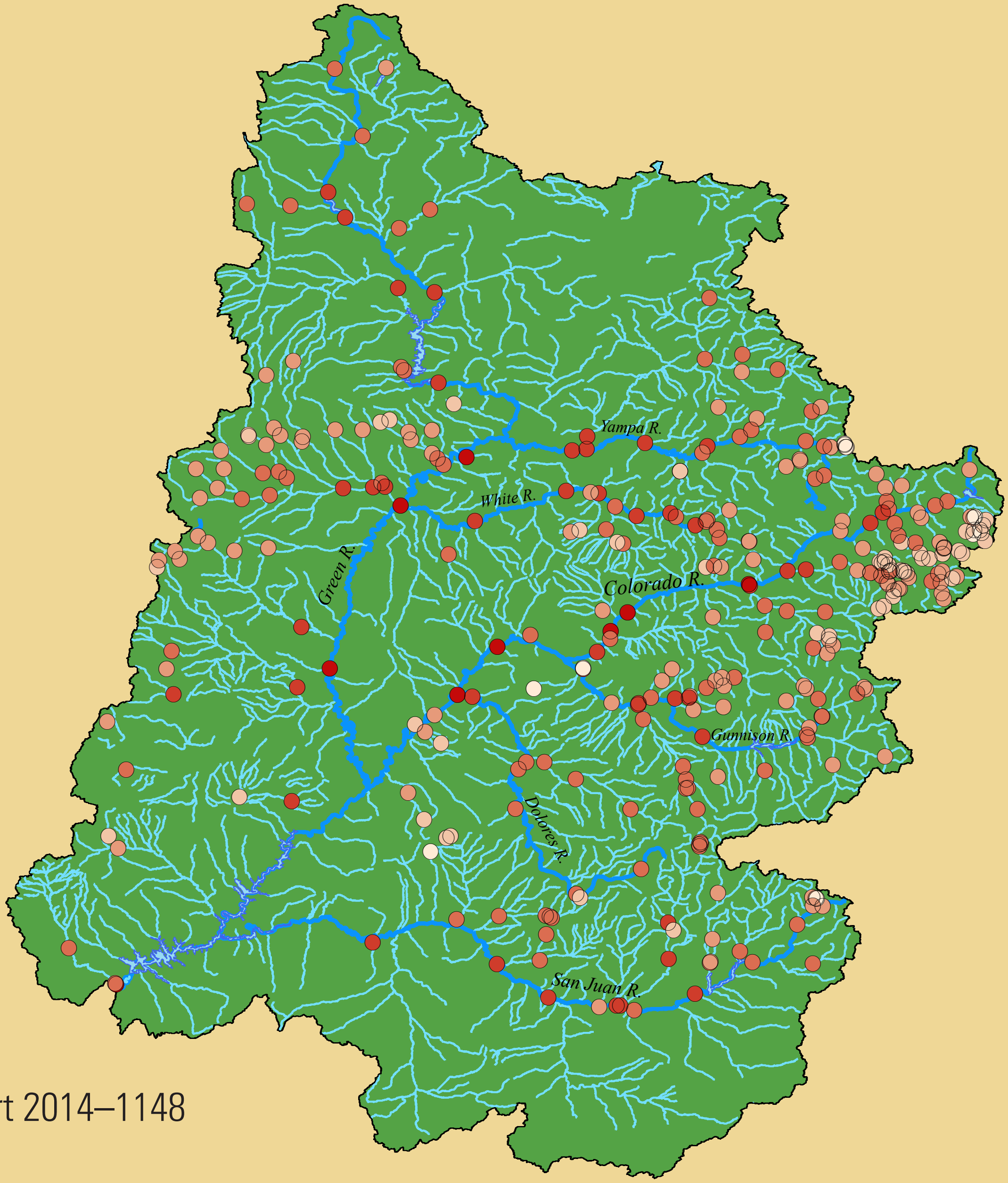
Prepared in cooperation with the Bureau of Reclamation

Updated Estimates of Long-Term Average Dissolved-Solids Loading in Streams and Rivers of the Upper Colorado River Basin



Open-File Report 2014–1148

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

FRONT COVER
Map of the Upper Colorado River Basin showing sites with estimated long-term mean annual dissolved-solids loading.

Updated Estimates of Long-Term Average Dissolved-Solids Loading in Streams and Rivers of the Upper Colorado River Basin

By Fred D Tillman and David W. Anning

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SALLY JEWELL, Secretary

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U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per year (ton/yr)	0.9072	metric ton per year
	Energy	
kilowatt hour (kWh)	3,600,000	joule (J)

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

Altitude, as used in this report, refers to distance above the vertical datum.

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

Updated Estimates of Long-Term Average Dissolved-Solids Loading in Streams and Rivers of the Upper Colorado River Basin

By Fred D Tillman and David W. Anning

Abstract

The Colorado River and its tributaries supply water to more than 35 million people in the United States and 3 million people in Mexico, irrigating over 4.5 million acres of farmland, and annually generating about 12 billion kilowatt hours of hydroelectric power. The Upper Colorado River Basin, part of the Colorado River Basin, encompasses more than 110,000 mi^2 and is the source of much of more than 9 million tons of dissolved solids that annually flows past the Hoover Dam. High dissolved-solids concentrations in the river are the cause of substantial economic damages to users, primarily in reduced agricultural crop yields and corrosion, with damages estimated to be greater than 300 million dollars annually. In 1974, the Colorado River Basin Salinity Control Act created the Colorado River Basin Salinity Control Program to investigate and implement a broad range of salinity control measures. A 2009 study by the U.S. Geological Survey, supported by the Salinity Control Program, used the Spatially Referenced Regressions on Watershed Attributes surface-water quality model to examine dissolved-solids supply and transport within the Upper Colorado River Basin. Dissolved-solids loads developed for 218 monitoring sites were used to calibrate the 2009 Upper Colorado River Basin Spatially Referenced Regressions on Watershed Attributes dissolved-solids model. This study updates and develops new dissolved-solids loading estimates for 323 Upper Colorado River Basin monitoring sites using streamflow and dissolved-solids concentration data through 2012, to support a planned Spatially Referenced Regressions on Watershed Attributes modeling effort that will investigate the contributions to dissolved-solids loads from irrigation and rangeland practices.

