.

U.S. Geological Survey, 2014, National Water Information System—Station 08361000: Rio Grande Below Elephant Butte Dam, NM: Accessed May 2014 at http://waterdata.usgs.gov/nm/nwis/uv/?site_no=08361000.

Wheeler, J.D., and Eddy-Miller, C.A., 2005, Seepage investigation on selected reaches of Fish Creek, Teton County, Wyoming, 2004: U.S. Geological Survey Scientific Investigations Report 2005–5133, 20 p. [Also available at http://pubs.usgs.gov/sir/2005/5133/.]

Wilberg, D.E., and Stolp, B.J., 2005, Seepage investigation and selected hydrologic data for the Escalante River drainage basin, Garfield and Kane Counties, Utah, 1909–2002: U.S. Geological Survey Scientific Investigations Report 04–5233, 39 p. [Also available at http://pubs.usgs.gov/sir/2004/5233/PDF/SIR2004_5233.pdf.]

Wilde, F.D., and Radtke, D.B., 2008, Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6. [Also available at http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html.]

Wilkins, D.W., 1986, Geohydrology of the southwest alluvial basins regional aquifer-systems analysis, parts of Colorado, New Mexico, and Texas: U.S. Geological Survey Water-Resources Investigations Report 84–4224, 61 p.

# Appendix 1

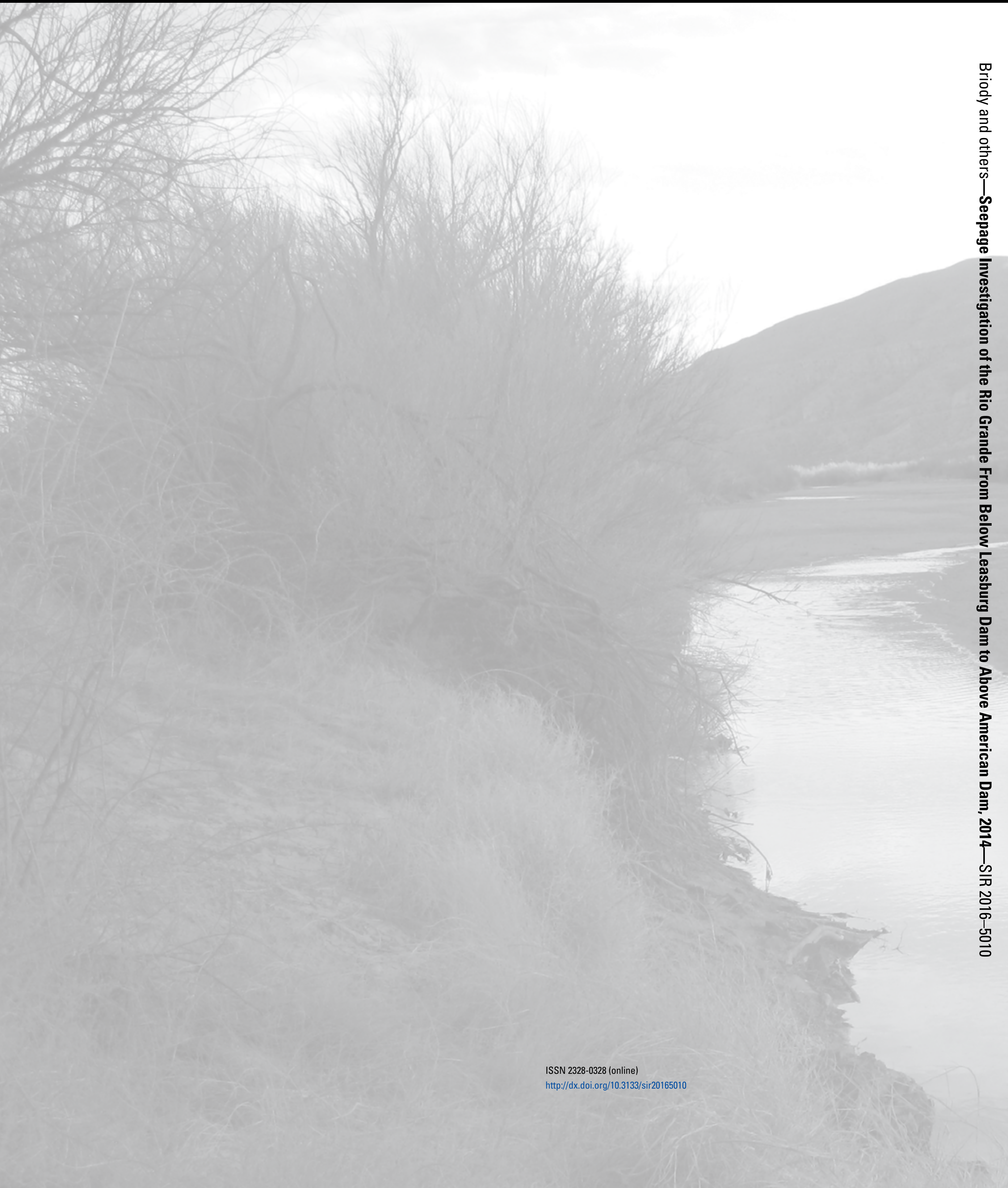
**Appendix 1.** Select field measurements and observations, Rio Grande seepage investigation, 2014.

