USGS
science for a changing world

Prepared in cooperation with the Bureau of Reclamation

Dissolved-Solids Load in Henrys Fork Upstream from the Confluence with Antelope Wash, Wyoming, Water Years 1970–2009

Scientific Investigations Report 2010–5048

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

Dissolved-Solids Load in Henrys Fork Upstream from the Confluence with Antelope Wash, Wyoming, Water Years 1970–2009

By Katharine Foster and Terry A. Kenney

Prepared in cooperation with the Bureau of Reclamation

Scientific Investigations Report 2010–5048

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

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

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

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Foster, K., and Kenney, T.A., 2010, Dissolved-solids load in Henrys Fork upstream from the confluence with Antelope Wash, Wyoming, water years 1970–2009: U.S. Geological Survey Scientific Investigations Report 2010–5048, 16 p.

Contents

Abstract 1
Introduction 1
  Purpose and Scope 3
  Description of the Study Area 3
    Geology and Soils 3
    Hydrologic Framework 3
  Previous Studies 4
Estimation of Dissolved-Solids Load 4
A Case Study Using the Upper Colorado River Basin SPARROW Model, Henrys Fork, Wyoming and Utah 6
  Adjustment of Predicted Dissolved-Solids Load from SPARROW Model for Henrys Fork near Manila, Utah 9
  Determination of Dissolved-Solids Load for Upper Henrys Fork Basin 12
  Distribution of Dissolved-Solids Load by Source at Selected Locations in Henrys Fork Basin 12
Summary 14
References Cited 15

Figures

1. Map showing location of the study area and irrigated lands in the upper Henrys Fork Basin, Wyoming and Utah 2

2–3. Graphs showing:
  2. Daily mean streamflow and discrete values of dissolved-solids concentration during water-quality sampling at U.S. Geological Survey streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009 5
  3. Annual streamflow and annual dissolved-solids load at streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009 8

Tables

1. Annual streamflow and annual dissolved-solids load at U.S. Geological Survey streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009 7
2. Ranked annual streamflow and annual dissolved-solids load from streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009 9
3. Predicted and adjusted dissolved-solids load from SPARROW model for selected locations in the Henrys Fork Basin, Wyoming, water year 1991 10

4. Dissolved-solids concentration and estimated mean dissolved-solids load in streamflow from Antelope Wash, Wyoming, August 2004 to September 2009............11
5. Dissolved-solids concentration and estimated daily dissolved-solids load in Peoples Canal, Wyoming, June 2004 to September 2009...13
6. Estimated dissolved-solids load in Peoples Canal, Wyoming, June 2004 to September 2009...14

Conversion Factors and Datums

Multiply	By	To obtain
	Area	
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-feet (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton	0.9072	metric ton
ton per day (ton/d)	0.9072	metric ton per day
tons per year	0.9072	metric tons per year

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

Concentrations of dissolved solids in water are given in milligrams per liter (mg/L).

Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. For example, the water year ending September 30, 2008, is called water year 2008.

Acronyms and Abbreviations

AMLE	Adjusted Maximum Likelihood Estimation
BOR	Bureau of Reclamation
LOADEST	LOAD ESTimator computer program
NWIS	National Water Information System
ROE	residue on evaporation at 180 degrees Celsius
R^2	coefficient of determination
S-LOADEST	LOAD ESTimator computer program run as an add-on in S-Plus
SOC	sum of constituents
SPARROW	Spatially Referenced Regression On Watershed attributes
S-PLUS	computer-based statistical package
USGS	U.S. Geological Survey

Dissolved-Solids Load in Henrys Fork Upstream from the Confluence with Antelope Wash, Wyoming, Water Years 1970–2009

By Katharine Foster and Terry A. Kenney

Abstract

Annual dissolved-solids load at the mouth of Henrys Fork was estimated by using data from U.S. Geological Survey streamflow-gaging station 09229500, Henrys Fork near Manila, Utah. The annual dissolved-solids load for water years 1970–2009 ranged from 18,300 tons in 1977 to 123,300 tons in 1983. Annual streamflows for this period ranged from 14,100 acre-feet in 1977 to 197,500 acre-feet in 1983. The 25-percent trimmed mean dissolved-solids load for water years 1970–2009 was 44,300 tons per year at Henrys Fork near Manila, Utah.