Introduction

More than 3 million people in Mexico and 35 million people in the United States depend on the Colorado River to supply their domestic and industrial water needs (Bureau of Reclamation, 2011; Colorado River Basin Salinity Control Forum, 2013). The Colorado River also supplies irrigation water for over 4.5 million acres of land in the United States and Mexico and hydroelectric power along the river and its tributaries generates about 12 billion kilowatt hours annually (Colorado River Basin Salinity Control Forum, 2011). From headwaters in the Rocky Mountains through seven states and Mexico, the Colorado River traverses more than 1,400 mi to discharge into the Gulf of California (fig. 1*A*). Dissolved-solids concentrations in the river increase from about 50 mg/L at the river headwaters to about 500 mg/L at Lees Ferry, Arizona to about 850 mg/L where it crosses the United States border with Mexico (Anning and others, 2007). More than 9 million tons of dissolved solids annually flow past Hoover Dam (Anning and others, 2007). The origin of Colorado River salinity is primarily geologic material that was deposited from ancient inland seas and waterways (Colorado River Basin Salinity Control Forum, 2013), and 55–60 percent of the salinity in the river system is from natural sources—primarily saline spring discharge and erosion of saline geologic formations (Kenney and others, 2009). Dissolved-solids concentrations also can increase through human activities that increase loading (primarily irrigation, but also municipal and industrial development, as well as mining and drilling operations) and through accumulation (evaporation from reservoir operations). The Bureau of Reclamation estimates that high salinity Colorado River water causes damages of more than 300 million dollars per year to users in the United States (Colorado River Basin Salinity Control Forum, 2013), primarily owing to reduced agricultural crop yields, corrosion, and plugging of pipes and water fixtures in housing and industry (Bureau of Reclamation, 2011).

In 2009, a U.S. Geological Survey (USGS) investigation of Upper Colorado River Basin (UCRB) dissolved-solids sources and transport used the Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface-water quality model to relate dissolved-solids loads to upland catchment attributes (Kenney and others, 2009). The 2009 UCRB SPARROW model focused on geologic and agricultural sources of dissolved solids in the basin and was calibrated to dissolved-solids loads from 218 water-quality monitoring sites estimated by Anning and others (2007). A new UCRB SPARROW model is planned that will further investigate dissolved-solids sources and transport in the basin by incorporating geospatial information on irrigation practices and contributions from rangelands, among other improvements. Updated dissolved-solids loadings for UCRB monitoring sites were developed to provide the revised SPARROW model with updated calibration data.

Purpose and Scope

This report documents the data and methods used to estimate long-term mean annual dissolved-solids loading at water-quality sites on UCRB streams and rivers. Existing streamflow and dissolved-solids concentration data from the USGS National Water Information System (NWIS) were used in the development of these estimates. Where sufficient data were available as described in this report, dissolved-solids load estimates were detrended to water year 2010. The UCRB boundary used in this study is the watershed delineated by USGS hydrologic unit code 14 (HUC14), established as part of the USGS hydrologic unit system (Seaber and others, 1987).

Description of Study Area

The Colorado River Basin drains parts of Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada, California, and Mexico, and is divided into upper and lower basins at the compact point of Lee Ferry, Arizona, a location 1 mi downstream of the mouth of the Paria River (fig. 1*A*, 1*B*; Anderson, 2004). The UCRB is defined for this study as the 113,406 mi^2 drainage area (HUC14) upstream of USGS streamflow-gaging station 09380000, Colorado River at Lees Ferry, Arizona (fig. 1*B*). Major tributaries to the Colorado River in the Upper Basin include the Dolores, Green, Gunnison, San Juan, White, and Yampa Rivers (fig. 1*B*). Average annual precipitation ranges from less than 10 in. in low elevation areas to more than 39 in. in high elevation areas in the Southern Rocky Mountains (fig. 1*C*, PRISM Climate Group, Oregon State University, 2012). UCRB land cover is predominately shrub/scrub and evergreen forest (Fry and others, 2011), with few high-density population centers (fig. 1*D*). Major dissolved constituents in UCRB streams and rivers are the cations calcium, magnesium, sodium, and potassium; and the anions sulfate, chloride, and bicarbonate; and neutral silica (Liebermann and others, 1989). Important geologic sources of dissolved solids in the UCRB include the Upper Cretaceous Mancos Shale, the Paradox Member of the Pennsylvanian Hermosa Formation, and the Eocene Green River Formation (Liebermann and others, 1989). Factors that are related to the transport of salinity to UCRB streams and rivers include the amount of precipitation, soil type and thickness, and land-surface elevation (Kenney and others, 2009).

Methods

Models of dissolved-solids concentrations were calibrated with streamflow and water-quality data by the Fluxmaster program that uses batch-processing methods in the SAS® statistical software to estimate flow and water-quality models across multiple stations (Schwarz and others, 2006). For each of three dissolved-solids parameters (described in section, “Data”), six models were considered for each site that included varying combinations of flow, time (trend), and seasonality. The best option was selected from the six models for each dissolved-solids parameter at each site, followed by selection of the best dissolved-solids model from the three dissolved-solids parameters. Concentration and load results were compared with published estimates from Anning and Flynn (2014).

