SPATIAL AND TEMPORAL VARIATIONS IN STREAMFLOW, DISSOLVED SOLIDS, NUTRIENTS, AND SUSPENDED SEDIMENT IN THE RIO GRANDE VALLEY STUDY UNIT, COLORADO, NEW MEXICO, AND TEXAS, 1993-95

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4224

National Water-Quality Assessment Program

USGS
science for a changing world

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By Stephanie J. Moore and Scott K. Anderholm

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CONVERSION FACTORS AND DATUMS

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
ton per day (ton/d)	0.9072	metric ton per day (t/d)
cubic foot per second (ft^3s)	0.02832	cubic meter per second (m^3/s)

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

$$°F = (1.8 \times °C) + 32.$$

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

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

SPATIAL AND TEMPORAL VARIATIONS IN STREAMFLOW, DISSOLVED SOLIDS, NUTRIENTS, AND SUSPENDED SEDIMENT IN THE RIO GRANDE VALLEY STUDY UNIT, COLORADO, NEW MEXICO, AND TEXAS, 1993-95

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ABSTRACT

Streamflow and water quality vary spatially and temporally in the Rio Grande from Del Norte, Colorado, to El Paso, Texas. The variations in streamflow and in concentrations of selected water-quality constituents—dissolved solids, dissolved nitrite plus nitrate as nitrogen, total phosphorus, and suspended sediment—are described in this report. A multivariate linear regression model, ESTIMATOR2000, was used to estimate loads for selected constituents.

Streamflow decreases in the downstream direction throughout most of the basin because outflows (due to agricultural use, leakage to ground water, and evapotranspiration) are greater than inflows. Streamflow increases between Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colorado, to Rio Grande at Otowi Bridge, near San Ildefonso, New Mexico, because ground-water and tributary inflow are greater than outflow.

Concentrations of dissolved solids, dissolved nitrite plus nitrate, total phosphorus, and suspended sediment generally increase in the downstream direction. Concentrations of dissolved solids, dissolved nitrite plus nitrate, and total phosphorus decrease between Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colorado, and Rio Grande at Otowi Bridge, near San Ildefonso, New Mexico, because of dilution by tributary inflow. Concentrations of dissolved nitrite plus nitrate, total phosphorus, and suspended sediment decrease between Rio Grande Floodway at San Marcial, New Mexico, and Rio Grande below Leasburg Dam, near Leasburg, New Mexico, because of reservoir effects (nutrient uptake and settling of sediment).

Several instances of decreasing streamflow and increasing loads indicate the presence of inflows with large constituent concentrations (relative to those of the Rio Grande immediately upstream from that inflow); this occurs (1) between Rio Grande near Del Norte, Colorado, and Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colorado, for dissolved solids, (2) between Rio Grande at Otowi Bridge, near San Ildefonso, New Mexico, and Rio Grande Floodway at San Marcial, New Mexico, for all constituents, and (3) between Rio Grande below Leasburg Dam, near Leasburg, New Mexico, and Rio Grande at El Paso, Texas, for all constituents.

Streamflow increases along every reach of the Rio Grande between the streamflow-gaging station Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colorado, and the station Rio Grande at Otowi Bridge, near San Ildefonso, New Mexico. These increases in streamflow result in increases in the loads of dissolved solids, total phosphorus, and suspended sediment regardless of changes in concentrations.

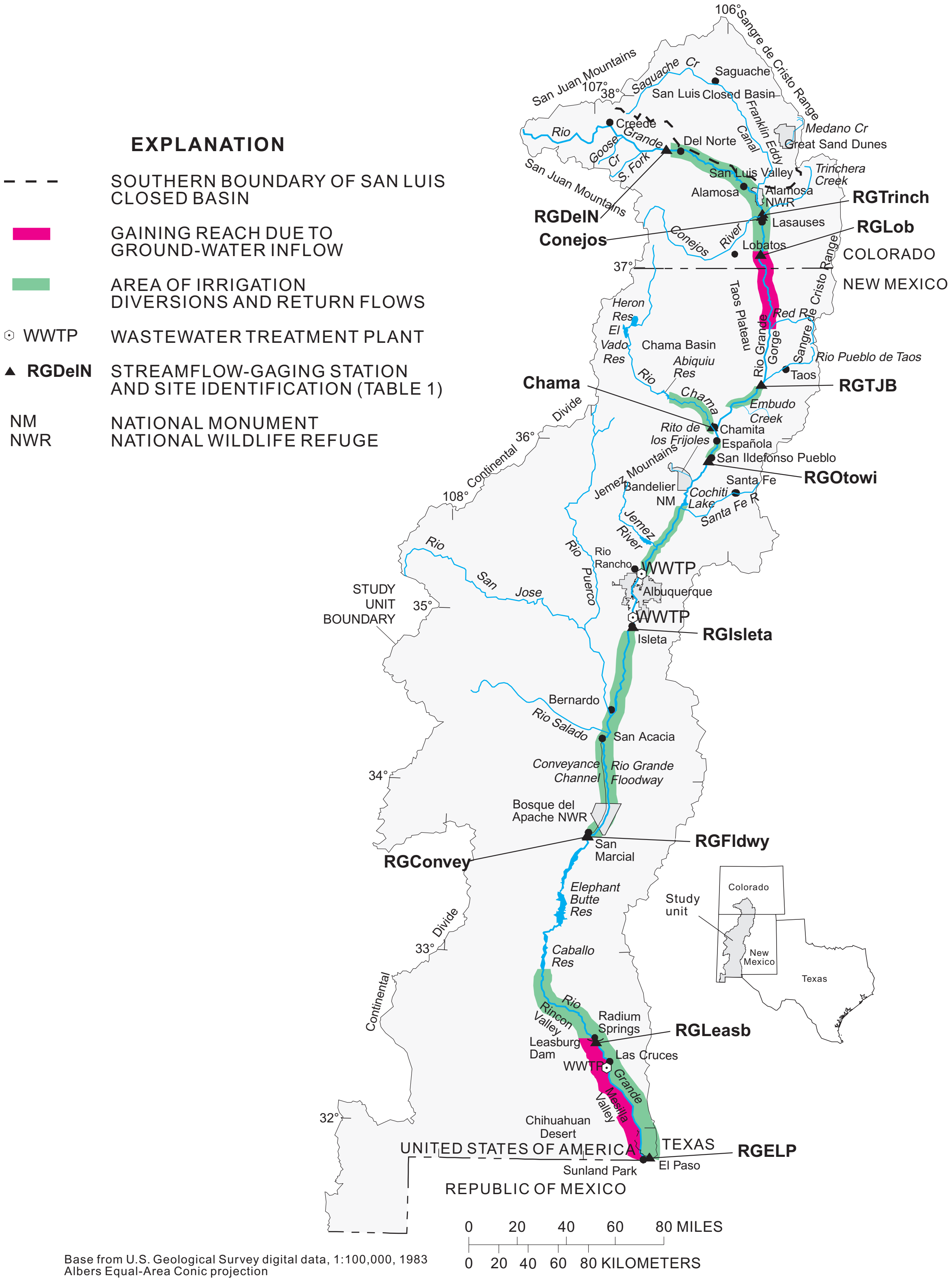
INTRODUCTION

In 1991, the U.S. Geological Survey began implementation of the National Water-Quality Assessment (NAWQA) Program. Goals of the NAWQA Program are to describe the status of and trends in the quality of the Nation’s surface- and ground-water resources and to improve understanding of the natural and anthropogenic factors that affect water-quality conditions. The NAWQA Program is studying many of the Nation’s most important surface- and ground-water systems, which are referred to as study units. Assessment activities in the Rio Grande Valley (RIOG) study unit (fig. 1) began in 1991, and the high-intensity sampling phase began in 1993.

The quality of water in the Rio Grande and its tributaries is of vital importance to the people that depend on the water for its many uses. The quality of water varies throughout the course of the Rio Grande primarily as a result of inflows of ground water and surface water to the river.

Purpose and Scope

This report describes the spatial and temporal variations in streamflow and water quality in the Rio



Base from U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal-Area Conic projection
Standard parallels 29°30´ and 45°30´, central meridian -96°00´

Figure 1. Rio Grande Valley study unit and selected sites.

Grande from Del Norte, Colorado, to El Paso, Texas. The variations in water as it moves downstream reflect the volume and composition of inflows to or outflows from the Rio Grande. Many times the variations are small in terms of actual concentration but large in terms of percent difference between two sites; nevertheless, determining the effects of inflows and outflows on streamflow and water quality is useful in evaluating the impact of natural and anthropogenic factors on the Rio Grande. Streamflow and selected water-quality data for 12 sites in the Rio Grande Valley study unit of the NAWQA Program are presented and discussed (table 1).

Selected water-quality constituents described in this report are dissolved solids, dissolved nitrite plus nitrate as nitrogen, total phosphorus, and suspended sediment. A multivariate linear regression model was used to estimate loads for selected constituents. Spatial and temporal variations in constituent concentrations and constituent loads are presented and discussed for water years (WY) 1993-95.

Description of Study Unit

The RIOG NAWQA study unit covers approximately 45,700 mi^2 in Colorado, New Mexico, and Texas; it includes the entire Rio Grande drainage basin upstream from the streamflow-gaging station Rio Grande at El Paso, Texas (RGELP), and the closed-basin part of the San Luis Basin in Colorado (fig. 1). A detailed description of the RIOG study unit is available in Ellis and others (1993). Land use in the study unit is predominantly rangeland (58 percent), forest (36 percent), and agriculture (4 percent) (fig. 2). Irrigation is the predominant water-use category (89 percent) in the study unit; public supply is the second largest water-use category (9 percent) (Richey and Ellis, 1993). The climatological variations throughout the study unit range from alpine tundra to Sonoran desert. Annual precipitation can exceed 50 in. in the headwaters of the Rio Grande, whereas other areas may receive less than 6 in. (Ellis and others, 1993).

Surface Water

The headwaters of the Rio Grande are in the San Juan Mountains, in south-central Colorado. Major tributaries are the South Fork of the Rio Grande, the Conejos River, and the Rio Chama (fig. 1). Other perennial tributaries include Goose Creek, Red River, Rio Pueblo de Taos, Embudo Creek, and the Jemez River (fig. 1). With the exception of the Jemez River, all these tributaries discharge to the Rio Grande upstream from the gaging station Rio Grande at Otowi Bridge, near San Ildefonso, New Mexico (RGOtowi)—that is, most surface-water inflow to the Rio Grande is derived from mountains adjacent to the Rio Grande upstream from RGOtowi; downstream from this gaging station, the river receives little surface-water inflow (Ortiz and Lange, 1996). Numerous intermittent and ephemeral streams discharge to the Rio Grande only during periods of intense rainfall and (or) heavy snowmelt. Although many of these intermittent and ephemeral streams typically contribute little surface-water inflow to the Rio Grande (flow for 1 day or less per precipitation event), the inflow can have large concentrations of suspended sediment (as much as 185,000 mg/L) and nutrients (dissolved nitrite plus nitrate concentration of 1.7 mg/L and total phosphorous concentration of 45 mg/L) (Healy, 1997). The Rio Puerco and Rio Salado are the largest ephemeral channels that discharge to the Rio Grande.

Surface-Water and Ground-Water Interactions

Surface water and ground water interact along the Rio Grande and its tributaries. Variations in the ground-water flow systems adjacent to the river can result in inflow of ground water to the Rio Grande or recharge from the Rio Grande to the ground-water system (outflow). Some reaches of the river receive ground-water discharge; these are referred to as gaining reaches. Winograd (1959) identified a gaining reach between Lobatos, Colorado, and the mouth of Red River. During a seepage test in the mid-1970’s, Wilson and others (1981) identified a gaining reach between Radium Springs and Las Cruces, New Mexico (fig. 1). Nickerson (1995) identified two distinct gaining reaches in the Las Cruces, New Mexico–El Paso, Texas, vicinity from 1988 to 1992.

In some reaches, water infiltrates from the river to adjacent aquifers; these are referred to as losing reaches. Between Cochiti Lake and San Acacia, New Mexico (fig. 1), the Rio Grande has become channelized and in some places is higher than the adjacent land surface, resulting in infiltration of surface water to the adjacent shallow aquifer. To prevent the water table from rising above land surface, riverside drains were constructed in the 1930’s to intercept shallow ground water and return it to the Rio Grande.