[ID, identifier; °C, degrees Celsius; µS/cm, microsiemens per centimeter; $ft^3/s$, cubic foot per second; mg/L, milligrams per liter; WWTP, wastewater treatment plant; —, not applicable; ADV, acoustic Doppler velocimeter; Reported-I, instantaneous metered discharge reported by plant; Reported-MDI, mean daily discharge computed from the reported total daily discharge; P-Flume, portable 3-inch Parshall flume; Q-Volm, volumetric discharge measure. Qualitative accuracy ratings: E, excellent (less than or equal to 2 percent); G, good (less than or equal to 5 percent); F, fair (less than or equal to 8 percent); P, poor (greater than 8 percent)]

| Site ID | USGS station ID | Station name | Sample date | Sample time (military) | Water temperature (°C) |
|---|---|---|---|---|---|
| 1 | 322841106551010 | Rio Grande below Leasburg Dam, NM | 2/11/2014 | 0856 | 9.3 |
| 2 | 322721106540810 | Rio Grande near Leasburg, NM | 2/11/2014 | 0938 | 7.4 |
| 3 | 322541106525110 | Selden Drain at Levee Road near Leasburg, NM | 2/11/2014 | 0948 | — |
| 4 | 322505106520110 | Rio Grande near Hill, NM | 2/11/2014 | 0950 | — |
| 5 | 322234106511710 | Rio Grande at Shalem Bridge near Dona Ana, NM | 2/11/2014 | 0958 | — |
| 6 | 322214106501410 | Spillway Number 5 near Dona Ana, NM | 2/11/2014 | 1000 | — |
| 7 | 322018106500910 | Rio Grande near Picacho, NM | 2/11/2014 | 1037 | — |
| 8 | 321745106492510 | Rio Grande below Picacho Bridge near Las Cruces, NM | 2/11/2014 | 1102 | — |
| 9 | 321735106492610 | Las Cruces WWTP Outfall, Las Cruces, NM | 2/11/2014 | 1110 | 19.0 |
| 10 | 321549106492910 | Rio Grande at NM-359 Bridge near Mesilla, NM | 2/11/2014 | 1103 | 17.1 |
| 11 | 321434106485610 | Picacho Drain above Mesilla Dam, NM | 2/11/2014 | 1120 | — |
| 12 | 321430106484910 | Rio Grande below Picacho Drain, NM | 2/11/2014 | 1135 | — |
| 13 | 321317106471510 | Rio Grande below Mesilla Dam near Santo Tomas, NM | 2/11/2014 | 1150 | — |
| 14 | 321224106453210 | Rio Grande at NM-28 Bridge near San Pablo, NM | 2/11/2014 | 1030 | — |
| 14A | 321131106441410 | Wasteway below NM-28 | 2/11/2014 | 1801 | — |
| 15 | 321014106431410 | Santo Tomas River Drain at Levee Road near San Miguel, NM | 2/11/2014 | 0821 | — |
| 16 | 320943106425810 | Rio Grande NM-192 Bridge near San Miguel, NM | 2/11/2014 | 0826 | — |
| 17 | 320648106400510 | Rio Grande at NM-189 Bridge near Vado, NM | 2/11/2014 | 0841 | — |