Previous simulations using a SPAtially Referenced Regression On Watershed attributes (SPARROW) model for dissolved solids specific to water year 1991 conditions in the Upper Colorado River Basin predicted an annual dissolved-solids load of 25,000 tons for the Henrys Fork Basin upstream from Antelope Wash. On the basis of computed dissolved-solids load data from Henrys Fork near Manila, Utah, together with estimated annual dissolved-solids load from Antelope Wash and Peoples Canal, this prediction was adjusted to 37,200 tons. As determined by simulations with the Upper Colorado River Basin SPARROW model, approximately 56 percent (14,000 tons per year) of the dissolved-solids load at Henrys Fork upstream from Antelope Wash is associated with the 21,500 acres of irrigated agricultural lands in the upper Henrys Fork Basin.

Introduction

Irrigated agriculture represents the largest use of water in the Colorado River Basin (fig. 1) and contributes the second largest amount of dissolved solids to the surface-water system following natural sources (Iorns and others, 1965; U.S. Department of the Interior, 2003; Kenney and others, 2009). The primary cause of salt loading from irrigated lands is deep percolation[1] of irrigation water through salt-bearing soils and underground shale formations (Natural Resources Conservation Service, 2006). Deep percolation can mobilize salts found naturally in soils. Therefore, one of the most important water-resource issues in the Colorado River Basin is control of dissolved solids as water moves downstream though the basin (U.S. Department of the Interior, 1999). The term "dissolved solids" is synonymous with the terms "salinity" and "salt." Natural processes and anthropogenic activities contribute to the dissolved-solids load in Colorado River Basin streams. Natural sources of salt include soils, geologic formations, and stream channels and banks (U.S. Department of the Interior, 2003). Agricultural, municipal, and industrial activities are potential anthropogenic sources of salt introduced into surface water. Agricultural irrigation practices can accelerate the dissolution of soluble materials that are present and concentrate salts in soils as plants consume water (Colorado River Basin Salinity Control Forum, 2002).

Following the Colorado River Salinity Control Act of 1974 (Public Law 93–320, amended as Public Law 98–569, 104–20, 104–127, and 106–459), the Colorado River Basin Salinity Control Forum has coordinated the implementation of Federal, State, and local salinity control projects (Colorado River Basin Salinity Control Forum, 1975). Irrigated agriculture has been the focus of many of these projects because changes to infrastructure and irrigation practices can yield substantial reductions in the transport of dissolved solids to streams (Colorado River Basin Salinity Control Forum, 2002).

Because of ongoing efforts to assess and control salinity from irrigated lands, the Bureau of Reclamation (BOR) needs to determine dissolved-solids loading to the Henrys Fork upstream from the confluence with Antelope Wash for irrigated areas of agriculture in Wyoming and Utah (fig. 1). To address this need, the U.S. Geological Survey (USGS), in cooperation with the BOR, conducted an investigation to estimate the mean annual dissolved-solids load associated with irrigated agricultural lands in the upper Henrys Fork Basin. About 21,500 acres of irrigated lands are in the upper Henrys Fork Basin (David Eckhart, Bureau of Reclamation, written commun., 2006). Of this total, about 15,900 acres are in Sweetwater and Uinta Counties in Wyoming, about 4,100 acres are in Summit County, Utah, and about 1,500 acres are in Daggett County, Utah (fig. 1).

[1]Water movement and losses below the root zone of the crop.