Table 1. Rio Grande Valley study unit sites

Site identification (fig. 1)	U.S. Geological Survey		Latitude	Longitude	Drainage area (square miles)	Contributing drainage area (square miles)
	Station number	Station name				
RGDelN	08220000	Rio Grande near Del Norte, Colo.	37°41'22"	106°27'38"	1,310	1,310
RGTrinch	08240000	Rio Grande above mouth of Trinchera Creek, near Lasauses, Colo.	37°18'58"	105°44'32"	5,680	2,750
Conejos	08249000	Conejos River near Lasauses, Colo.	37°18'01"	105°44'47"	789	789
RGLob	08251500	Rio Grande near Lobatos, Colo.	37°04'42"	105°45'22"	7,520	4,590
RGTJB	08276500	Rio Grande below Taos Junction Bridge, near Taos, N. Mex.	36°19'12"	105°45'14"	9,460	6,530
Chama	08290000	Rio Chama near Chamita, N. Mex.	36°04'26"	106°06'40"	3,140	3,040
RGOtowi	08313000	Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.	35°52'29"	106°08'30"	13,960	10,930
RGIsleta	08331000	Rio Grande at Isleta, N. Mex.	34°54'21"	106°41'04"	17,570	14,540
RGConvey	08358300	Rio Grande Conveyance Channel at San Marcial, N. Mex.	33°41'07"	106°59'40"	[1]--	[1]--
RGFldwy	08358400	Rio Grande Floodway at San Marcial, N. Mex.	33°40'50"	106°59'30"	28,900	24,740
RGLeasb	08363500	Rio Grande below Leasburg Dam, near Leasburg, N. Mex.	32°28'36"	106°55'03"	38,500	29,000
RGELP	08364000	Rio Grande at El Paso, Tex.	31°48'10"	106°32'25"	39,580	30,080

[1] Conveyance channel is an anthropogenic structure that was not assigned a drainage area

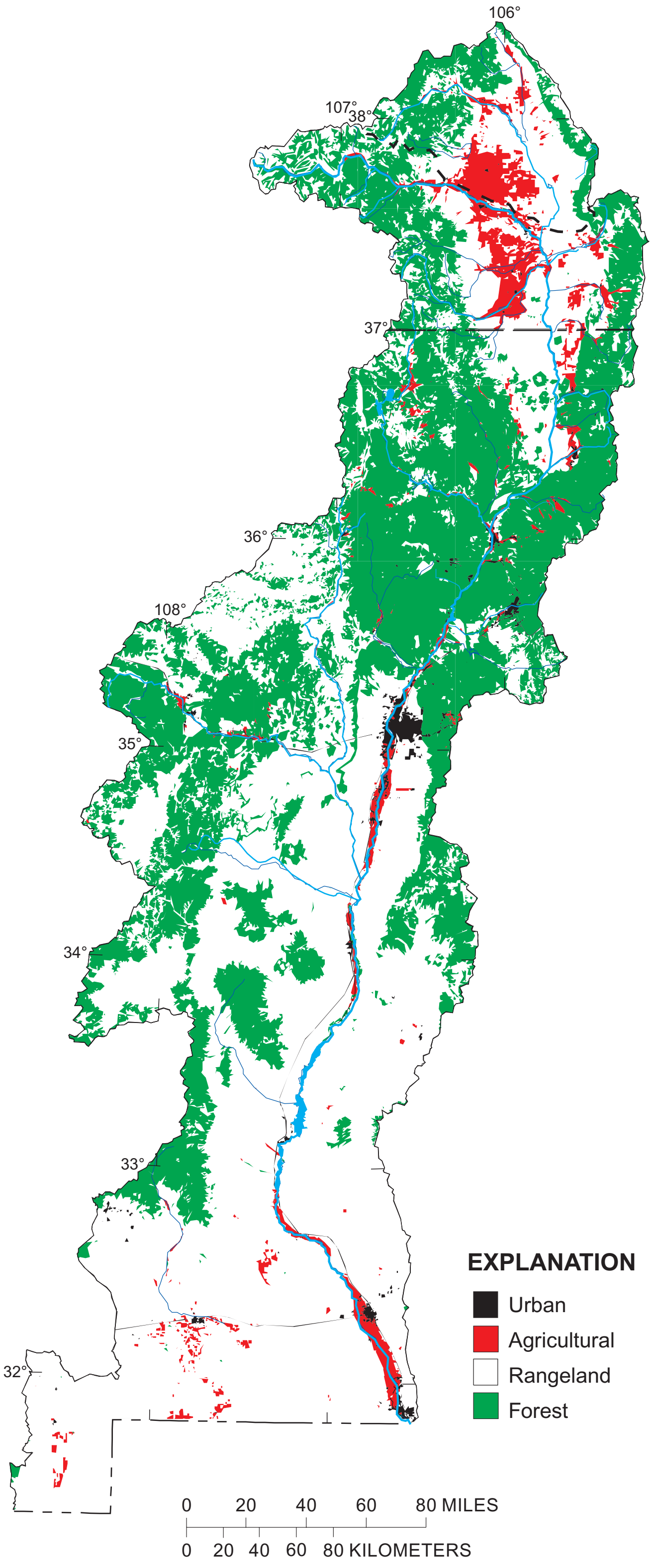


Figure 2. Areas of urban, agricultural, rangeland, and forest land-use and land-cover classifications for the Rio Grande Valley study unit.

Anthropogenic Structures

Many anthropogenic structures affect streamflow in the Rio Grande. Eighteen reservoirs have storage capacities greater than 5,000 acre-ft in the Rio Grande study unit (Ellis and others, 1993). These reservoirs alter the natural flow of the river, often dampening seasonal effects and allowing for increased evapotranspiration. Three reservoirs that affect the Rio Grande are Cochiti Lake, Elephant Butte Reservoir, and Caballo Reservoir (fig. 1). The Rio Chama, a major tributary to the Rio Grande, is affected by three reservoirs: Heron, El Vado, and Abiquiu.

Numerous irrigation diversions (outflows) and return flows (inflows) are in agricultural areas (fig. 1). In Colorado, surface water is diverted to irrigate crops such as alfalfa, small grains, irrigated meadows, and irrigated pastures. In the intensively farmed area north of the Rio Grande, in the San Luis Closed Basin, surface water is used to recharge the shallow ground-water aquifer and is subsequently withdrawn by pumping through center-pivot sprinklers to irrigate alfalfa, small grains, potatoes, and a variety of other vegetables. In New Mexico, surface water is typically diverted for irrigation and routed to the fields through irrigation canals; return flows are routed back to the Rio Grande through open drains. Return flows consist of (1) water that was originally diverted for irrigation purposes but was not used and (or) (2) any water (generally water from the Rio Grande or the irrigation system) that infiltrates to the shallow alluvial aquifer and discharges to the drains.

The Rio Grande Conveyance Channel and the Rio Grande Floodway are located between San Acacia, New Mexico, and San Marcial, New Mexico; both discharge to Elephant Butte Reservoir immediately downstream from San Marcial. In this reach of the Rio Grande, there is streamflow in either the Floodway, which is the stabilized natural river channel, or the Conveyance Channel, which was built in the 1950's to increase streamflow to Elephant Butte Reservoir during periods of low flow. During the 1960's and 1970's, most streamflow was diverted into the Conveyance Channel. Since 1985, most streamflow is in the Floodway, whereas streamflow in the Conveyance Channel consists of return flows from agricultural areas between San Acacia and San Marcial, New Mexico.

Effluent discharge from wastewater treatment plants (WWTP's) provides inflow to the Rio Grande (WWTP inflow); any wastewater effluent can affect water quality in the Rio Grande. Many WWTP's are located along the Rio Grande; the largest WWTP's are in Rio Rancho, Albuquerque, and Las Cruces (fig. 1).

The Franklin Eddy Canal, part of the Bureau of Reclamation San Luis Valley Closed Basin Project, discharges water pumped from the aquifer in the closed basin part of the San Luis Valley to the Rio Grande.

Water Quality

Many natural and anthropogenic factors affect the quality of surface and ground water in the RIOG study unit. Natural factors include the chemical composition of surface (tributary) water and ground water discharged to the Rio Grande, the chemical composition of precipitation, dissolution of minerals, nutrient uptake, decay of organic matter, erosion, and evapotranspiration. Anthropogenic factors include effects of irrigation, wastewater effluent, urban runoff, septic-tank discharge, and leaching of fertilizers. In addition to these anthropogenic factors, human activities may enhance natural processes such as erosion and evapotranspiration.

Inflows to a river or stream can potentially affect constituent concentrations and constituent loads. When an inflow mixes with river water, the resulting constituent concentration can increase, stay the same, or decrease relative to the concentration in the river immediately upstream from the inflow. The constituent concentration and volume of inflow relative to those of the river determine the magnitude of change in the resulting concentration. When an inflow mixes with river water, constituent loads almost always increase because of the addition of mass; however, if a particular constituent is completely absent from an inflow (the constituent concentration is zero), then the constituent load will remain unchanged (although the resulting concentration will have decreased because of dilution).

Outflows from a river or stream generally do not affect constituent concentrations; however, suspended-sediment concentrations can be an exception. An outflow causing a large decrease in streamflow results in a decrease in stream velocity, causing sediment to settle out of suspension, which results in a decrease in suspended-sediment concentrations. Outflows result in a decrease in constituent loads because of the net loss of constituent mass.

STUDY METHODS

Data Collection

Water samples generally were collected monthly from April 1993 to September 1995. Depth- and width-integrated samples were collected and processed according to protocols described in Shelton (1994). A detailed description of the RIOG-NAWQA water-quality sampling program and site-specific statistical data summaries are available in Healy (1997).

Box Plots

Concentrations of selected water-quality constituents are presented in the form of box plots. Box plots provide a concise graphical representation of the distribution of a data set. They provide a visual representation of (1) the center of the data (the median), (2) the variation or spread (the interquartile range, defined as the 75th percentile minus the 25th percentile), (3) the skewness or quartile skew (represented by the relative size of the box halves), and (4) the presence or absence of unusual values or outliers (Helsel and Hirsch, 1992).

Loads

In a river system, the load of a particular constituent is defined as the quantity (mass or weight) of that constituent transported past a given point in a given period of time. The instantaneous load (sometimes referred to as a flux) is the product of the constituent concentration and streamflow (discharge); thus, the units are mass per time.

Loads are affected by changes in streamflow (inflows and outflows) or changes in concentration. A constituent load will increase only if constituent mass is added to the river; this can occur either directly (for example, resuspension or erosion of sediment during high-velocity flow events) or indirectly, when water containing some of that constituent is added to the river (for example, tributary or ground-water inflow). A constituent load will decrease only when some of that constituent is removed from the river; this can occur either directly (for example, the settling of suspended sediment or nutrient uptake) or indirectly, when water containing that constituent is diverted or removed (for example, irrigation diversions).

Evapotranspiration will not affect loads of conservative constituents simply because the quantity of water removed is always proportional to the increase in constituent concentration. Return flows in agricultural areas will not affect loads of conservative constituents if there are no sources or sinks and no change in ground-water storage in the surrounding aquifer. Assuming there is no annual change in ground-water storage, then annual return flows equal annual diversions minus evapotranspiration; therefore, the load diverted is equal to the load returned. Generally, dissolved solids can be considered conservative, whereas nutrients (dissolved nitrite plus nitrate and total phosphorus) are not conservative because of nutrient uptake and addition of nutrients due to the leaching of fertilizers.

Load Estimation

Constituent loads were estimated using ESTIMATOR2000 (Cohn and others, 1992). ESTIMATOR2000 performs a multivariate linear regression on the natural log of instantaneous concentration and instantaneous streamflow data. Streamflow, time, and seasonality are used as explanatory (or predictor) variables. The regression is then applied to the daily mean streamflow (arithmetic mean of all continuous streamflow measurements for that day) to compute daily constituent loads. The daily loads are summed to estimate the total monthly and total annual loads. From the total annual load, an estimated daily mean load (the average load on any given day for a particular year) is calculated.

Two common problems with regression applications are (1) retransformation bias and (2) large amounts of censored data (concentrations less than the minimum reporting level). ESTIMATOR2000 uses a minimum variance unbiased estimator (MVUE) to reduce bias introduced during retransformation; the adjusted maximum likelihood estimator is a generalization of the MVUE designed to deal with non-normal data distributions, such as those encountered in data sets with large amounts of censored data (Cohn and others, 1992).

ESTIMATOR2000 requires the user to define the model for each site and constituent. Cohn and others (1992) determined that this model satisfactorily captures most of the variability in constituent concentrations:

$$\ln[C] = B_0 + B_1 \ln[Q] + B_2 \ln[Q]^2 + B_3 T + B_4 T^2 \quad (1)$$

$$+ B_5 \sin[2PiT] + B_6 \cos[2PiT] + E,$$

where

ln[ ] denotes the natural logarithm function;
C is the daily mean constituent concentration;
Q is the daily mean streamflow;
T is time, expressed in years; and
E is an independent and random error.

This model requires the estimation of seven parameters: B_0, a constant; B_1 and B_2, a quadratic fit to the logarithm of streamflow (these parameters remove the variability related to flow dependence); B_3 and B_4, a quadratic fit to time (these parameters remove variability related to time trends); B_5 and B_6, a sinusoidal, first-order Fourier function (these parameters remove the effects of annual seasonality). For purposes of this report, the seven-parameter model was used for each site and constituent. Not all parameter estimates were statistically different from zero. However, all explanatory variables were used in every case, regardless of whether the parameter estimates were statistically different from zero, because "there was no *a priori* reason to believe that the parameter values should be equal to zero" (Cohn and others, 1992, p. 2358). In addition, if a parameter estimate is not statistically different from zero, then its regression coefficient will have little effect on estimated values.

ESTIMATOR2000 assumes that the instantaneous constituent concentration and the instantaneous streamflow are representative of average daily conditions (Robertson and Roerish, 1999). Large standard error in load estimates at a particular site is in part due to an instantaneous concentration or instantaneous streamflow that is not representative of average daily conditions.

Loads were estimated for all sites in the RIOG study unit for WY 1993-95, with the following exceptions. Loads were not estimated for Rio Grande at Isleta, New Mexico (RGIsleta), because a continuous streamflow record was not available at this site. Dissolved nitrite plus nitrate loads were not estimated upstream from San Marcial, New Mexico, because of insufficient data (too much censored data) for model calibration. Load estimates are presented in tables 2-5, along with the standard errors of prediction for the estimated loads.