Data

Dissolved-solids concentration and daily streamflow data from NWIS (http://waterdata.usgs.gov/nwis) for UCRB study area sites were used to calibrate the dissolved-solids models. Data for different measures of dissolved solids, including specific conductance (SC; p00095), residue on evaporation at 180 °C (ROE; p70300), and sum of the dissolved constituents (SUM; p70301), were compiled from NWIS. Dissolved-solids concentration data for more than 210,000 observations from 710 sites in the UCRB constituted the base water-quality dataset for the study. The period of record for data used in calibrating dissolved-solids flux estimates was from October 1, 1984 to September 30, 2012. The selected period of record was a balance of the necessity of having sufficient data with which to calibrate models with the desire to represent recent conditions in the study area. A search for outliers and quality issues in the dissolved-solids data was performed first by visually inspecting plots of data for all sites. Data that appeared to have quality issues (for example, a decimal place error), were low or high values relative to nearby points, or were few in number and distant in time (most more than 7 years) from other data were removed from the dataset. A second investigation of the dissolved-solids data was performed by computing ratios of the different dissolved-solids parameters (p70300/p00095, p70301/p00095, and p70301/p70300) for times when multiple parameter data were available and removing observations that caused anomalously high or low ratios. The outlier search identified 49 observations that were removed from the nearly 80,000 available for the period of interest.

Development and Evaluation of Dissolved-Solids Models

The Fluxmaster program (Schwarz and others, 2006) was used to estimate mean annual loads of dissolved solids at UCRB sites. Fluxmaster estimates log-transformed dissolved-solids concentrations from log-transformed mean daily streamflow and other explanatory variables (described in this section) using a bias-corrected, log-linear regression model with ordinary least squares estimation (Cohn, 2005). Mean annual loads are predicted using adjusted maximum likelihood with retransformation bias correction developed by Cohn (2005). Criteria for data

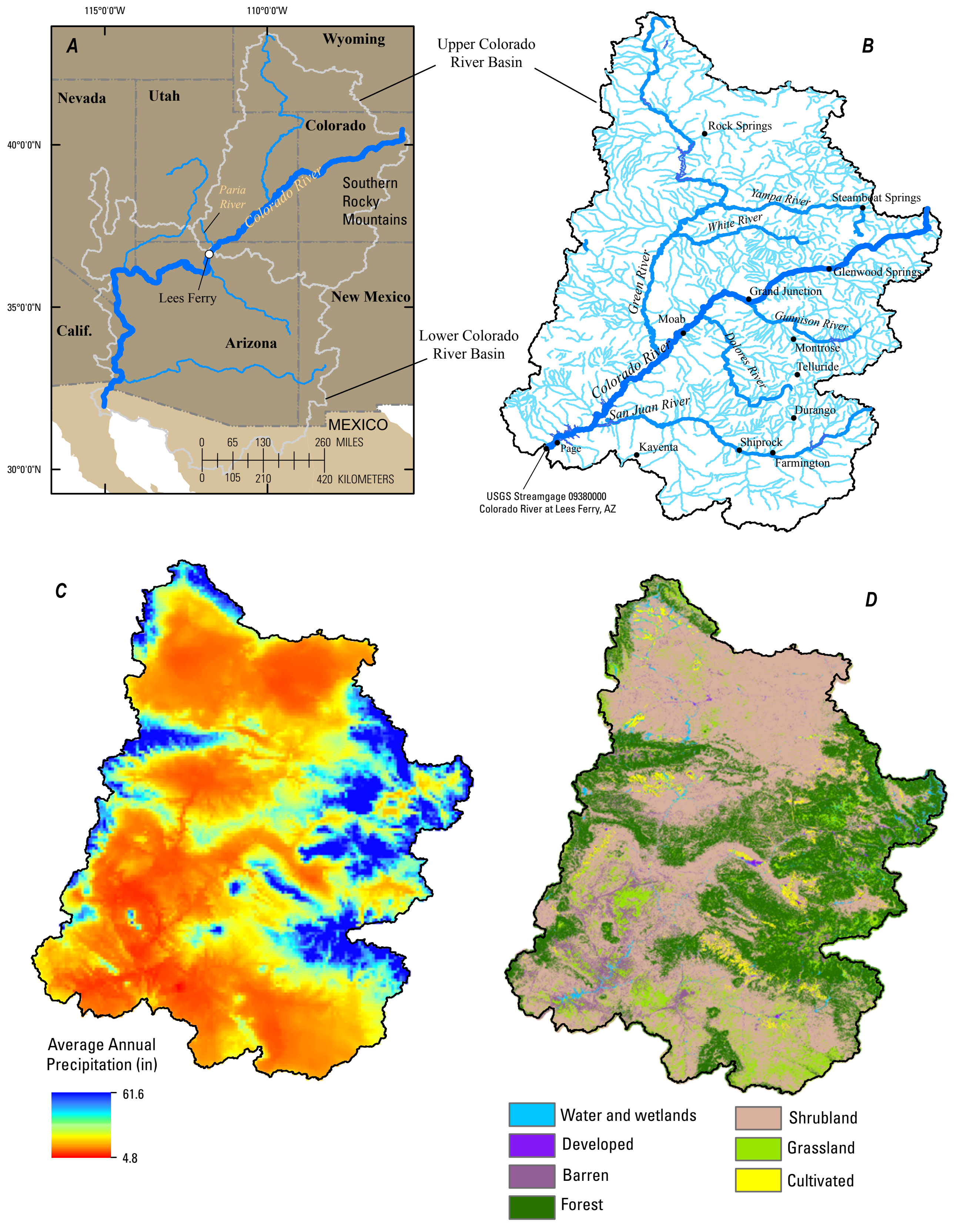


Figure 1. Maps showing (*A*) Upper Colorado River Basin study area, (*B*) major streams and rivers, (*C*) average annual precipitation (PRISM Climate Group, Oregon State University, 2012), and (*D*) major land-cover classifications (Fry and others, 2011).

used in Fluxmaster to estimate loads at UCRB sites include only water-quality and streamflow observations between October 1, 1984 and September 30, 2012; a minimum of 20 observations must be available for the dissolved-solids parameter; and data must span a minimum of 5 years.