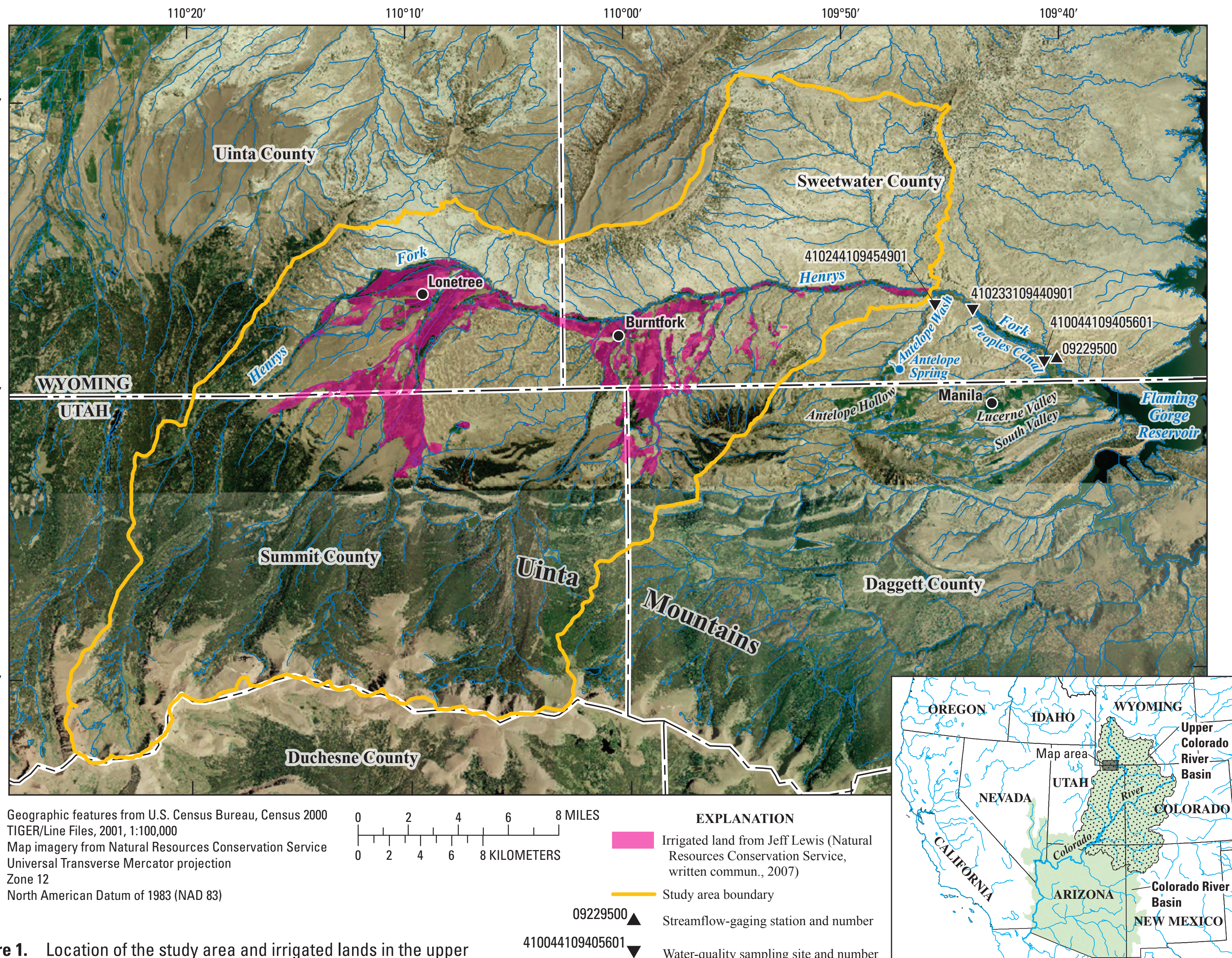

Figure 1. Location of the study area and irrigated lands in the upper Henrys Fork Basin, Wyoming and Utah.

Purpose and Scope

This report presents the results of data analysis used to determine the dissolved solids contributed to Henrys Fork from the portion of the basin upstream from the confluence with Antelope Wash. Estimates of dissolved-solids load based on data from USGS streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, for water years 1970–2009 were compared with predicted dissolved-solids load from a SPAtially Referenced Regression On Watershed attributes (SPARROW) model specific to the Upper Colorado River Basin to determine dissolved-solids load and sources of dissolved-solids load in the study area.

Description of the Study Area

In this report, the study area is referred to as the upper Henrys Fork Basin (fig. 1) and is defined as the basin area of Henrys Fork upstream from the confluence of Antelope Wash. The study area encompasses parts of Sweetwater and Uinta Counties in Wyoming, and Daggett and Summit Counties in Utah. The towns of Lonetree and Burntfork, in southwestern Wyoming, are in the upper Henrys Fork Basin. Much of the climate, geology, surface water, and groundwater have been described by Lowham and others (1985), Mason and Miller (2004), and Gerner and others (2006).