The standard error of prediction, which represents variability in the system in addition to variability related to uncertainty in the model parameters, is a measure of the root mean squared error of the difference between the estimated load and the true load. The standard errors of prediction are presented in tons per day and as a percentage of the estimated daily mean loads (tables 2-5). Generally, the dissolved-solids model yielded estimates with the lowest standard errors of prediction (1 to 16 percent), and the suspended-sediment model yielded estimates with the highest standard errors of prediction (16 to 45 percent). The authors have chosen to focus discussion of dissolved-solids and nutrient-load estimates on WY 1994 because this year generally has the most data and the lowest standard errors of prediction; however, discussion of suspended-sediment load estimates will include WY 1993-95 because of the larger annual variability in estimated suspended-sediment loads.

STREAMFLOW

A general knowledge of the spatial and temporal variations in streamflow of the Rio Grande is necessary to understand the variations in constituent concentrations and the downstream transport of constituents. Temporal variations in streamflow can be used to determine how inflows and outflows (1) vary from year to year and (2) vary throughout the year. By examining spatial variations in streamflow, locations of major inflows and outflows along the Rio Grande can be determined.

Annual mean streamflow (the arithmetic mean of the arithmetic mean monthly streamflows for a specific year) allows for general comparison of streamflow (1) at a single site from year to year and (2) from site to site throughout the basin. During the 3-year study period, WY 1995 was the wettest at all 12 sites; WY 1994 was the driest at most sites on the Rio Grande (fig. 3). On the basis of long-term streamflow records, WY 1993-95 were wetter than the typical year (Crowfoot and others, 1996; Ortiz and Lange, 1996).

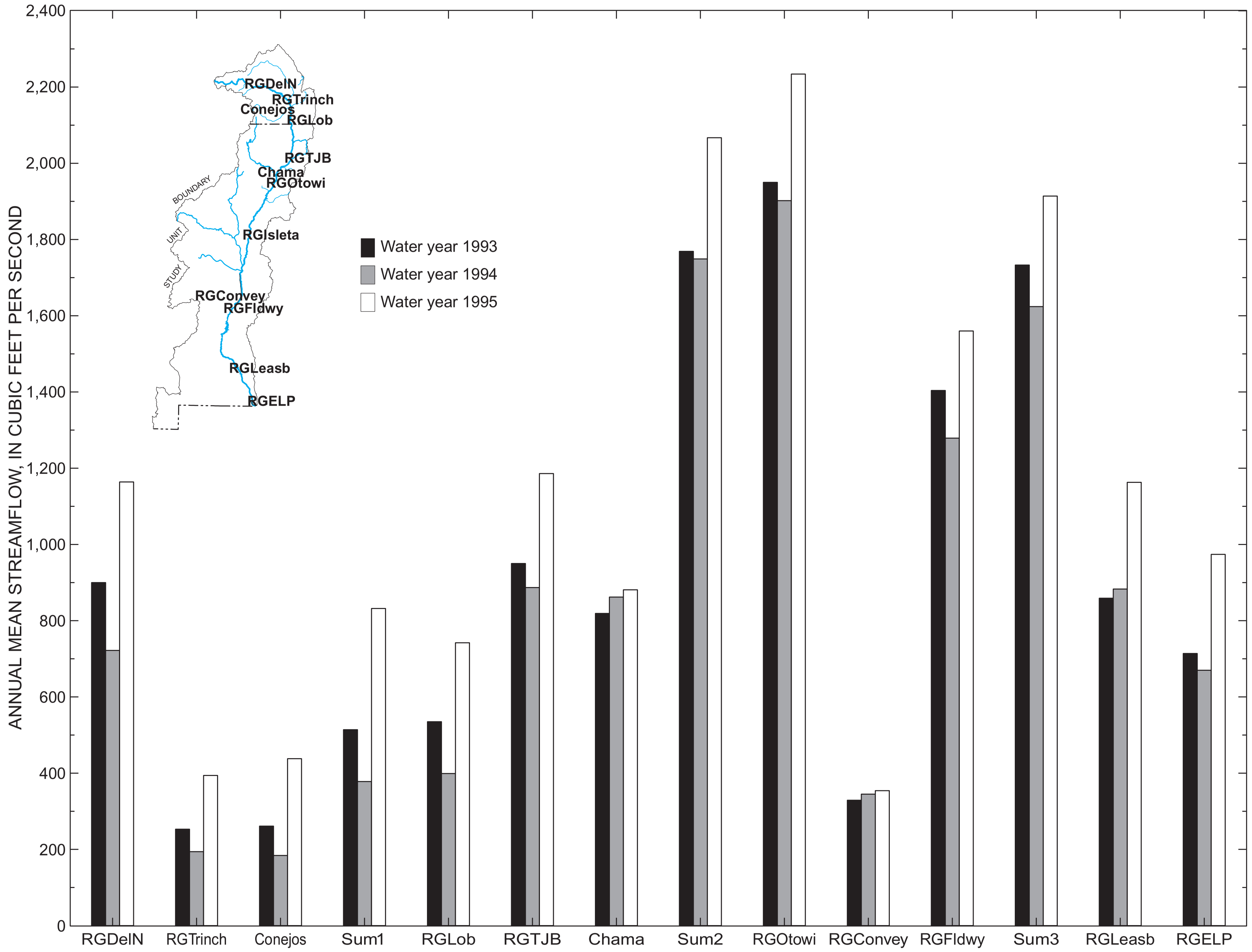


Figure 3. Annual mean streamflow at selected sites in the Rio Grande Valley study unit, water years 1993-95 (station names in table 1). (Sum1 = RGTrinch + Conejos; Sum2 = RGTJB + Chama; Sum3 = RGConvey + RGFldwy)

Spatial Variations in Streamflow

During WY 1993-95, annual mean streamflow at Rio Grande near Del Norte, Colorado (RGDelN), ranged from 722 to 1,164 ft^3/s (fig. 3). Streamflow decreased approximately 650 ft^3/s from RGDelN to Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colorado (RGTrinch), indicating an outflow between the two sites. Much of the outflow between RGDelN and RGTrinch was due to irrigation diversions to the San Luis Valley; from WY 1993 to WY 1995, diversions to the San Luis Valley ranged from approximately 530 to 840 ft^3/s, which is approximately 73 percent of flow at RGDelN (Colorado Division of Water Resources, 2002). Downstream from RGTrinch, the Conejos River discharges to the Rio Grande. Streamflow at Conejos River near Lasauses, Colorado (Conejos), was approximately equal to streamflow at RGTrinch (fig. 3). Thus, the resulting streamflow (RGTrinch plus Conejos), hereafter referred to as Sum1 streamflow, was almost twice that at RGTrinch. Sum1 streamflow was roughly equivalent to streamflow at Rio Grande near Lobatos, Colorado (RGLob), indicating no additional major inflows or outflows between RGTrinch and RGLob. Between RGLob and Rio Grande below Taos Junction Bridge, near Taos, New Mexico (RGTJB), streamflow increased approximately 450 ft^3/s; this is considerably larger than surface-water tributary inflow (approximately 390 ft^3/s) between the two sites (Ortiz and Lange, 1996), indicating the presence of another source of inflow, most likely ground water. Winograd (1959) indicated ground-water discharge to this section of the Rio Grande to be approximately 90 ft^3/s. Downstream from RGTJB, the Rio Chama discharged approximately 800 ft^3/s to the Rio Grande; the resulting streamflow (RGTJB plus Chama), hereafter referred to as Sum2 streamflow, was approximately twice that at RGTJB. Streamflow at RGOtowi was slightly larger than Sum2 streamflow (fig. 3), indicating inflow (probably tributary) between these two sites. No annual mean streamflow data are available for Rio Grande at Isleta, New Mexico (RGIsleta). Streamflow at Rio Grande Conveyance Channel at San Marcial, New Mexico (RGConvey), remained relatively constant (approximately 350 ft^3/s) from WY 1993 to WY 1995. Streamflow at Rio Grande Floodway at San Marcial, New Mexico (RGFldwy), ranged from 1,279 to 1,560 ft^3/s. Total discharge to Elephant Butte Reservoir (RGConvey plus RGFldwy), hereafter referred to as Sum3 streamflow, ranged from 1,624 to 1,914 ft^3/s. Streamflow decreased between RGOtowi and Sum3 (fig. 3) because outflows (due to irrigation diversions, ground-water outflow, and evapotranspiration) were greater than ground-water and surface-water inflows (from the Jemez River, the Rio Puerco, the Rio Salado, the Albuquerque WWTP, and the Rio Rancho WWTP). Elephant Butte Reservoir, Caballo Reservoir, and numerous irrigation diversion structures control flow at Rio Grande below Leasburg Dam, near Leasburg, New Mexico (RGLeasb). Streamflow at RGLeasb was smaller than Sum3 streamflow (by approximately 790 ft^3/s; fig. 3); the smaller flow was due to outflows for irrigation diversions between Elephant Butte Reservoir and Leasburg, the change in storage in the two reservoirs, and evapotranspiration. Streamflow decreased approximately 180 ft^3/s between RGLeasb and RGELP because outflows (due to irrigation diversions, evapotranspiration, and possibly leakage from the Rio Grande to the shallow ground-water system) were greater than ground-water and surface-water inflows.

Temporal Variations in Streamflow

Most sites in the RIOG study unit had the largest flows during the snowmelt season (from about April through July) and the smallest flows (base flow, which is primarily ground-water discharge) during the winter months (from about November through February) (figs. 4A-L). Annually, there can be large variation in streamflow during the snowmelt season relative to the variation in streamflow during the winter months.

At RGDelN (fig. 4A), large flows resulted from snowmelt in the late spring and early summer, whereas late summer thunderstorms (July, August) produced large flows of a lesser duration. Streamflow at RGTrinch (fig. 4B) was largest during the snowmelt season and smallest from July to October, when the largest irrigation diversions occurred (Colorado Division of Water Resources, 2002). Streamflow at Chama (fig. 4F) is regulated by upstream reservoirs. Some seasonal variation remained, however, in spite of these controls; the largest flow occurred from April to June. At RGConvey (fig. 4I), streamflow was directly related to the rate of ground-water discharge to agricultural drains, which was indirectly controlled by the volume of water diverted and used for irrigation purposes. Seasonal variations at RGLeasb (fig. 4K) and RGELP (fig. 4L) were directly related to releases from Caballo and Elephant Butte Reservoirs. Thus, flows are larger during the growing season, which extends from March through September, and are smaller when little or no water is released from Caballo Reservoir, from October through February.

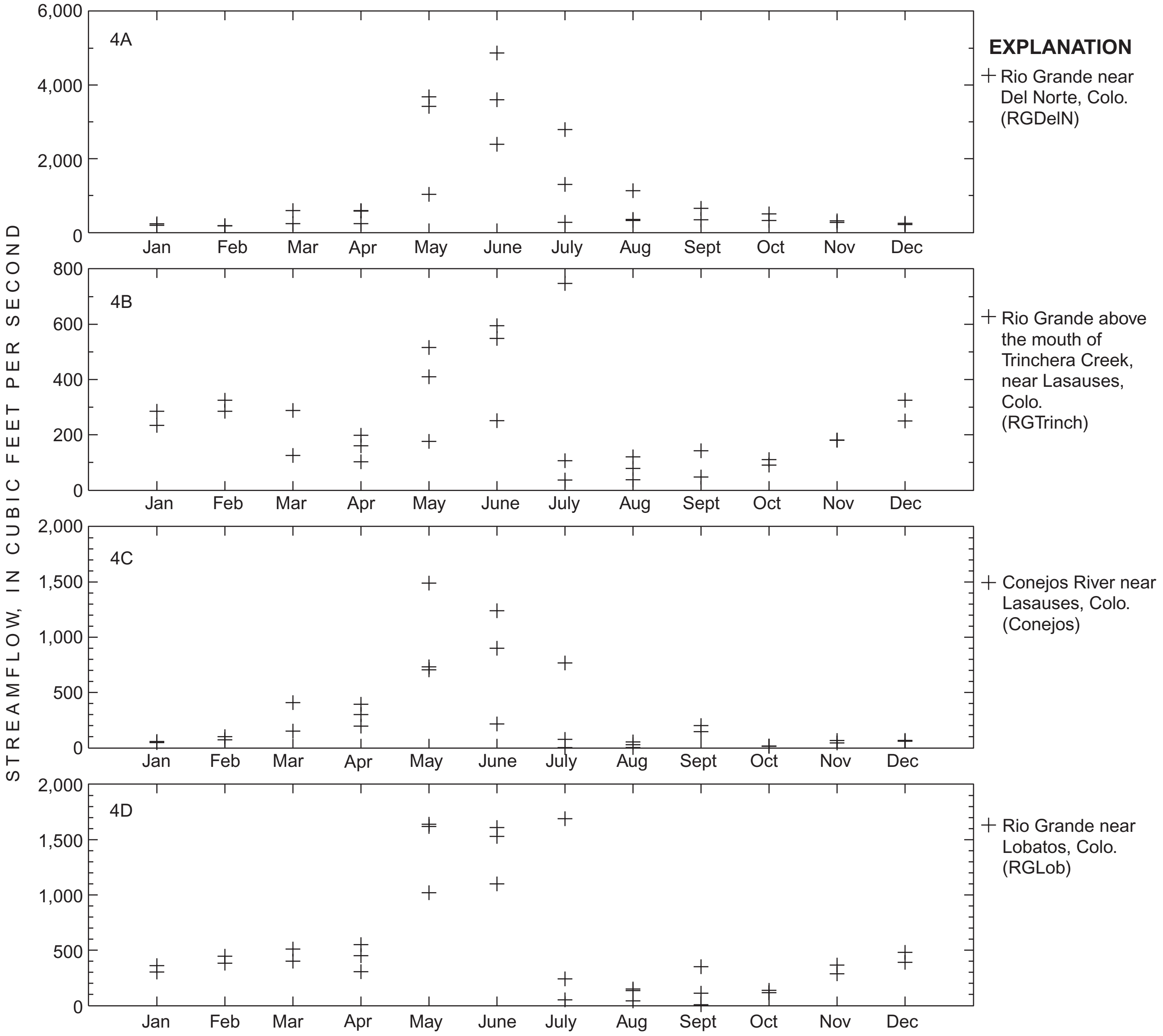


Figure 4. Temporal variation in instantaneous streamflow measurements at selected sites in the Rio Grande Valley study unit, water years 1993-95. Location of sites in figure 1.