Six different dissolved-solids regression models were estimated for each UCRB site where sufficient data were available (see table 1):

where

DS is the modeled dissolved-solids parameter (SC, ROE, and SUM),

flow is mean daily streamflow (ft^3/s),

T is decimal time, and

b_n are regression coefficients determined by Fluxmaster.

Explanatory variables of sine and cosine of decimal time account for seasonal patterns in dissolved-solids concentrations with either first or second-order harmonics (linear or squared function). The long-term trend in dissolved-solids concentration is represented by T and T^2.

A daily streamflow model is estimated by Fluxmaster for UCRB sites for use in computing dissolved-solids loads. This streamflow model is calibrated using maximum likelihood estimation and relates the logarithm of daily streamflow to the following variables (see table 2):

where

AR3 is a 3-day autoregression term in the residuals to account for serial correlation in the daily values, and all other variables are previously defined.

Information from the streamflow model (model 7) is used to develop a series of daily streamflow values that are subsequently used in the dissolved-solids model (models 1–6) to estimate daily dissolved-solids concentrations. Fluxmaster generates daily loads from the product of daily streamflow and dissolved-solids concentrations, and these daily loads are summed on a water-year basis for an estimate of mean annual load. The long-term mean annual load is determined as the average of the available mean annual loads. A base year of 2010 was selected to detrend Fluxmaster load estimates. Detrending gives an estimate of the load that would have occurred if the dynamic factors causing trend were held constant throughout the entire period (equal to the values on the base date). This allows for comparison of loads for sites at different locations that were estimated for different periods (fig. 2; Schwarz and others, 2006). To ensure that load estimates were not extrapolated too distant in time to the 2010 base year, dissolved-solids and streamflow data were required to be available within a "recent" period, relative to 2010, for detrending to be performed. Recent was defined as no more than 20 percent of the length of record for a site before 2010. For example, if a site had 10 years of streamflow data, then the streamflow record must end no more than 2 years (20 percent of 10 years) before 2010 for detrending of streamflow from that site. Because results from the dissolved-solids concentration and streamflow models potentially may be detrended, daily dissolved-solids loads are estimated by Fluxmaster in one of four ways.

1. If recent (as defined previously) measured data are available for both streamflow and dissolved-solids concentration at a site, then a daily series of streamflow values detrended to base year 2010 is estimated using the measured daily streamflow data with the trend component removed, based on the estimated streamflow model coefficients b_5 and b_6 from model 7 (fig. 2). These detrended daily flow values are then input to the dissolved-solids concentration model to simulate a series of daily concentration estimates without introducing a concentration trend owing to a trend in flow. In addition, the concentration prediction methods account for non-flow related trend components described by regression coefficients for T and T^2 in models 1–3 and 5, resulting in a daily dissolved-solids concentration series detrended to the 2010 base year. A daily series of dissolved-solids loads, detrended to 2010, is then generated by multiplying the detrended daily flow values by the detrended daily concentration estimates.
2. If recent data are available for flow but are not available for dissolved-solids concentrations, then a daily series of streamflow values detrended to base year 2010 is estimated using the measured daily streamflow data with the trend component removed; these detrended daily flow values are then input to the dissolved-solids concentration model as previously mentioned. No detrending of non-flow components, however, is performed on the dissolved-solids concentration model. In this case, the daily series of dissolved-solids loads, partially detrended to 2010, is generated by multiplying the detrended daily flow values by the partially detrended daily concentration estimates.
3. If recent data are not available for both streamflow and dissolved-solids concentration at a site, then detrending of flow is not performed and measured daily streamflow data are used directly in the concentration model. The dissolved-solids concentration model and the resulting daily concentration estimates also are not detrended. In this case, the daily series of dissolved-solids loads is generated by multiplying the non-detrended daily flow data by the non-detrended daily concentration estimates.
4. The fourth case in which there are recent dissolved-solids concentration data but no recent streamflow data does not occur in the dataset for this study and is not discussed here.

The final dissolved-solids model used to estimate long-term daily and annual loads at each UCRB site was selected by a three-step process: (1) eliminating models that achieve a poor fit—determined using an observed/estimated ratio, (2) selecting models for each site for each dissolved-solids parameter with the lowest Akaike information criterion corrected for finite sample sizes (AICc), and (3) selecting the model from the three parameters at each site with the lowest adjusted

Table 1. Dissolved-solids regression models

Model No.	Model specifications
1	$\log_e(DS) = \text{intercept} + b_1\log_e(flow) + b_2\log_e(flow)^2 + b_3\sin(2\pi T) + b_4\cos(2\pi T) + b_5\sin(2\pi T)^2 + b_6\cos(2\pi T)^2 + b_7 T + b_8 T^2$
2	$\log_e(DS) = \text{intercept} + b_1\log_e(flow) + b_2\log_e(flow)^2 + b_3\sin(2\pi T) + b_4\cos(2\pi T) + b_5\sin(2\pi T)^2 + b_6\cos(2\pi T)^2 + b_7 T$
3	$\log_e(DS) = \text{intercept} + b_1\log_e(flow) + b_2\sin(2\pi T) + b_3\cos(2\pi T) + b_4\sin(2\pi T)^2 + b_5\cos(2\pi T)^2 + b_6 T$
4	$\log_e(DS) = \text{intercept} + b_1\log_e(flow) + b_2\sin(2\pi T) + b_3\cos(2\pi T) + b_4\sin(2\pi T)^2 + b_5\cos(2\pi T)^2$
5	$\log_e(DS) = \text{intercept} + b_1\log_e(flow) + b_2 T$
6	$\log_e(DS) = \text{intercept} + b_1\log_e(flow)$