| 18 | 320610106393110 | Del Rio Drain at Levee Road near Vado, NM | 2/11/2014 | 0846 | — |
| 18A | 320525106393410 | Dona Ana Co South Central WWTP Outfall near Vado, NM | 2/11/2014 | 0920 | 16.9 |
| 19 | 320356106394510 | Rio Grande at NM-226 Bridge near Berino, NM | 2/11/2014 | 0935 | — |
| 20 | 320214106392510 | La Mesa Drain at Levee Road near Chamberino, NM | 2/11/2014 | 1215 | — |
| 21 | 320212106391810 | Rio Grande below La Mesa Drain near Chamberino, NM | 2/11/2014 | 1300 | — |
| 21A | 320122106385610 | Anthony WWTP Outfall at NM-186 Bridge near Anthony, NM | 2/11/2014 | 1402 | 18.2 |
| 22 | 315958106380710 | Rio Grande at NM-225 Bridge near Anthony, NM | 2/11/2014 | 1350 | — |
| 23 | 315957106380610 | Pipe Inflow at NM-225 Bridge near Anthony, NM | 2/11/2014 | 1517 | 14.5 |
| 24 | 315807106361910 | East Side Drain at Levee Road near Anthony, TX | 2/11/2014 | 1610 | — |
| 25 | 315733106361610 | Rio Grande at Vinton Bridge near Vinton, TX | 2/11/2014 | 1620 | — |
| 26 | 315454106360610 | Rio Grande at TX-259 Bridge, Canutillo, TX | 2/11/2014 | 0845 | — |
| 27 | 315309106355510 | Rio Grande at Borderland Bridge near Borderland, TX | 2/11/2014 | 0915 | — |
| 28 | 315046106361810 | Rio Grande at TX-260 Bridge near Santa Teresa, NM | 2/12/2014 | 0845 | — |
| 29 | 314824106345710 | Rio Grande near Sunland Park, NM | 2/11/2014 | 1710 | — |
| 30 | 314755106332510 | Sunland Park WWTP Outfall, Sunland Park, NM | 2/11/2014 | 1130 | 18.5 |
| 31 | 314756106331610 | Rio Grande at Sunland Park Bridge, Sunland Park, NM | 2/11/2014 | 1130 | 18.6 |
| 32 | 314810106324610 | Montoya Drain at Sunland Park, NM | 2/11/2014 | 1600 | 15.2 |
| 32A | 314812106324410 | El Paso Electric Plant Wastewater Outfall, Sunland Park, NM | 2/11/2014 | 1701 | — |
| 33 | 314818106323910 | Keystone Reservoir Inlet, El Paso, TX | 2/11/2014 | 1346 | 16.7 |
| 33A | 314813106322810 | Side-Channel Inlet above Courchesne Bridge, El Paso, TX | 2/11/2014 | 0952 | 8.8 |
| 34 | 08364000 | Rio Grande at El Paso, TX | 2/11/2014 | 1303 | 15.8 |
| 34A | 314802106321710 | Side-Channel Inlet below Courchesne Bridge, El Paso, TX | 2/11/2014 | 1107 | 8.1 |
| 35 | 314718106313410 | EPWU-Northwest WWTP Outfall, El Paso, TX | 2/11/2014 | 1255 | 21.7 |
| 36 | 314713106313610 | Rio Grande above American Dam, El Paso, TX | 2/11/2014 | 1513 | 18 |