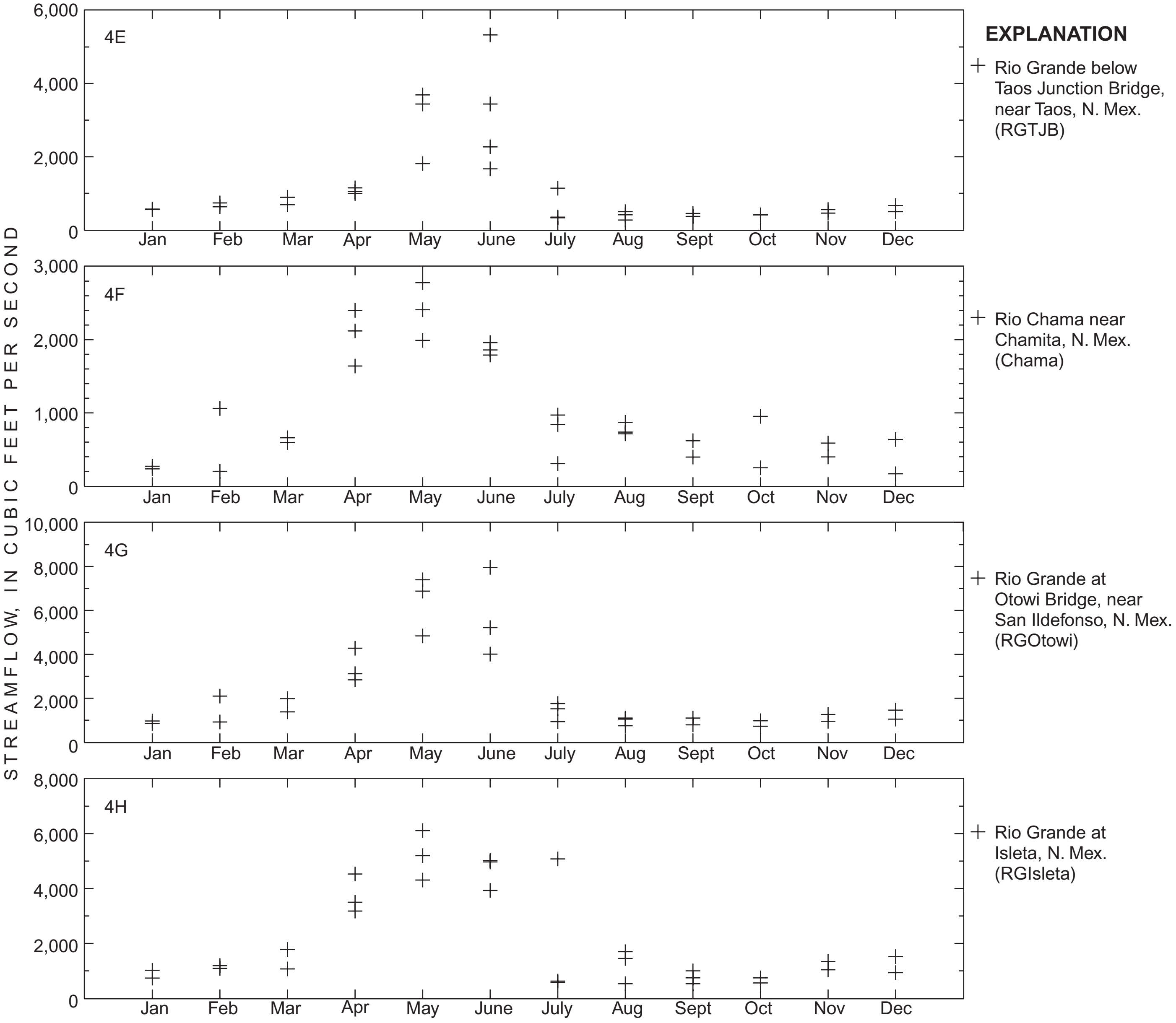


Figure 4. Temporal variation in instantaneous streamflow measurements at selected sites in the Rio Grande Valley study unit, water years 1993-95--Continued. Location of sites in figure 1.

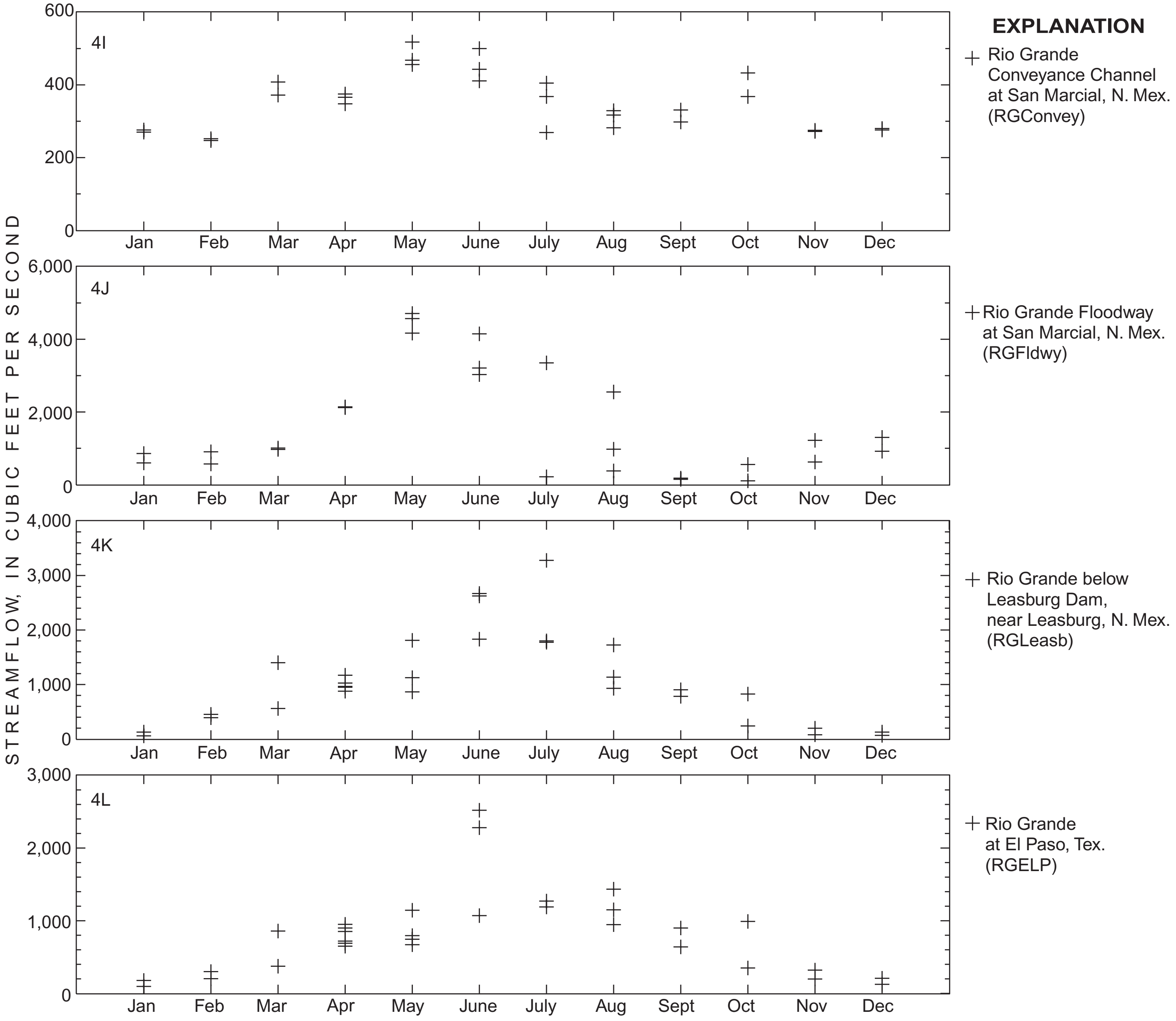


Figure 4. Temporal variation in instantaneous streamflow measurements at selected sites in the Rio Grande Valley study unit, water years 1993-95--Concluded. Location of sites in figure 1.

Downstream Temporal Variations in Streamflow

Downstream from RGDelN, diversions during the growing season caused smaller flows at RGTrinch (fig. 5). Except for the winter months, streamflow at RGTrinch was less than that at RGDelN, indicating diversions between the two sites. A similar situation occurred between RGLeasb and RGELP (fig. 6), although the diversions were smaller than those between RGDelN and RGTrinch. During winter months, water is not released from Caballo Reservoir; ground-water discharge to the Rio Grande between RGLeasb and RGELP contributes to the increasing streamflow between the sites.

Sum2 streamflow was approximately equal to streamflow at RGOtowi (fig. 7). In May and from November through January, RGOtowi streamflow was greater than Sum2 streamflow, indicating the presence of tributary inflow (other than the Rio Chama) or ground-water discharge to the Rio Grande between RGTJB and RGOtowi. In August 1994 and 1995, RGOtowi streamflow was less than Sum2 streamflow, indicating that outflows were greater than inflows between RGTJB and RGOtowi.

DISSOLVED SOLIDS

The concentration of dissolved solids is a general indicator of water quality; it is a measure of the dissolved ions in a water sample, including bicarbonate, calcium, chloride, magnesium, potassium, silica, sodium, and sulfate. Many natural and anthropogenic factors affect dissolved-solids concentrations in water. Natural factors include composition of precipitation, evapotranspiration, and the dissolution of minerals. Anthropogenic factors include wastewater effluent, application and subsequent leaching of agricultural chemicals, and increased evapotranspiration due to reservoirs and irrigation.

Spatial Variations in Dissolved-Solids Concentrations

Median dissolved-solids concentrations ranged from 73 mg/L at RGDelN to 652 mg/L at RGELP (fig. 8). An increase in the median dissolved-solids concentration was fourfold between RGDelN and RGTrinch. Possible causes of the increased dissolved-solids concentrations at RGTrinch are (1) surface-water inflow and (or) ground-water discharge to the Rio Grande, (2) surface-water inflow of ground water pumped from the San Luis Valley Closed Basin Project through the Franklin Eddy Canal, and (3) inflow from the WWTP in Alamosa, Colorado (Levings and others, 1998). Edelmann and Buckles (1984, p. 17) and Emery and others (1973, pl. 4) identified regions of “very high salinity hazard” (regions with a specific conductance greater than 2,250 µS/cm at 25 °C), which correspond to regions of large dissolved-solids concentrations (greater than 1,500 mg/L) in the shallow unconfined aquifer adjacent to the Rio Grande near Alamosa, Colorado (fig. 1); these regions may contribute ground-water discharge to the Rio Grande between RGDelN and RGTrinch. The median dissolved-solids concentration was smaller at RGLob (191 mg/L) than at RGTrinch (298 mg/L) because of dilution from Conejos inflow (fig. 8). From RGLob to RGOtowi, dissolved-solids concentrations varied little (fig. 8), indicating that concentrations of the inflow(s) were similar to those at RGLob. The median dissolved-solids concentration increased from RGOtowi (196 mg/L) to RGFldwy (299 mg/L) as the result of surface-water inflow (return flows, WWTP inflow, and tributaries) and ground-water discharge to the Rio Grande. Large concentrations at RGConvey (543 mg/L) resulted from irrigation effects (the concentration of solutes by evapotranspiration when Rio Grande water is diverted to fields for irrigation), evapotranspiration in riparian areas, and regional ground-water discharge to agricultural drains. The median dissolved-solids concentration at RGLeasb (448 mg/L) was greater than that at RGFldwy (299 mg/L) because of evapotranspiration (including evapotranspiration in riparian and agricultural areas and evaporation from reservoirs), ground-water discharge to the Rio Grande, and RGFldwy water mixing with more concentrated water from RGConvey in Elephant Butte Reservoir. From RGLeasb to RGELP, the median dissolved-solids concentration increased by 204 mg/L (fig. 8) because of irrigation effects and ground-water discharge.

Dissolved-solids concentrations at most sites in the RIOG study unit exhibited little variation, such as RGDelN, where concentrations ranged from 41 to 93 mg/L (fig. 8).