Table 2. Daily streamflow model

Model No.	Model specifications
7	$\log_e(flow) = \text{intercept} + b_1\sin(2\pi T) + b_2\cos(2\pi T) + b_3\sin(2\pi T)^2 + b_4\cos(2\pi T)^2 + b_5 T + b_6 T^2 + AR3$

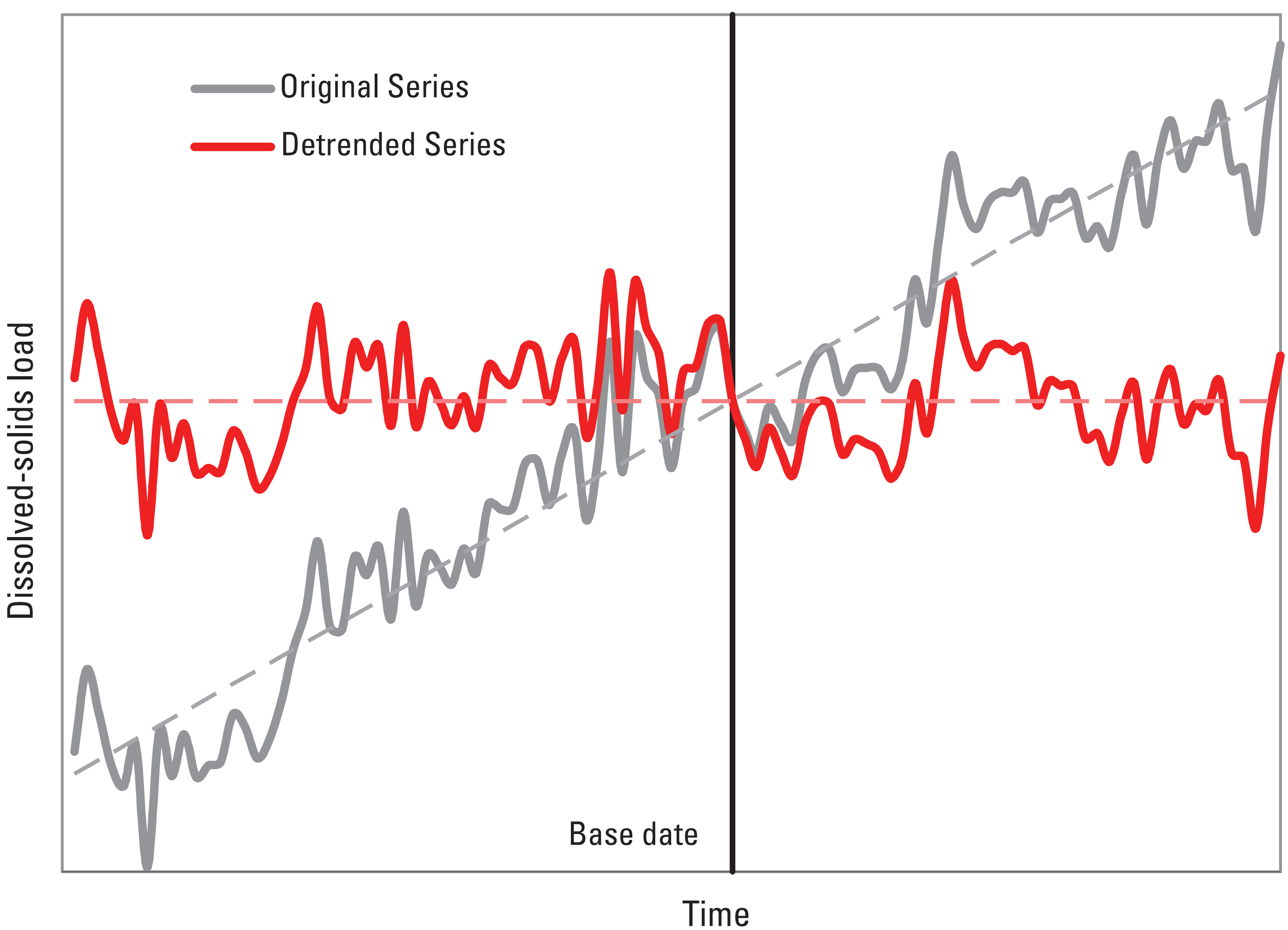


Figure 2. Graphical depiction of an example detrended series. Adapted from Schwarz and others (2006).

percent error for the load estimate. For each model estimated by Fluxmaster, a weighted average ratio of the observed daily load divided by a weighted predicted daily load for monitored days is computed. This observed-to-estimated ratio will be greater than 1 if the dissolved-solids load is underpredicted and less than 1 if load is overpredicted. For this study, models were eliminated from further consideration if the estimated loads differed from observed loads by more than ±15 percent, resulting in observed-to-estimated ratios less than 0.87 or greater than 1.18. To select one of the six models for each site, the AICc statistic was compared for all models for each of the dissolved-solids parameters. AICc incorporates a measure of model error with a penalty for additional model variables (Helsel and Hirsch, 2002). The model with the lowest AICc statistic was selected for each site for each parameter. For stations and parameters with multiple models with the same AICc value, the simplest of the models (highest of model numbers in table 1) was selected.

Finally, to select among the three dissolved-solids parameters for the final model at each site, an adjusted percentage error of the long-term annual load estimates for each model was computed by combining the error from the load estimate with the error from converting loads to common units. First, the percentage error of the estimated load was calculated for each parameter at each site as the standard error of the average flux divided by the average flux. Next, ratios of SUM to SC values and SUM to ROE values were calculated for all times where both dissolved-solids parameters were measured, and an average ratio for each site was computed. The percentage error for these conversion ratios also was calculated as the standard error of the ratio divided by the mean of the ratio. For sites without available data to compute the ratios, the overall average of all UCRB sites was used to compute the percentage error. To combine the variance associated with the load estimation and the parameter ratio used to convert SC and ROE loads to SUM loads, an adjusted percentage error for the load at each site was computed as:

$$\text{adjusted \% error} = \sqrt{(\text{\% error of load})^2 + (\text{\% error of SUM conversion ratio})^2}$$

The model with the lowest adjusted percentage error was selected to estimate the long-term average load at each site. The average load at each site estimated by the final model was converted to SUM units (if the model was not already a SUM model) using the site-specific ratios or UCRB average ratio as previously described.