| Site ID | Specific conductance at 25 °C (µS/cm) | Dissolved oxygen (mg/L) | pH | Discharge measurement (ft³/s) | Discharge measurement type | Qualitative accuracy rating of discharge measurement | Streamflow conditions | Channel conditions |
|---|---|---|---|---|---|---|---|---|
| 1 | 3,490 | 10.96 | 8.17 | 1.06 | ADV | P | Steady | Sand, firm, even. |
| 2 | 3,429 | 10.61 | 8.02 | 0.563 | ADV | P | Steady | Silt-mud, soft, even. |
| 3 | — | — | — | 0 | — | — | No flow | — |
| 4 | — | — | — | 0 | — | — | No flow | — |
| 5 | — | — | — | 0 | — | — | No flow | — |
| 6 | — | — | — | 0 | — | — | No flow | — |
| 7 | — | — | — | 0 | — | — | No flow | — |
| 8 | — | — | — | 0 | — | — | No flow | — |
| 9 | 1,290 | 7.5 | 6.45 | 12.0 | Reported-I | F | — | — |
| 10 | 1,291 | 11.78 | 7.78 | 4.23 | ADV | P | Pulsating | Sand, even, firm. |
| 11 | — | — | — | 0 | — | — | No flow | — |
| 12 | — | — | — | 0 | — | — | No flow | — |
| 13 | — | — | — | 0 | — | — | No flow | — |
| 14 | — | — | — | 0 | — | — | No flow | — |
| 14A | — | — | — | 0 | — | — | No flow | — |
| 15 | — | — | — | 0 | — | — | No flow | — |
| 16 | — | — | — | 0 | — | — | No flow | — |
| 17 | — | — | — | 0 | — | — | No flow | — |
| 18 | — | — | — | 0 | — | — | No flow | — |
| 18A | 1,405 | 2.4 | 7.61 | 0.616 | Reported-MDI | P | — | — |
| 19 | — | — | — | 0 | — | — | No flow | — |
| 20 | — | — | — | 0 | — | — | No flow | — |
| 21 | — | — | — | 0 | — | — | No flow | — |
| 21A | 2,640 | 7.95 | 7.5 | 0.788 | Q-Volm | P | — | — |
| 22 | — | — | — | 0 | — | — | No flow | — |
| 23 | 1,750.0 | 3.9 | 6.8 | 0.051 | Q-Volm | E | — | — |
| 24 | — | — | — | 0 | — | — | No flow | — |
| 25 | — | — | — | 0 | — | — | No flow | — |
| 26 | — | — | — | 0 | — | — | No flow | — |
| 27 | — | — | — | 0 | — | — | No flow | — |
| 28 | — | — | — | 0 | — | — | No flow | — |
| 29 | — | — | — | 0 | — | — | No flow | — |
| 30 | 1,745 | 6.31 | 7.76 | 2.16 | Reported-MDI | P | — | — |
| 31 | 1,757 | 9.29 | 8.03 | 3.20 | ADV | F | Steady | Sand, firm, even. |
| 32 | 5,340 | 13.18 | 8.53 | 8.59 | ADV | F | Steady | Silt-mud, soft, even. |
| 32A | — | — | — | 0 | — | — | No flow | — |
| 33 | 3,130 | 9.97 | 8.49 | 0.711 | ADV | F | Steady | Silt-mud, soft, even. |
| 33A | 3,531 | 6.21 | 8.01 | 0.010 | P-Flume | F | Pulsating | Silt-mud, firm, even. |
| 34 | 4,681 | 14.19 | 8.44 | 12.9 | ADV | F | Steady | Sand, firm, even. |
| 34A | 3,432 | 12.7 | 8.26 | 0.097 | P-Flume | F | — | — |
| 35 | 1,823 | 7.77 | 7.61 | 15.0 | ADV | F | Pulsating | Gravel, firm, even. |
| 36 | 3,512 | 12.55 | 8.44 | 25.1 | ADV | F | Pulsating | Gravel, firm, even. |

Publishing support provided by
Lafayette Publishing Service Center



Briody and others—**Seepage Investigation of the Rio Grande From Below Leasburg Dam to Above American Dam, 2014**—SIR 2016–5010

ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20165010