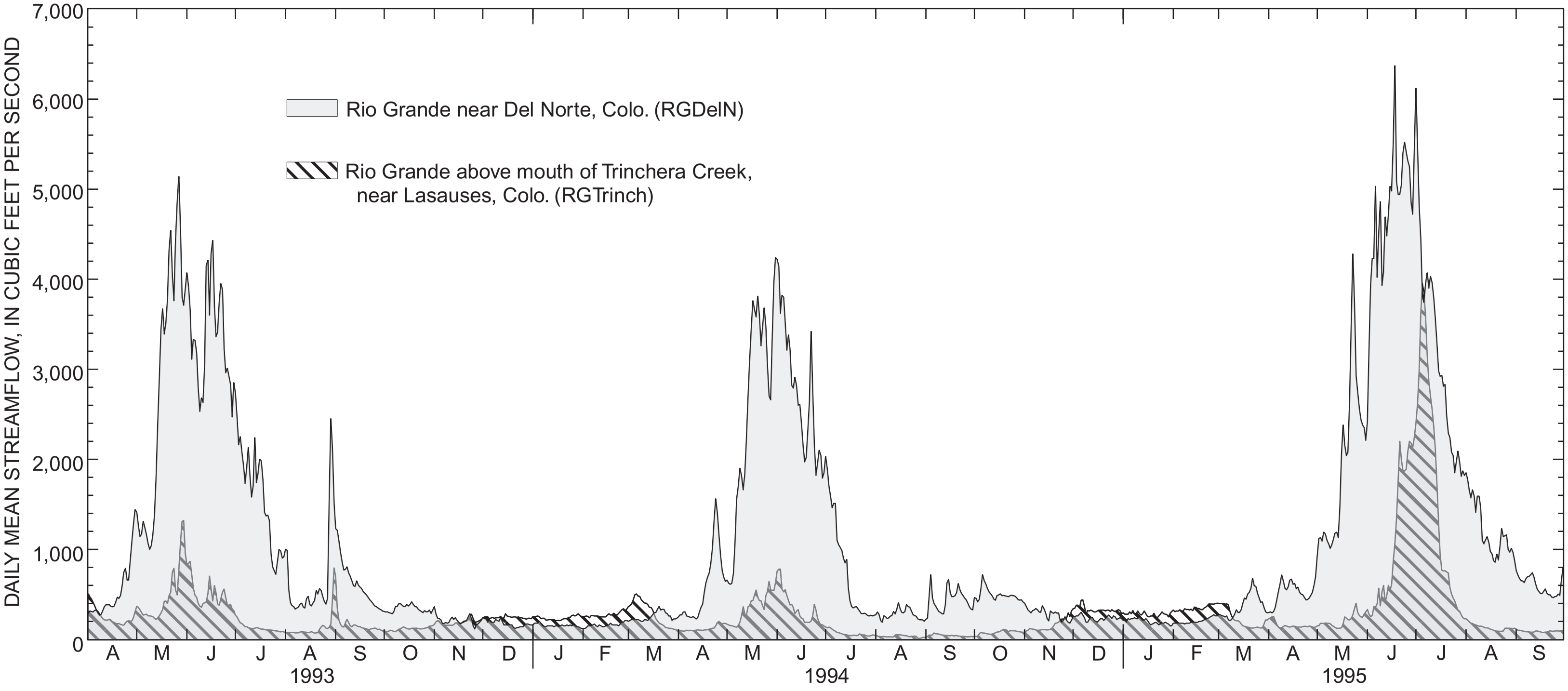


Figure 5. Daily mean streamflow at Rio Grande near Del Norte, Colo., and Rio Grande above the mouth of Trinchera Creek, near Lasauses, Colo., water years 1993-95. Location of sites in figure 1.

Figure 6

Figure 7

Figure 8

Concentrations at RGTrinch, RGLob, RGFldwy, RGLeasb, and RGELP had the largest variations (range greater than 260 mg/L) in the study unit. Generally, large variations in dissolved-solids concentrations at RGTrinch, RGFldwy, RGLeasb, and RGELP were caused by large variations in the quantity and quality of inflows.

Temporal Variations in Dissolved-Solids Concentrations

Temporal variations of dissolved-solids concentrations indicate four seasonal patterns (fig. 9). Six of 12 sites in the RIOG study unit (fig. 9A) had (1) larger dissolved-solids concentrations during the late fall and winter months (September-February), when streamflow is dominated by ground-water discharge, and (2) smaller concentrations during the spring and summer months (April through August), when flow is dominated by snowmelt and rainfall runoff. RGLob, RGTJB, and RGFldwy had the largest dissolved-solids concentrations in August and September (fig. 9), during the period of small flows (fig. 4) (except for the occasional large flows on the Rio Puerco that resulted in large flows at RGFldwy), and the smallest concentrations during May and June (fig. 9) because of large flows of snowmelt runoff (fig. 4). RGTrinch had a unique seasonal pattern; the smallest dissolved-solids concentrations occurred from November to February (fig. 9C). RGLeasb and RGELP had the largest concentrations from October to January (fig. 9D); at this time, flow in the Rio Grande consists of return flow and (or) ground-water discharge because water is not being released from Caballo Reservoir.

Downstream Temporal Variations in Dissolved-Solids Concentrations

Plots of instantaneous concentrations of dissolved solids allow for close examination of downstream temporal variations (fig. 10). In general, dissolved-solids concentrations were largest between RGDelN and RGTrinch (approximately 200 mg/L) from May to August (fig. 10A); this coincides with the largest diversions between RGDelN and RGTrinch (Colorado Division of Water Resources, 2002, and fig. 5). In WY 1995, dissolved-solids increases between RGDelN and RGTrinch (approximately 80 mg/L) were smallest during the winter months (December through February) when the smallest diversions occur (fig. 5); the smaller concentrations at RGTrinch during winter months could be attributed to a larger percentage of streamflow at RGTrinch from RGDelN. Water at RGTrinch mixes with inflow from the Conejos River, resulting in smaller dissolved-solids concentrations at RGLob relative to RGTrinch (fig. 10B). Generally, the decreases were largest from May to August when (1) large flows on the Conejos River result in a larger percentage of Conejos River water at RGLob and (2) dissolved-solids concentrations are largest at RGTrinch and smallest at Conejos (fig. 10B); the decreases were smallest from October to February when small flows on the Conejos River resulted in a smaller percentage of Conejos River water at RGLob. Dissolved-solids concentrations were approximately equal at RGLob and RGTJB (fig. 10C). Concentrations generally increased less than 100 mg/L between RGOtowi and RGFldwy (fig. 10D) because the amount of inflow was small and water quality of the inflow was very similar to that of the Rio Grande. Dissolved-solids concentrations increased 300 to 500 mg/L between RGOtowi and RGFldwy during late summer (August and September) because of large inflows from the Rio Puerco and the Rio Salado, ephemeral streams known for their large dissolved-solids concentrations. From RGLeasb to RGELP, concentrations increased approximately 200 mg/L throughout the year (fig. 10E).

Estimated Dissolved-Solids Loads

Given the large streamflow at RGDelN (fig. 3), the estimated daily mean dissolved-solids load was small (106 tons/d) because of the small dissolved-solids concentrations (fig. 8). Downstream at RGTrinch, streamflow decreased by more than a factor of two, yet the estimated daily mean dissolved-solids load increased by 31 tons/d (table 2). Decreasing streamflow indicates a net loss, yet increasing dissolved-solids load indicates a source with larger dissolved-solids concentrations than those at RGDelN or RGTrinch. Possible sources of dissolved solids are ground water from the shallow unconfined aquifer adjacent to the Rio Grande near Alamosa, Colorado, and surface-water inflow from the San Luis Closed Basin Project through the Franklin Eddy Canal. From WY 1993 to WY 1995, approximately 16 percent of the load at RGTrinch was from the Franklin Eddy Canal; however, from December through February,

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Figure 9 - 2 of 2 pages

Figure 10 - 1 of 2

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Table 2. Estimated daily mean dissolved-solids load and standard error of prediction, water years 1993-95
[Station names in table 1.
Sum1 = RGTrinch + Conejos; Sum2 = RGTJB + Chama; Sum3 = RGConvey
+ RGFldwy; NA, not applicable]

			Dissolved solids		
Site identification (table 1)	USGS station number	Water year	Estimated daily mean load (tons/day)	Standard error of prediction (tons/day)	Standard error of prediction (percent)
RGDelN	08220000	1993	143	4.82	3.38
RGDelN	08220000	1994	106	2.74	2.59
RGDelN	08220000	1995	173	5.08	2.94
RGTrinch	08240000	1993	157	13.63	8.69
RGTrinch	08240000	1994	137	6.53	4.78
RGTrinch	08240000	1995	249	23.20	9.31
Conejos	08249000	1993	58	2.43	4.18
Conejos	08249000	1994	40	1.45	3.58
Conejos	08249000	1995	67	2.25	3.37
Sum1	NA	1993	215	NA	NA
Sum1	NA	1994	177	NA	NA
Sum1	NA	1995	316	NA	NA
RGLob	08251500	1993	297	27.76	9.34
RGLob	08251500	1994	184	8.87	4.83
RGLob	08251500	1995	345	27.67	8.02
RGTJB	08276500	1993	456	18.66	4.09
RGTJB	08276500	1994	402	8.39	2.09
RGTJB	08276500	1995	544	14.69	2.70
Chama	08290000	1993	419	16.91	4.04
Chama	08290000	1994	425	9.79	2.30
Chama	08290000	1995	426	11.54	2.71
Sum2	NA	1993	875	NA	NA
Sum2	NA	1994	827	NA	NA
Sum2	NA	1995	970	NA	NA
RGOtowi	08313000	1993	946	43.17	4.57
RGOtowi	08313000	1994	885	18.74	2.12
RGOtowi	08313000	1995	1,091	28.12	2.58
RGConvey	08358300	1993	479	16.16	3.37
RGConvey	08358300	1994	504	6.58	1.30
RGConvey	08358300	1995	529	8.26	1.56
RGFldwy	08358400	1993	932	146.70	15.73
RGFldwy	08358400	1994	943	69.19	7.33
RGFldwy	08358400	1995	1,192	91.25	7.65
Sum3	NA	1993	1,412	NA	NA
Sum3	NA	1994	1,448	NA	NA
Sum3	NA	1995	1,722	NA	NA
RGLeasb	08363500	1993	985	43.52	4.42
RGLeasb	08363500	1994	1,076	28.20	2.62
RGLeasb	08363500	1995	1,309	43.34	3.31
RGELP	08364000	1993	1,180	44.49	3.77
RGELP	08364000	1994	1,214	23.09	1.90
RGELP	08364000	1995	1,550	44.50	2.87

as much as 45 percent of the dissolved-solids load at RGTrinch was from the Franklin Eddy Canal (E.M. Herrera, Bureau of Reclamation, written commun., 2001).

From RGTrinch to RGLob, the estimated daily mean dissolved-solids load increased from 137 to 184 tons/d (table 2), annual mean streamflow doubled (fig. 11), and the median dissolved-solids concentration decreased by one-third (fig. 8). Despite the large increase in streamflow, the load increased by only 47 tons/d because the dissolved-solids concentrations at Conejos were small relative to those at RGTrinch (fig. 8).

From RGLob to RGOtowi, changes in dissolved-solids load corresponded to changes in streamflow (fig. 11), and dissolved-solids concentrations showed only slight variations (fig. 8). In this reach, the load was affected primarily by increasing streamflow resulting from surface-water inflow and ground-water discharge to the Rio Grande. From RGTJB to RGOtowi, the estimated daily mean dissolved-solids load more than doubled because of an incoming load from Chama that was approximately equal to the load at RGTJB (table 2).

From RGOtowi to Sum3 (RGFldwy plus RGConvey), the estimated daily mean dissolved-solids load increased from 885 to 1,448 tons/d because of larger dissolved-solids concentrations (fig. 8) and smaller streamflow (fig. 3); that is, concentrations increased more than streamflow decreased. From Sum3 to RGLeasb, the dissolved-solids load decreased from 1,448 to 1,076 tons/d because of changes in storage in Elephant Butte and Caballo Reservoirs.

From RGLeasb to RGELP, streamflow decreased by 213 ft^3/s and the estimated daily mean load increased by 138 tons/d. Decreasing streamflow indicates a net loss, yet the increasing load indicates a source(s) of larger dissolved-solids concentrations than those at RGLeasb or RGELP. Regional ground-water discharge with large concentrations in the area (Wilson and others, 1981, p. 77) is the most likely cause of the increasing load.