Dissolved-Solids Concentration Models and Estimated Loading

Sufficient data were available to calibrate 2,916 dissolved-solids models (model numbers 1–6) from 326 UCRB sites in the NWIS dataset. Removing dissolved-solids models in which estimated loads differed from observed loads by more than ±15 percent resulted in eliminating 59 models, and an average observed-to-estimated ratio of 0.994 for the remaining models. A model for each dissolved-solids parameter at each UCRB site was selected from the lowest AICc value among the remaining models. The lowest AICc selection resulted in 482 dissolved-solids models from 323 UCRB sites. The mean ratio of SUM concentrations to SC concentrations for all UCRB sites was 0.668, comparable to the value of 0.645 reported by Anning and others (2007) for sites in the southwestern United States and the ratio of 0.616 reported by Anning and Flynn (2014) for sites throughout the United States. The mean ratio of SUM to ROE concentrations for UCRB sites was 0.953, comparable to the 0.931 ratio for United States sites reported in Anning and Flynn (2014). Final models for estimating long-term dissolved-solids loads at UCRB sites were selected by the lowest adjusted percentage error of the load for models at each site as previously described and are presented in appendix 1. One-third of the final models selected for estimating loads were of the form described by model 2, with nearly two-thirds of the models as described by model 2 or 4 (fig. 3, appendix 1). The dissolved-solids parameter most often represented in the final models for UCRB sites was specific conductance, accounting for 85 percent of the models (fig. 3, appendix 1).

Long-term mean annual and daily dissolved-solids loads were estimated for UCRB sites using the concentration model selected for each site, with the loads detrended to 2010 for sites with recent data. Approximately one-third of the sites (100) had recent data for both streamflow and dissolved-solids concentrations that permitted full detrending to 2010 of dissolved-solids loads; another approximately one-third of the sites (110) had recent data only for streamflow, resulting in detrending of only the flow-component of trend in dissolved-solids loads; and a final approximately one-third of the sites (113) had insufficient streamflow and dissolved-solids concentration data to permit any detrending of the dissolved-solids loads (appendix 2). For sites with dissolved-solids models with parameters other than SUM, loads were adjusted to SUM units by multiplying by the site-specific SUM-to-parameter ratio, or by the overall UCRB ratio if site-specific data were not available. Appendix 2 presents long-term mean annual dissolved-solids load, adjusted load, and yield information for UCRB sites, and indicates whether the load values were adjusted using a site-specific ratio or a UCRB-wide ratio. Estimated dissolved-solids flow-weighted concentrations (long-term mean annual dissolved-solids load divided by long-term daily flow) had a median value of 113 mg/L for UCRB sites (table 3). For 170 comparable sites, the estimated mean annual flow-weighted concentrations in this study are generally lower than estimates reported in Anning and Flynn (2014) that were detrended to 2000 (fig. 4*A*)—likely a result of decreasing trends in dissolved-solids concentration at many sites in the Anning and Flynn (2014) study. The SUM-adjusted, long-term mean annual loads for

Table 3. Summary percentiles for estimated dissolved-solids concentration, long-term mean annual load, and mean annual yield for 323 sites in the Upper Colorado River Basin.

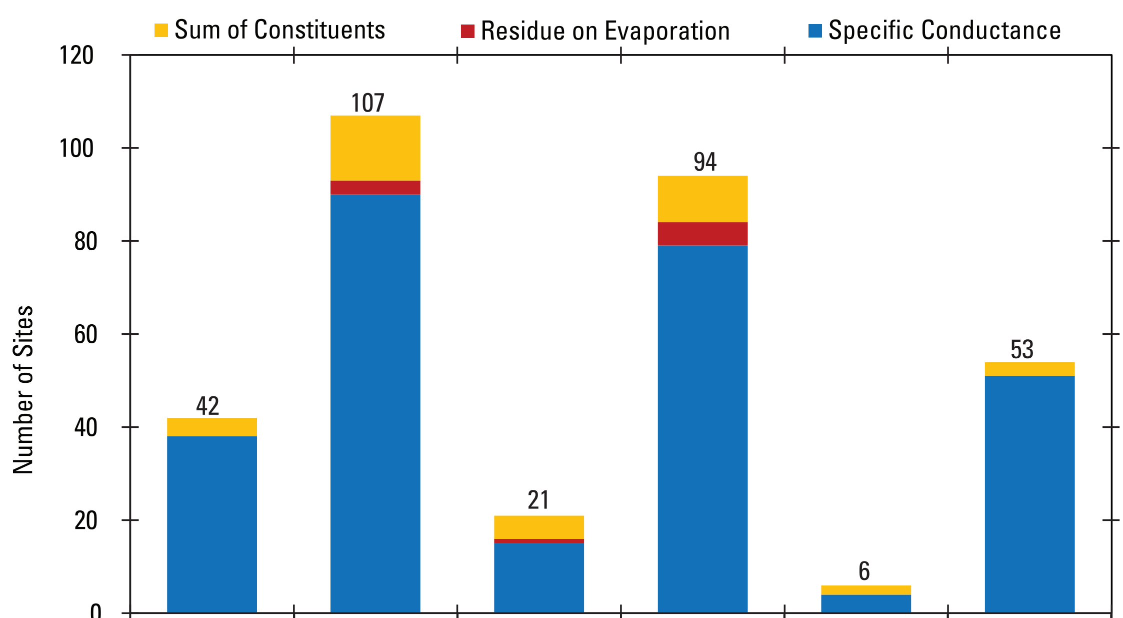
[mg/L = milligrams per liter; tons/yr = tons per year; (tons/yr)/mi^2 = tons per year per square mile; SUM = sum of constituents; SC = specific conductance; ROE = residue on evaporation]

	Percentile						
	Minimum	**10th**	**25th**	**Median**	**75th**	**90th**	**Maximum**
Flow-weighted concentration (mg/L)	4	22	50	113	247	627	2,763
Long-term mean annual[1] load (tons/yr)	23	426	1,569	9,643	47,800	174,379	6,017,846
Mean annual yield[2] [(tons/yr)/mi^2]	4	21	36	62	118	208	[3]663

[1]Load adjusted to SUM units for regression models using SC or ROE dissolved-solids parameters.