Geology and Soils

The study area is underlain by sediments that make up the early Tertiary-age Wasatch, Green River, and Bridger Formations (Love and Christiansen, 1985). These formations consist of varied amounts of limestone (marls), shale, sandstone (partly tuffaceous), and mudstone that were deposited in lacustrine (Green River Formation) and fluvial (Wasatch and Bridger Formations) environments. Most of the land in the Wyoming portion of the study area is underlain by the Bridger Formation, which weathers into badlands, such as the area north of Henrys Fork (Koenig, 1960). Irrigated lands south of Henrys Fork are underlain by the Laney Member of the Green River Formation (Mason and Miller, 2004). Quaternary-age alluvium and colluvial deposits also are present along the flood plain of Henrys Fork as well as along smaller tributary drainages throughout the study area. These deposits consist primarily of sand and gravel that have been transported downstream from the Uinta Mountains.

Soils in the study area are derived from a variety of rock types, including shale, sandstone, and mudstone (Schwarz and Alexander, 1995). The most common soils in the study area are classified within the Luhon-Evanston complex. These soils are on 3- to 30-percent slopes, are in the shallow loamy ecological site[2] and have a slightly sodic horizon (U.S. Department of Agriculture, 2004b). Where the Bridger Formation crops out, the soils are classified within the Roto-Rockinchair-Rencot complex and the Blazon thin solum-Blazon-Lilsnake complex. The Roto-Rockinchair-Rencot complex is derived mainly from limestone and sandstone parent material, is on 1- to 10-percent slopes, and is in the shallow loamy to loamy ecological sites. The Blazon thin solum-Blazon-Lilsnake complex is derived from weathered shale and sandstone, is on 2- to 40-percent slopes, and is in the shale and shallow loamy ecological site. Both complexes have a slightly sodic horizon (U.S. Department of Agriculture, 2004b). Along the flood plain of the upper Henrys Fork, soils derived from the alluvial sediments are part of the Hagga-Cowestglen association. These soils are on 0- to 2-percent slopes. The Hagga component is in the subirrigated ecological site and has a slightly sodic horizon, whereas the Cowestglen component is in the lowland ecological site and does not have a sodic horizon (U.S. Department of Agriculture, 2004b). Therefore, soils developed from the Green River and Bridger Formations can contribute to salinity loading (Schwarz and Alexander, 1995).

Hydrologic Framework

The surface waters of the study area originate in the Uinta Mountains in the southwestern part of the basin and flow generally south to north to Henrys Fork then east through the study area and eventually discharge into Flaming Gorge Reservoir (fig. 1). Because precipitation in the study area is low, many streams in the study area are intermittent or ephemeral, with most flows resulting from local and regional snowmelt and rainfall runoff (Mason and Miller, 2004). Henrys Fork has the largest flow of any stream in the study area, and moderate to large flows are a result of runoff from snowmelt in mountainous areas in the northern and southwestern parts of the basin (Mason and Miller, 2004). Annual streamflow values for the period of record (water years 1929–2009) at Henrys Fork near Manila, Utah, range from 11,900 acre-feet (acre-ft) in 1934 to 197,500 acre-ft in 1983. The median annual streamflow for the period of record is 51,000 acre-ft, and the median annual streamflow for the study period (water years 1970–2009) is 49,300 acre-ft. There is a break in the period of record from 1994 to 2001 at Henrys Fork near Manila, Utah, when the streamflow-gaging station was not in operation (USGS National Water Information System, NWIS; *http://nwis.waterdata.usgs.gov*).

[2]An ecological site is distinctive kind of land with specific soil and physical characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances (U.S. Department of Agriculture, 2004a).

Snowmelt runoff, groundwater inflows, springs, or a combination of these sources maintain streamflows throughout most years in perennial reaches; whereas ephemeral reaches exist where streamflows generally are less than water losses to seepage, evaporation, diversions, or a combination of these factors. Antelope Wash originates from Antelope Spring in Antelope Hollow and then flows northeast to join Henrys Fork (Gerner and others, 2006; fig. 1). Peoples Canal diverts streamflow from Henrys Fork and delivers it to the Lucerne Valley for irrigation. Although Antelope Wash and Peoples Canal are not within the study area, the dissolved-solids load contributed to Henrys Fork from Antelope Wash and the dissolved-solids load diverted into Peoples Canal are described in subsequent sections of this report.