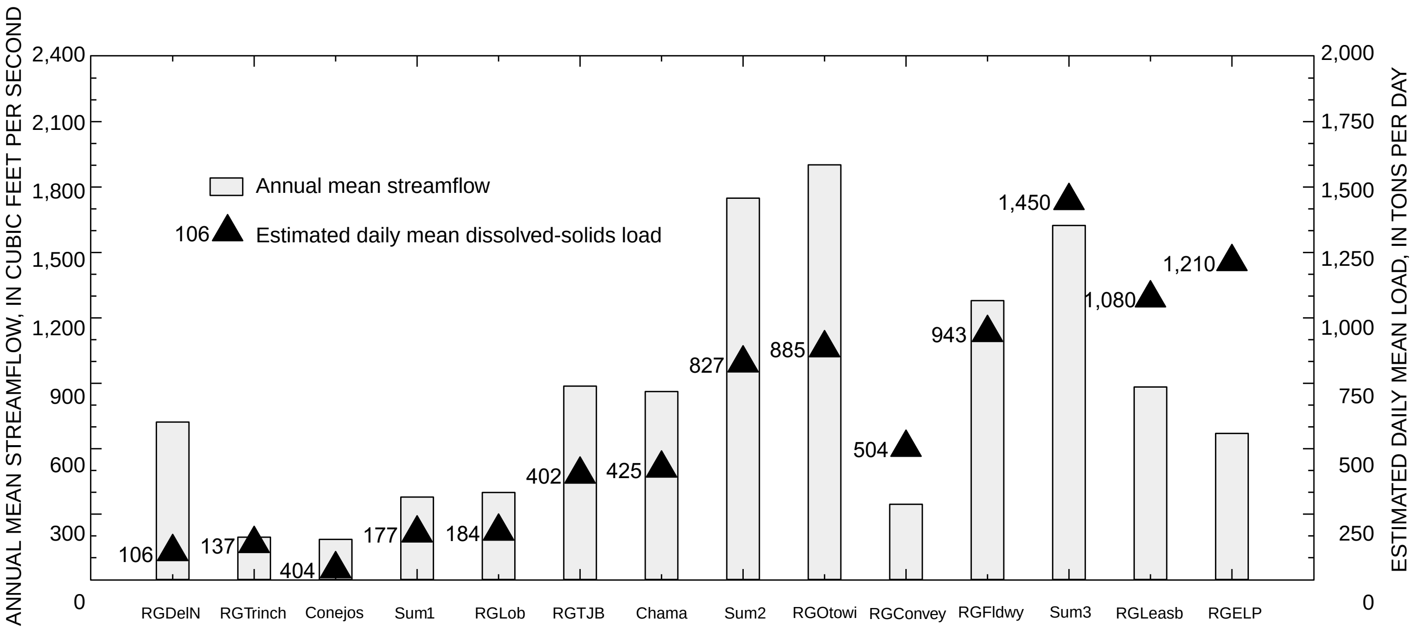

Figure 11. Annual mean streamflow and estimated daily mean dissolved-solids load at selected sites in the Rio Grande Valley study unit, water year 1994. Station names in table 1; location of sites in figure 1. (Sum1 = RGTrinch + Conejos; Sum2 = RGTJB + Chama; Sum3 = RGConvey + RGFldwy)

NUTRIENTS

Nutrients are elements that are essential to living organisms. Because of the scarcity of nitrogen and phosphorus relative to other essential elements, nitrogen and phosphorus are considered to regulate or “limit” plant productivity. This report limits discussion of nutrients to nitrogen and phosphorus.

Natural nutrient sources include atmospheric deposition, decaying organic material, and weathering of rocks and minerals. Anthropogenic nutrient sources include human, animal, and domestic waste (for example, wastewater effluent and runoff from animal feedlot facilities), phosphate detergents, fertilizers, septic-tank discharge, industrial waste, and urban runoff.

Nitrate and nitrite are soluble forms of nitrogen commonly detected in surface and ground water of the RIOG study unit. For this report, the authors limit the discussion to dissolved nitrite plus nitrate. In the RIOG study unit, dissolved nitrite concentrations were typically less than 0.01 mg/L, indicating that dissolved nitrite plus nitrate concentrations are essentially dissolved nitrate; thus, dissolved nitrite plus nitrate is hereafter referred to as dissolved nitrate.

Concentrations of total phosphorus are generally much larger than concentrations of dissolved phosphorus (Healy, 1997) because phosphorus is relatively insoluble and is sorbed by sediment (Hem, 1985, p. 126). Total phosphorous and suspended-sediment concentrations generally exhibit a statistically significant positive correlation on the Rio Grande (Anderholm and others, 1995, p. 76). Part of the phosphorus sorbed to sediment is available to plants and could contribute to excessive plant growth.

Dissolved Nitrate Concentrations

Spatial Variations in Dissolved Nitrate Concentrations

Concentrations of dissolved nitrate ranged from less than the minimum reporting level (0.05 mg/L) to 2.0 mg/L throughout the Rio Grande (fig. 12). Concentrations were less than 0.05 mg/L at RGDelN, Conejos, RGLob, and Chama and probably resulted from large surface-water inflow from undeveloped areas, which generally yield dissolved nitrate concentrations less than 0.04 mg/L (Clark and others, 2000). Upstream from RGIsleta, dissolved nitrate concentrations were small (median concentrations of 0.12 mg/L or less) and showed only slight variations (fig. 12). The larger concentrations at RGTrinch, RGTJB, and RGOtowi relative to other sites upstream from RGIsleta are due to ground-water and surface-water inflows. The decreases in dissolved nitrate concentrations at RGLob (relative to RGTrinch) and RGOtowi (relative to RGTJB) are due to dilutions from surface-water inflow water containing small dissolved nitrate concentrations, as seen in figure 12 by tributary inflow from the Conejos River and the Rio Chama. The median dissolved nitrate concentration increased from 0.06 to 0.66 mg/L between RGOtowi and RGIsleta because of WWTP inflow and, to a lesser extent, return flows. The median concentration at RGConvey (0.18 mg/L) was smaller than those at RGIsleta (0.66 mg/L) and RGFldwy (0.71 mg/L), indicating that return flows have small dissolved nitrate concentrations relative to irrigation water (water at RGIsleta and RGFldwy). The smaller dissolved nitrate concentrations in the Conveyance Channel indicate that (1) nutrient uptake occurs during irrigation and (2) leaching of nitrogen-based fertilizers does not cause increased dissolved nitrate concentrations. The interquartile range of concentrations at RGFldwy was similar to that at RGIsleta (fig. 12), indicating little effect on concentrations from surface-water inflows (from the Rio Puerco and Rio Salado). The median dissolved nitrate concentration decreased from 0.71 to 0.08 mg/L between RGFldwy and RGLeasb because of nutrient uptake in Elephant Butte and Caballo Reservoirs. The median dissolved nitrate concentration increased from 0.08 mg/L at RGLeasb to 0.31 mg/L at RGELP; potential causes include WWTP inflow, ground-water discharge to the Rio Grande, and (or) return flow.

Sites with small variability in dissolved nitrate concentrations include sites that drain basins with few urban or agricultural land uses (fig. 2): RGDelN, Conejos, and Chama. Sites with large variability in dissolved nitrate concentrations include RGIsleta, RGFldwy, and RGELP, all of which are affected by WWTP inflow. The large variability in concentrations at sites affected by WWTP inflow is due to seasonal variations in streamflow, which results in varying degrees of dilution of wastewater effluent; for example, when streamflow is small, WWTP inflow constitutes a larger percentage of total streamflow in the Rio Grande.

Figure 12

Temporal Variations in Dissolved Nitrate Concentrations

Five sites (RGDelN, RGTrinch, RGLob, RGOtowi, and RGELP) had their largest dissolved nitrate concentrations during the fall and winter (generally November–April) and their smallest concentrations during the spring and summer (generally March–October) (fig. 13A, 13B, 13D, 13G, 13L). Possible causes of smaller dissolved nitrate concentrations during spring and summer months are (1) dilution effects from large streamflows with small dissolved nitrate concentrations (snowmelt runoff) and (2) increased nutrient uptake resulting from longer days and warmer temperatures.

At RGTJB, RGIsleta, and RGFldwy, dissolved nitrate concentrations were smallest during May and June when streamflow was greatest (fig. 13E, 13H, 13J). Dissolved nitrate concentrations generally were largest during the winter months (fig. 13E, 13H, 13J) because of (1) less dilution of WWTP inflow by snowmelt runoff and (2) less nutrient uptake.

At Chama, dissolved nitrate concentrations were greater than the minimum reporting level (0.05 mg/L) only during the summer and early fall months (June–October) (fig. 13F). Chama streamflow ranged from 250 to 1,960 ft^3/s between June and October. Therefore, detectable nitrate concentrations at Chama are not related to a particular flow regime.

Dissolved nitrate concentrations at RGConvey were generally largest in March and from August to October (fig. 13I). Because streamflow at RGConvey was relatively constant throughout the year (fig. 4I), dissolved nitrate concentrations are probably not related to streamflow but rather to agricultural practices.

At RGLeasb, dissolved nitrate concentrations generally were largest from October to January (fig. 13K) when return flows and WWTP inflows constitute a larger percentage of water in the Rio Grande (because little or no water is released from Caballo Reservoir). Dissolved nitrate concentrations were generally smallest from March to September (less than 0.10 mg/L), indicating that return flows and WWTP inflows are diluted by large streamflows with small dissolved nitrate concentrations. Dissolved nitrate concentrations generally decreased from January to April (fig. 13K) because of dilution as discharge from Caballo Reservoir increased.

Downstream Temporal Variations in Dissolved Nitrate Concentrations

Small but consistent increases in dissolved nitrate concentrations (generally less than 0.1 mg/L) occurred between RGLob and RGTJB throughout the year, except during the snowmelt season (generally, May–July) when dissolved nitrate concentrations at both sites were less than 0.1 mg/L (fig. 14A). This indicates an inflow source (with larger dissolved nitrate concentrations) diluted by large streamflows during the snowmelt season and increased nutrient uptake during the growing season.

Dissolved nitrate concentrations increased by as much as 1.6 mg/L between RGOtowi and RGIsleta, most likely because of WWTP inflow (fig. 14B). The increases were smallest during the snowmelt season when WWTP inflow is diluted by large flows.

Generally, dissolved nitrate concentrations were similar at RGIsleta and RGFldwy, indicating little effect from inflows and little nutrient uptake as water moves downstream in the Rio Grande (fig. 14C). However, dissolved nitrate concentrations at RGConvey were smaller than at RGIsleta (fig. 14C). Water in the Conveyance Channel consists of return flows. Water at RGIsleta is representative of water used for irrigation. The smaller dissolved nitrate concentrations at RGConvey relative to those in irrigation water are indicative of nutrient uptake as water is applied to fields and moves through the ground-water system to agricultural drains and eventually to the Conveyance Channel.

Estimated Dissolved Nitrate Loads

As already stated, dissolved nitrate loads were not estimated upstream from San Marcial because of insufficient data for model calibration. In WY 1994, estimated daily mean dissolved nitrate loads decreased between Sum3 (2.58 tons/d) and RGLeasb (0.19 ton/d), then increased between RGLeasb and RGELP (0.64 ton/d) (fig. 15 and table 3). Dissolved nitrate loads at RGFldwy (2.40 tons/d) were greater than those at RGConvey (0.18 ton/d) because streamflow at RGFldwy was greater than that at RGConvey (fig. 3) and, most importantly, because dissolved nitrate concentrations at RGFldwy were larger than those at RGConvey (fig. 12). The dissolved nitrate load decreased from Sum3 to RGLeasb because streamflow decreased (due to storage in Elephant Butte and Caballo Reservoirs) and dissolved nitrate concentrations decreased (due to nutrient uptake in the reservoirs). The estimated daily mean dissolved

Figure 13 - 1 of 3

Figure 13 - 2 of 3

Figure 13 - 3 of 3

Figure 14

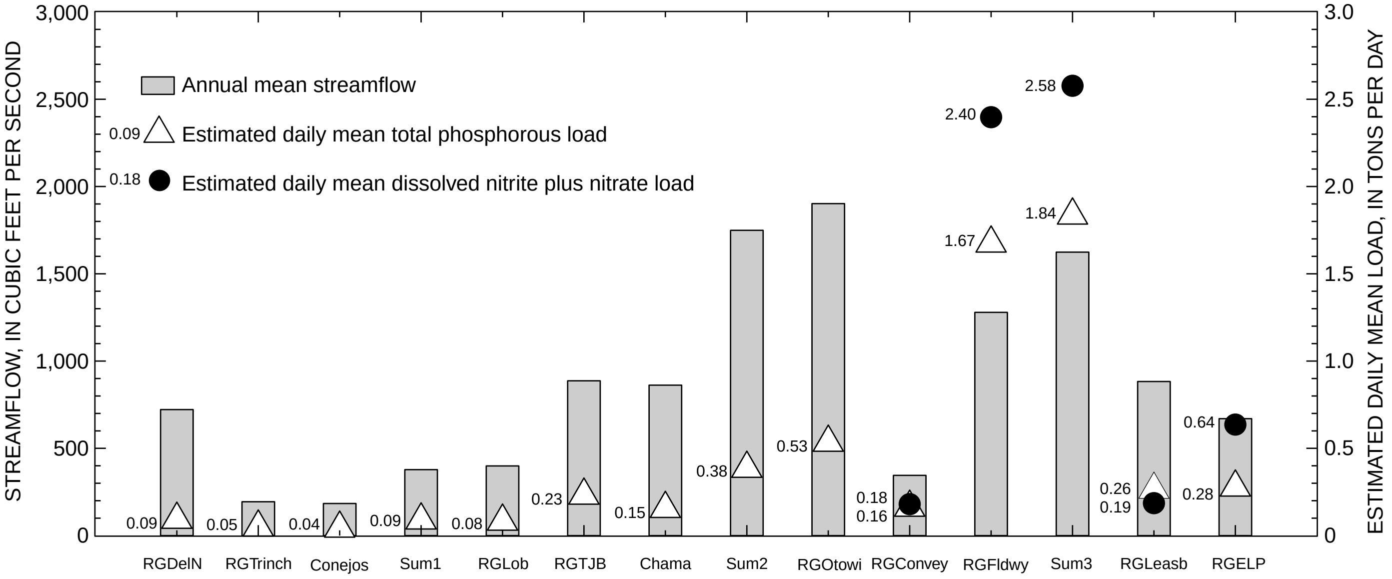

Figure 15. Annual mean streamflow and estimated daily mean dissolved nitrite plus nitrate and total phosphorous loads at selected sites in the Rio Grande Valley study unit, water year 1994. Station names in table 1. (Sum1 = RGTrinch + Conejos; Sum2 = RGTJB + Chama; Sum3 = RGConvey + RGFldwy)

Table 3

nitrate load increased from RGLeasb to RGELP because, although streamflow decreased (fig. 3), dissolved nitrate concentrations increased (fig. 12). Healy (1996) indicated that in this area, dissolved nitrate loads to the Rio Grande from non-agricultural sources (such as WWTP inflow) were greater than those from return flows.