[2]Five sites had no drainage area information, so yield percentiles are based on 318 sites.

[3]Yield not estimated for Reed wash near Mack, Colorado (gaging station 09153290) because flow is suspected to contain water from adjacent agricultural areas that are not strictly part of the site's drainage area.



Model term	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
intercept	X	X	X	X	X	X
flow	X	X	X	X	X	X
$flow^2$	X	X				
seasonality	X	X	X	X		
$seasonality^2$	X	X	X	X		
trend	X	X	X		X	
$trend^2$	X					

Figure 3. Graph showing model term and dissolved-solids parameter for models used in estimating long-term dissolved-solids loads at selected sites in the Upper Colorado River Basin.

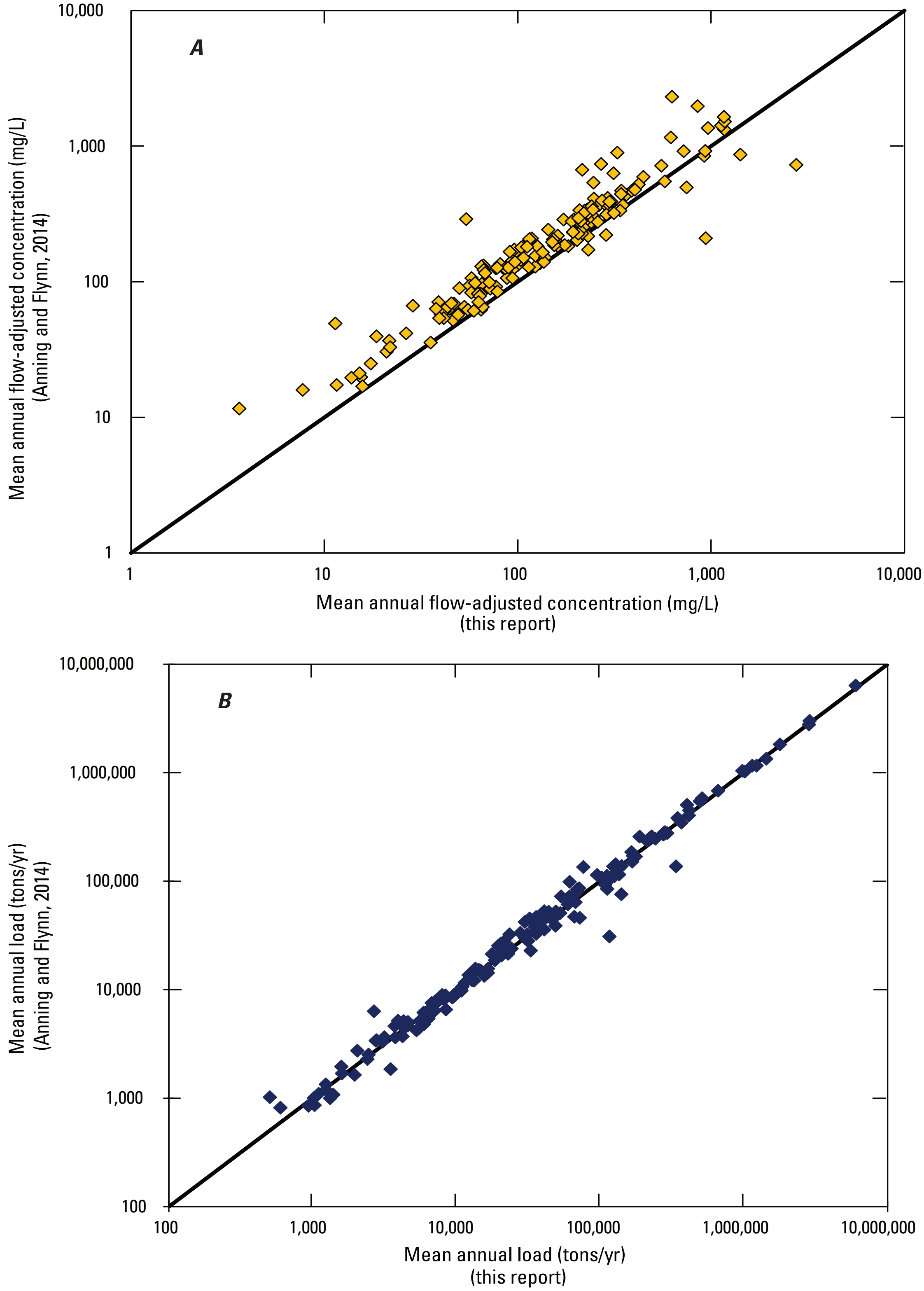


Figure 4. Graphs showing comparison of estimated dissolved-solids mean annual flow-adjusted concentrations (*A*) and mean annual loads (*B*) with values reported in Anning and Flynn (2014), Upper Colorado River Basin. Concentrations and loads were detrended to base year 2000 (Anning and others, 2014) or base year 2010 (this report) if dissolved-solids concentration and flow data sufficiently recent to the base year were available.