Total Phosphorous Concentrations

Spatial Variations in Total Phosphorous Concentrations

Concentrations of total phosphorus generally were small (less than 0.1 mg/L) and had small variability from RGDelN to RGOtowi (fig. 16). Total phosphorous concentrations were largest and had the largest variability at RGIsleta and RGFldwy.

The median total phosphorous concentration was larger at RGTrinch (0.10 mg/L) than at RGDelN (0.04 mg/L) because of inflow between the two sites. The median total phosphorous concentration increased from RGOtowi (0.07 mg/L) to RGIsleta (0.32 mg/L) most likely because of WWTP inflow. The median total concentration increased from RGIsleta (0.32 mg/L) to RGFldwy (0.43 mg/L) because of inflows from the Rio Puerco, which can have large concentrations of phosphorus (Healy, 1997). The median total phosphorous concentration decreased from 0.43 to 0.06 mg/L from RGFldwy and RGLeasb because of settling and nutrient uptake in Elephant Butte and Caballo Reservoirs. The median total phosphorous concentration increased from RGLeasb to RGELP (0.12 mg/L) in part because of WWTP inflows (Healy, 1996).

Temporal Variations in Total Phosphorous Concentrations

Total phosphorous concentrations at five sites (RGDelN, RGTrinch, Conejos, RGTJB, and RGOtowi) were smaller during the winter months (December–February) and larger throughout the rest of the year (March–November); total phosphorous concentrations were largest during snowmelt (May and June) (fig. 17A-C, 17E, 17G). The larger total phosphorous concentrations during snowmelt are due to increased streamflow and the associated increase in suspended-sediment concentrations. The larger total phosphorous concentrations in May and June could also be related to fertilizer applications; concurrent increases in dissolved nitrate concentrations were not observed, however. Total phosphorous concentrations at RGLob and Chama seemed to lack a consistent seasonal pattern (fig. 17D, 17F). This could indicate the presence of a variety of phosphorous sources in these basins.

Total phosphorous concentrations at RGIsleta and RGFldwy generally were smallest from April through June (fig. 17H, 17J) due to dilution of WWTP inflow by large streamflow. Total phosphorous concentrations in wastewater effluent (3 to 15 mg/L, Snoeyink and Jenkins, 1980, p. 301) were larger than those at RGOtowi during snowmelt (as much as 0.3 mg/L, fig. 17G). For this reason, whereas large streamflow (during snowmelt) resulted in increased total phosphorous concentrations at some sites (fig. 17A-C, 17E, 17G), large streamflow caused total phosphorous concentrations to decrease at sites affected by WWTP inflow because the concentrations (upstream from WWTP inflows) were still small relative to those in wastewater effluent.

Total phosphorous concentrations increased during snowmelt because nonpoint sources dominated the large flows. In contrast, total phosphorous concentrations decreased during snowmelt at RGIsleta because the point sources were dominated by snowmelt runoff.

At RGConvey, total phosphorous concentrations were largest at two distinct times throughout the year: during March and August through October. Total concentrations at RGLeasb and RGELP were smallest in April, May, November, and December.

Downstream Temporal Variations in Total Phosphorous Concentrations

Generally, total phosphorous concentrations were larger at RGLob than at RGTJB (fig. 18A), indicating that ground-water and surface-water inflows between the two sites diluted the larger concentrations detected at RGLob. However, during the 1994 and 1995 snowmelt seasons, total phosphorous concentrations were larger at the downstream site, RGTJB, which indicates a source of total phosphorus between the two sites.

Total phosphorous concentrations generally increased between RGOtowi and RGIsleta (fig. 18B). The smallest increases in concentration occurred during the snowmelt season because of more dilution due to increased streamflow. Large increases in concentration occurred in July 1993 and August 1994 because of less dilution of WWTP inflow or possibly increased storm runoff.

Figure 16

Figure 17 - 1 of 3

Figure 17 - 2 of 3

Figure 17 - 3 of 3

Figure 18

Total phosphorous concentrations at RGIsleta and RGFldwy generally were similar (fig. 18C). This similarity indicates either (1) little settling or nutrient uptake of phosphorus occurs between sites or (2) increases in concentrations due to surface-water inflow (from the Rio Puerco or Rio Salado) are balanced by decreases in total phosphorous concentrations due to settling or nutrient uptake. Occasionally, total phosphorous concentrations at RGFldwy were much larger (by as much as 1 mg/L) than those at RGIsleta. These larger concentrations at RGFldwy indicate that either (1) surface-water inflow from the Rio Puerco or Rio Salado occurred or (2) sediment (and sorbed phosphorus), which was previously deposited in the Rio Grande by the Rio Puerco or Rio Salado, was resuspended.

Estimated Total Phosphorous Loads

In WY 1994, the total phosphorous load decreased from RGDelN (0.09 ton/d) to RGTrinch (0.05 ton/d) as did streamflow (fig. 3), indicating a net outflow of total phosphorus. The load at Conejos (0.04 ton/d) was approximately equivalent to that at RGTrinch (0.05 ton/d). From Sum1 (0.09 ton/d) to RGLob (0.08 ton/d) (table 5), the estimated daily mean load remained fairly constant, indicating that phosphorous inputs equaled phosphorous outputs in this reach. The total phosphorous load increased between RGLob (0.08 ton/d) and RGTJB (0.23 ton/d), as did streamflow; however, concentrations decreased. The total phosphorous load from the Rio Chama (0.15 ton/d) was smaller than that at RGTJB (0.23 ton/d). The increase in estimated daily mean load between Sum2 (0.38 ton/d) and RGOtowi (0.53 ton/d) indicates a source of total phosphorus (other than surface-water inflow from the Rio Chama to the Rio Grande) between RGTJB and RGOtowi.

The estimated daily mean total phosphorous load increased from RGOtowi (0.53 ton/d) to Sum3 (1.84 tons/d) despite a decrease in streamflow (fig. 15 and table 4). The increase in load indicates an inflow. The decrease in streamflow indicates that outflows are greater than inflows between RGOtowi and Sum3. Therefore, the total phosphorous concentration of the inflow must have been greater than that at RGOtowi. Possible sources of inflow would be WWTP inflow, tributary inflow, and return flow. Wastewater effluent can have total phosphorous concentrations as large as 15 mg/L (Snoeyink and Jenkins, 1980, p. 301). Both the Rio Puerco and the Rio Salado discharge directly into the Rio Grande. Water-quality data for the Rio Puerco show that the median total phosphorous concentration for WY 1993-95 was 2.7 mg/L (Healy, 1997), which is large relative to the concentration at RGOtowi (0.07 mg/L). The estimated daily mean total phosphorous load at RGConvey (0.16 ton/d) was approximately equal to that at Chama; however, streamflow at Chama was about 2.5 times greater than streamflow at RGConvey.

The estimated daily mean total phosphorous load at RGLeasb (0.26 ton/d) was smaller than that at Sum3 (1.84 tons/d) because of a combination of (1) smaller streamflow at RGLeasb, due to changes in storage at Elephant Butte and Caballo Reservoirs, and (2) smaller total phosphorous concentrations that resulted from nutrient uptake and the settling of phosphorus in the reservoirs.

Total phosphorous loads at RGLeasb (0.26 ton/d) and RGELP (0.28 ton/d) were about the same despite decreases in streamflow; this indicates an inflow with larger concentrations than at RGLeasb. Inflows could include WWTP inflow and return flows; Healy (1996, p. 39) indicated that total phosphorous loads from these two sources are approximately equal.

SUSPENDED SEDIMENT

Suspended sediment is a measure of sand- to clay-sized suspended material in a water sample. The percentage of sand, silt, and clay varies (1) from site to site and (2) over time at a particular site. Suspended-sediment concentrations are related to a variety of physical factors, such as streamflow velocity, availability of erodible material in a watershed, and the grain size and distribution of material in a watershed. In the RIOG study unit, suspended-sediment concentrations generally are positively correlated with streamflow (Anderholm and others, 1995).

Ephemeral streams periodically contribute large amounts of suspended sediment to the Rio Grande and its tributaries. Some of this sediment is deposited in the channel of the Rio Grande near the mouth of the stream. This sediment can then be resuspended and transported later during periods of increased streamflow; this results in large variability of suspended-sediment concentrations.

Table 4

Table 5

Spatial Variations in Suspended-Sediment Concentrations

Median suspended-sediment concentrations generally increased from RGDelN to RGFldwy (fig. 19). The range of median suspended-sediment concentrations throughout the study unit was three orders of magnitude, which is greater than the range observed in other constituents (figs. 8, 12, 16). Concentrations increased from 12 to 52 mg/L between RGDelN and RGTrinch. Suspended-sediment concentrations at RGLob (42 mg/L) decreased slightly because of dilution from Conejos (22 mg/L), which had small concentrations relative to those at RGLob. Suspended-sediment concentrations decreased between RGLob (42 mg/L) and RGTJB (36 mg/L), possibly because of a decrease in available sediment or dilution from ground-water and surface-water inflow. The interquartile range of suspended-sediment concentrations at Chama was larger than that at any other site, indicating that suspended-sediment concentrations on the Rio Chama were highly variable. Surface-water inflow from the Rio Chama and other tributaries resulted in an increase in suspended-sediment concentrations from RGTJB to RGOtowi. RGIsleta had a slightly smaller concentration (272 mg/L) than RGOtowi (332 mg/L), possibly because of settling of suspended sediment in Cochiti Lake. From RGIsleta to RGFldwy, the median suspended-sediment concentration increased from 272 to 1,610 mg/L; this was caused by the exceptionally large concentrations in the Rio Puerco and the Rio Salado (Anderholm and others, 1995). Downstream from RGFldwy, concentrations decreased because of settling of suspended sediment in Elephant Butte and Caballo Reservoirs. Suspended-sediment concentrations increased from RGLeasb (141 mg/L) to RGELP (219 mg/L) most likely as a result of agricultural activities, surface-water inflow from ephemeral streams, and resuspension and erosion of previously deposited sediments.

Generally, suspended-sediment concentrations at a particular site can vary by an order of magnitude or more, whereas dissolved-solids, dissolved nitrate, and total phosphorous concentrations at a particular site have much smaller variability. Sites with the largest variability in suspended-sediment concentrations include RGDelN, Chama, and RGIsleta. Concentrations at RGDelN were generally less than 50 mg/L, whereas suspended-sediment concentrations at Chama and RGIsleta generally were greater than 70 mg/L.

Suspended Sediment/Streamflow Relations

In general, suspended-sediment concentrations are positively correlated with streamflow, but the strength of the relation, which depends on a variety of factors, varies from site to site. Sites that had the strongest suspended-sediment/streamflow relation are RGDelN, Conejos, RGTJB, RGLeasb, and RGELP (fig. 20). These sites generally had the largest suspended-sediment concentrations from May to August.

Estimated Suspended-Sediment Loads

Estimated daily mean suspended-sediment loads varied at individual sites from year to year and between sites (table 5 and fig. 21) because of (1) natural variation in streamflow and delivery of sediment to various reaches of the Rio Grande and (2) data limitations related to the large variability in suspended-sediment concentrations at a site from year to year and the short period of record used for model calibration. The large standard errors of prediction associated with estimated suspended-sediment loads (table 5) are due in part to the larger variability in suspended-sediment concentrations (at a particular site) and trend-related coefficients that are statistically different from zero (B_3 and B_4, eq. 1). The errors resulting from large variability in suspended-sediment concentrations could indicate that more frequent instantaneous concentrations are needed to accurately characterize the variability in suspended-sediment concentrations. Trend-related coefficients that are statistically different from zero indicate time trends; these could be due to the short period of record used for model calibration. Because of the larger annual variability in suspended-sediment loads, WY 1993-95 are discussed.

Estimated daily mean suspended-sediment loads at RGDelN and RGTrinch were smallest in WY 1993 and 1994 and largest in WY 1995 (table 5 and fig. 21). Between these sites, the load decreased by about a factor of four (every year) despite increases in suspended-sediment concentrations; the decrease in suspended-sediment load was due to the decrease in streamflow.

Figure 19

Figure 20

Figure 21

Estimated daily mean suspended-sediment loads at Conejos were approximately equal in WY 1993 and 1995; the load in WY 1994 was less than half the load in WY 1993 or 1995. When the incoming load from Conejos was small (29.6 tons/d in WY 1994), there was little change in the suspended-sediment load from RGTrinch (41.2 tons/d) to RGLob (51.6 tons/d) (table 5). However, when larger loads entered the Rio Grande from the Conejos River (73.2 tons/d in WY 1993 and 74.4 tons/d in WY 1995), the suspended-sediment loads increased by factors of about two and three, respectively (table 5).

Although the suspended-sediment concentrations decreased from RGLob to RGTJB (fig. 19), the suspended-sediment load increased every year. This resulted in estimated daily mean suspended-sediment loads ranging from 175 tons/d (WY 1993) to 405 tons/d (WY 1995) at RGTJB (table 5).

Suspended-sediment loads at Chama varied by an order of magnitude, from 221 tons/d (WY 1993) to 1,846 tons/d (WY 1995). The large variation in loads at Chama is reflected in the large variation in suspended-sediment loads at RGOtowi (table 5). By comparing the estimated daily mean total suspended-sediment load of Sum2 to the load at RGOtowi, it is apparent that the load entering the Rio Grande (between RGTJB and RGOtowi), besides the Rio Chama, varied greatly from year to year. The smallest incoming suspended-sediment load occurred in WY 1993 with a minimum of 88 tons/d entering the Rio Grande; the largest incoming load occurred in WY 1994 with a minimum of 1,512 tons/d entering the Rio Grande.

The estimated daily mean total suspended-sediment load at Sum3 was relatively consistent from year to year, as was streamflow. Suspended-sediment loads at RGConvey varied from 270 tons/d in WY 1994 to 593 tons/d in WY 1995. Loads at RGConvey were approximately equal to loads at RGTJB, although the streamflow at RGConvey was generally less than half the streamflow at RGTJB (fig. 21).

Estimated daily mean suspended-sediment loads at RGFldwy were larger than those at any other site in the RIOG study unit and exhibited little variation from year to year (table 5). Although Cochiti Lake allows for increased settling of suspended sediment between RGOtowi and RGFldwy, the suspended-sediment load increased from 484 to 9,420 tons/d in WY 1993 and tripled in WY 1994 and 1995 despite decreases in streamflow. The increases in load at RGFldwy can be attributed, at least partially, to the incoming suspended-sediment loads from ephemeral streams; the median suspended-sediment load in the Rio Puerco for WY 1993-95 was 12,900 tons/d (Healy, 1997).

The estimated daily mean suspended-sediment load decreased from Sum3 to RGLeasb because of decreases in streamflow and settling of suspended sediment in Elephant Butte and Caballo Reservoirs. Suspended-sediment loads at RGLeasb varied by an order of magnitude, from 447 tons/d in WY 1993 to 4,533 tons/d in WY 1995 (table 5). Although streamflow at RGLeasb did not vary by an order of magnitude, the smallest and largest streamflows correspond to the smallest and largest suspended-sediment loads.

The suspended-sediment load at RGELP varied from year to year, with the smallest load occurring in WY 1994 (637 tons/d) and the largest load occurring in WY 1995 (2,130 tons/d). In WY 1993, the suspended-sediment load increased from RGLeasb to RGELP. In WY 1994, the load at RGELP was approximately equal to the load at RGLeasb. In WY 1995, the suspended-sediment load decreased from RGLeasb (4,530 tons/d) to RGELP (2,130 tons/d). The variation may be due to inflow of ephemeral streams, including the deposition of suspended sediment in the Rio Grande and the subsequent slow, downstream transport of suspended sediment.

EFFECTS OF VARIATIONS IN STREAMFLOW AND CONCENTRATIONS ON LOADS IN THE RIO GRANDE VALLEY STUDY UNIT

From RGDelN to RGTrinch (fig. 22), streamflow decreased from 722 to 194 ft^3/s because outflows (primarily from agricultural diversions) are larger than inflows. Median dissolved-solids concentrations increased by a factor of four (from 73 to 298 mg/L), median dissolved nitrogen concentrations increased from less than 0.05 to 0.06 mg/L, median total phosphorous concentrations increased from 0.04 to 0.10 mg/L, and median suspended-sediment concentrations increased by a factor of four (from 12 to 52 mg/L). Changes in streamflow and water quality resulted in an increase in the estimated daily mean dissolved-solids load (from 106 to 137 tons/d), a decrease in total phosphorous load (from 0.092 to 0.048 ton/d), and a decrease in suspended-sediment load (from 169 to 41 tons/d). Therefore, the incoming dissolved-solids load was larger than that diverted, and

Figure 22

the incoming total phosphorous and suspended-sediment loads were smaller than those diverted. Furthermore, this indicates that inflow in this reach had large dissolved-solids concentrations (relative to RGDelN) but small total phosphorous and suspended-sediment concentrations (relative to RGDelN).

From RGTrinch to RGOtowi, streamflow increased from 194 to 1,902 ft^3/s because of inflow (primarily tributary inflow). Inflow from the Conejos River accounts for most of the increases in streamflow (184 ft^3/s) between RGTrinch and RGLob; however, comparison of Sum1 and RGLob indicates additional inflow (approximately 21 ft^3/s). Inflow from the Rio Chama accounts for most of the increases in streamflow (862 ft^3/s) between RGTJB and RGOtowi; however, comparison of Sum2 and RGTJB indicates additional inflow (approximately 153 ft^3/s). From RGTrinch to RGOtowi, median dissolved-solids concentrations decreased from 298 to 196 mg/L (primarily because of dilution by tributary inflow), median dissolved nitrate concentrations did not change, median total phosphorous concentrations decreased from 0.10 to 0.07 mg/L, and median suspended-sediment concentrations increased from 52 to 332 mg/L. The large increase in streamflow caused increases in dissolved-solids load (137 to 885 tons/d), total phosphorous load (0.048 to 0.53 ton/d), and suspended-sediment load (41 to 3,035 tons/d), indicating that incoming loads are greater than outgoing loads in this reach.

From RGOtowi to RGFldwy (fig. 22), streamflow decreased from 1,902 to 1,279 ft^3/s because outflows were larger than inflows. Median dissolved-solids concentrations increased from 196 to 299 mg/L, median dissolved nitrate concentrations increased from 0.06 to 0.71 mg/L, median total phosphorous concentrations increased from 0.07 to 0.43 mg/L, and median suspended-sediment concentrations increased from 332 to 1,610 mg/L; these changes in concentrations are due to inflows from WWTP’s, tributaries, and return flows. Despite the decrease in streamflow, all loads increased. The dissolved-solids load increased from 885 to 943 tons/d, total phosphorous load increased from 0.53 to 1.67 tons/d, and suspended-sediment load increased from 3,035 to 10,517 tons/d. Because return flows and evapotranspiration do not affect dissolved-solids loads, the most likely cause is regional ground-water inflow and tributary inflow. The increases in nutrient loads are caused by WWTP inflow, return flows, and inflow from ephemeral channels. The increase in suspended-sediment load is caused by inflow from ephemeral streams (the Rio Puerco and Rio Salado).

From RGFldwy to RGLeasb (fig. 22), Elephant Butte and Caballo Reservoirs have major impacts on streamflow. During this study, the reservoirs generally caused decreases in streamflow because of changes in storage and evapotranspiration, increases in dissolved-solids concentrations due to evapotranspiration, decreases in nutrient concentrations due to settling and nutrient uptake, and decreases in suspended-sediment concentrations due to settling. The result is an increase in dissolved-solids load and decreases in dissolved nitrate, total phosphorous, and suspended-sediment loads.

From RGLeasb to RGELP (fig. 22), streamflow decreased from 883 to 670 ft^3/s, indicating that outflows were greater than inflows. Median dissolved-solids concentrations increased from 448 to 652 mg/L, median dissolved nitrate concentrations increased from 0.08 to 0.31 mg/L, median total phosphorous concentrations increased from 0.06 to 0.12 mg/L, and median suspended-sediment concentrations increased from 141 to 219 mg/L. Despite the decrease in streamflow, the dissolved-solids load increased from 1,076 to 1,214 tons/d, the dissolved nitrate load increased from 0.19 to 0.64 ton/d, the total phosphorous load increased from 0.26 to 0.28 ton/d, and changes in suspended-sediment loads varied from year to year (see previous discussion). The increase in dissolved-solids load is due to regional ground-water inflow. Increases in nutrient loads are due to WWTP inflow and return flows. Changes in suspended-sediment loads are caused by tributary inflow.

SUMMARY

This report describes spatial and temporal variations in streamflow and water quality in the Rio Grande from Del Norte, Colorado, to El Paso, Texas. Selected water-quality constituents presented in this report are dissolved solids, dissolved nitrite plus nitrate as nitrogen, total phosphorus, and suspended sediment. A multivariate linear regression model, ESTIMATOR2000, was used to estimate loads for selected constituents.

Streamflow decreases in the downstream direction throughout most of the basin because outflows (from agricultural use, leakage to ground water, and evapotranspiration) are greater than inflows. Streamflow increases between RGTrinch and

RGOtowi because ground-water and tributary inflow are greater than outflow.

Median dissolved-solids concentrations ranged from 73 mg/L at RGDelN to 652 mg/L at RGELP. An increase in the median dissolved-solids concentration was fourfold between RGDelN and RGTrinch because of ground-water discharge to the Rio Grande and surface-water inflow from the Franklin Eddy Canal. Dissolved-solids concentrations increased from RGOtowi to RGFldwy as the result of surface-water inflow and ground-water discharge to the Rio Grande. Large dissolved-solids concentrations at RGConvey resulted from irrigation effects, evapotranspiration in riparian areas, and regional ground-water discharge to agricultural drains. Dissolved-solids concentrations increased between RGFldwy and RGELP because of evapotranspiration, irrigation effects, and ground-water discharge to the Rio Grande. Dissolved-solids concentrations varied seasonally at most sites; concentrations were smaller during the spring and summer months (April through August).

In WY 1994, dissolved-solids loads increased in the Rio Grande from RGDelN to Sum3 (RGFldwy plus RGConvey), decreased from Sum3 to RGLeasb, and increased from RGLeasb to RGELP. From RGOtowi to Sum3, the dissolved-solids load increased because of larger concentrations and a smaller streamflow. From RGLeasb to RGELP, the dissolved-solids load increased because of increases in concentrations, which result from regional ground-water inflow and smaller streamflow.

Dissolved nitrate concentrations ranged from less than the minimum reporting level (0.05 mg/L) to 2.0 mg/L throughout the Rio Grande. Nitrate concentrations increased between RGDelN and RGTrinch and again between RGLob and RGTJB because of ground-water and surface-water inflows. The median dissolved nitrate concentration increased from 0.06 to 0.66 mg/L between RGOtowi and RGIsleta because of WWTP inflow and, to a lesser extent, return flows. The median concentration increased from 0.08 mg/L at RGLeasb to 0.31 mg/L at RGELP because of WWTP inflow, ground-water discharge to the Rio Grande, and (or) return flow.

Dissolved nitrate loads were not estimated upstream from San Marcial, New Mexico, because of insufficient data for model calibration. Loads decreased between Sum3 and RGLeasb because of decreases in streamflow and concentrations. Dissolved nitrate loads increased between RGLeasb and RGELP because although streamflow decreased, dissolved nitrate concentrations increased.

Total phosphorous concentrations generally were small (less than 0.1 mg/L) and had small variability from RGDelN to RGOtowi. Total phosphorous concentrations were largest and had the largest variability at RGIsleta and RGFldwy.

From RGDelN to RGOtowi, estimated daily mean phosphorous loads generally reflect increases and decreases in streamflow, indicating that the phosphorous concentration in inflows was relatively similar to that of the Rio Grande. From RGOtowi to Sum3, the total phosphorous load increased from 0.53 to 1.8 tons/d despite a decrease in streamflow; this indicates the presence of inflow(s) with a total phosphorous concentration greater than that at RGOtowi, most likely WWTP effluent or inflow from ephemeral streams.

Median suspended-sediment concentrations generally increased from RGDelN to RGFldwy. The downstream variation in suspended-sediment concentrations (three orders of magnitude) was much greater than downstream variation observed in other constituents. Median suspended-sediment concentrations increased from 12 to 52 mg/L between RGDelN and RGTrinch. From RGIsleta to RGFldwy, the median suspended-sediment concentration increased from 272 to 1,610 mg/L because of inflow from ephemeral streams. Downstream from RGFldwy, suspended-sediment concentrations decreased because of settling of suspended sediment in Elephant Butte and Caballo Reservoirs.

Estimated daily mean suspended-sediment loads varied at individual sites from year to year and between sites because of (1) natural variation in streamflow and delivery of sediment to various reaches of the Rio Grande and (2) data limitations related to the large variability in suspended-sediment concentrations at a site from year to year and the short period of record used for model calibration. Between RGDelN and RGTrinch, the suspended-sediment load decreased by about a factor of four (every year) despite increases in suspended-sediment concentrations; the decrease in load is due to the decrease in streamflow. Suspended-sediment loads at RGFldwy were larger than those at any other site in the RIOG NAWQA study unit and exhibited little variation from year to year. The load decreased from Sum3 to RGLeasb because of decreases in streamflow and settling of suspended sediment in Elephant Butte and Caballo Reservoirs.

Several instances of decreasing streamflow and increasing loads indicate the presence of inflows with large constituent concentrations (relative to those of the Rio Grande immediately upstream from that inflow); this occurs (1) between RGDelN and RGTrinch for dissolved solids, (2) between RGOtowi and RGFldwy for all constituents, and (3) between RGLeasb and RGELP for all constituents.

Streamflow increases along every reach of the Rio Grande between RGTrinch and RGOtowi. These increases in streamflow result in increases in dissolved-solids loads, total phosphorous loads, and suspended-sediment loads regardless of changes in concentrations.

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