UCRB sites were as high as 6 million tons/yr at Colorado River at Lees Ferry (streamflow-gaging station 09380000; table 3, appendix 2). Load estimates from this study are generally in line with estimates from Anning and Flynn (2014; fig. 4*B*). The distribution of mean-annual-yield estimates from UCRB sites were generally close to the median value of 62 (tons/yr)/mi^2 (table 3, appendix 2).

The spatial distribution of stations with adequate data and dissolved-solids models for estimating dissolved-solids loading in UCRB streams and rivers indicates a majority of the 323 sites are in the eastern part of the study area (fig. 5). The highest dissolved-solids loads are at sites along the main stems of the Colorado, Green, Gunnison, San Juan, and Yampa Rivers that accumulate loads from feeder

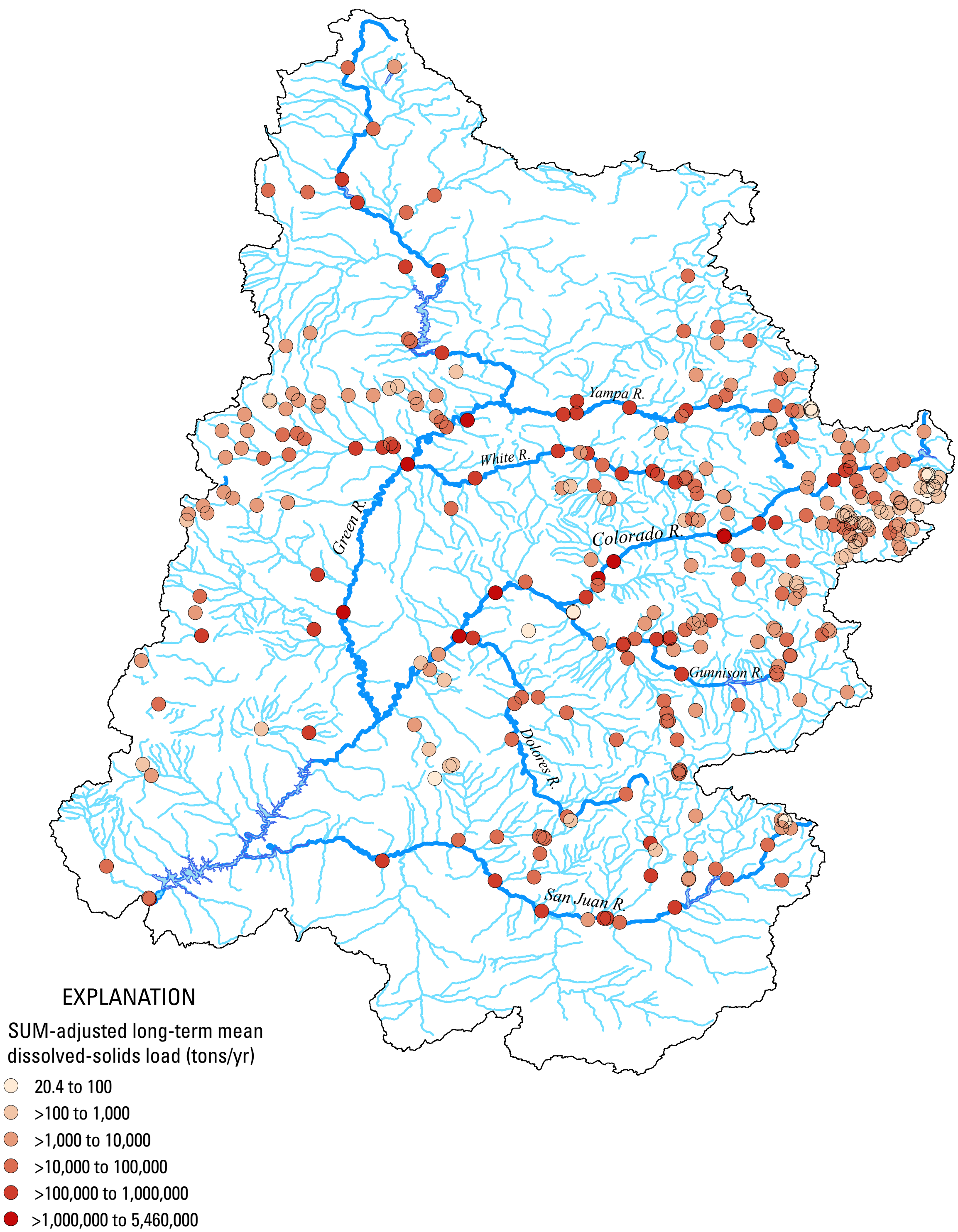


Figure 5. Map showing sites with log of estimated long-term mean annual dissolved-solids loading in the Upper Colorado River Basin. Information on site names, locations, and dissolved-solids concentrations, loads, and yields are listed in appendixes 1 and 2.

streams, and lowest dissolved-solids loads are at sites in headwaters in the eastern and western parts of the UCRB (fig. 5; Appendix 2).

Summary and Conclusions

Estimates of dissolved-solids loading for water-quality sites on Upper Colorado River Basin streams and rivers were developed using multiple linear regression to model observed dissolved-solids concentrations. Data for different dissolved-solids parameters including specific conductance, residue on evaporation at 180 °C, and sum of the dissolved constituents were compiled from the U.S. Geological Survey National Water Information System database. The Fluxmaster program was used to estimate log-transformed, dissolved-solids concentration data from log-transformed mean daily streamflow, seasonal trend, and long-term trend explanatory variables. The best model for each site was determined through examination of the AICc statistic and the adjusted percentage error for all models at each site. Dissolved-solids models were developed for 323 Upper Colorado River Basin sites. Daily and mean annual dissolved-solids loads were predicted at the 323 sites for a base year of 2010 when recent data were available; otherwise, predicted loads were not detrended.

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