Previous Studies

The most recent study of dissolved solids in the Henrys Fork Basin was an investigation to determine the amount of dissolved solids contributed to Flaming Gorge Reservoir from Lucerne Valley, South Valley, Antelope Hollow, and lower Henrys Fork near Manila, Utah (Gerner and others, 2006). The report includes a description of the occurrence and distribution of dissolved solids in water resources in or near the agricultural lands near Manila, Utah, downstream from the confluence of Henrys Fork and Antelope Wash. Some results from that study are used in this report.

Kenney and others (2009) documented the methods and data used to develop a SPAtially Referenced Regression On Watershed attributes (SPARROW) model for dissolved solids in the Upper Colorado River Basin for water year 1991. Published results include estimates of dissolved-solids load for all defined stream reaches in the basin with incremental catchments ranging from less than 1 square mile (mi^2) to 78 mi^2. The report describes the model-generated coefficients specific to their role in calculating dissolved-solids input and stream transport, and the applicability of the SPARROW model results to other time periods. Limitations and uncertainties associated with the model results and interpretation are also described.

Estimation of Dissolved-Solids Load

The USGS program LOADEST (Runkle and others, 2004), which can be run as an add-on program to a computer-based statistics package, S-PLUS (TIBCO Software, Inc., 2008), was used for estimating dissolved-solids load at USGS streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, on the basis of data obtained from the NWIS (*http://nwis.waterdata.usgs.gov*). When the LOADEST program is run as an add-on to S-PLUS, it is referred to S-LOADEST. The S-LOADEST program is a menu-driven version of the LOAD Estimator (LOADEST) FORTRAN computer program of Runkel and others (2004) and uses values of streamflow and constituent concentration to develop regression models in nine different predefined formulations. The user then selects the most appropriate model formulated by LOADEST by evaluating statistical parameters that relate to model performance. The formulated regression model for estimating dissolved-solids load from a time series of streamflow data is then used to estimate daily dissolved-solids loads, which are aggregated into an annual dissolved-solids load. The calibration and estimation procedure used within S-LOADEST to estimate dissolved-solid load in Henrys Fork is based on the Adjusted Maximum Likelihood Estimation (AMLE) method (Cohn, 1988).

Data from Henrys Fork near Manila, Utah, used to calibrate the model included daily mean streamflow for water years 1970–93 and 2002–09, and 188 discrete water-quality samples collected intermittently from October 24, 1969, to November 20, 2008 (fig. 2). During water years 1994–2001, the streamflow-gaging station at Henrys Fork near Manila, Utah, was not in operation (fig. 2). Dissolved-solids concentrations in water-quality samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado, using two analytical methods: (1) sum of constituents (SOC) and (2) residue on evaporation at 180 degrees Celsius (ROE). The standard analytical techniques for both methods are described in Fishman and Friedman (1989). Because of the widespread use of ROE analysis for samples collected in the Upper Colorado River Basin, ROE was the preferred dissolved-solids concentration analysis for this study. When ROE data were not available, SOC data were used. Because the relation between streamflow and water-quality data generally is not linear, S-LOADEST uses natural logarithm transformations to improve the model fit and normality of the residuals. The selected dissolved-solids regression model for Henrys Fork near Manila, Utah, is given by equation 1:

$$1\mathrm{n}\, L = 4.16 + 0.749\ 1\mathrm{n}\, Q - 0.127 \sin(2\pi dtime) + 0.072 \cos(2\pi dtime), \quad (1)$$

where

L represents the daily dissolved-solids load, in tons per day;

Q represents daily mean streamflow, in cubic feet per second; and

$dtime$ represents decimal time, which is computed by dividing the day of the year, numbered 1 through 365, by 365.

The model in equation 1 is an appropriate model because the estimated dissolved-solids load had a large coefficient of determination (R^2) value and small values of residual variance and root mean square error. On the basis of water-quality and streamflow data from station 09229500, the R^2 value for equation 1 is 0.9699, the estimated residual variance[3] is 0.036, and

[3]Estimated residual variance is the adjusted maximum likelihood estimation variance corrected for the number of observations and number of parameters in the regression model.

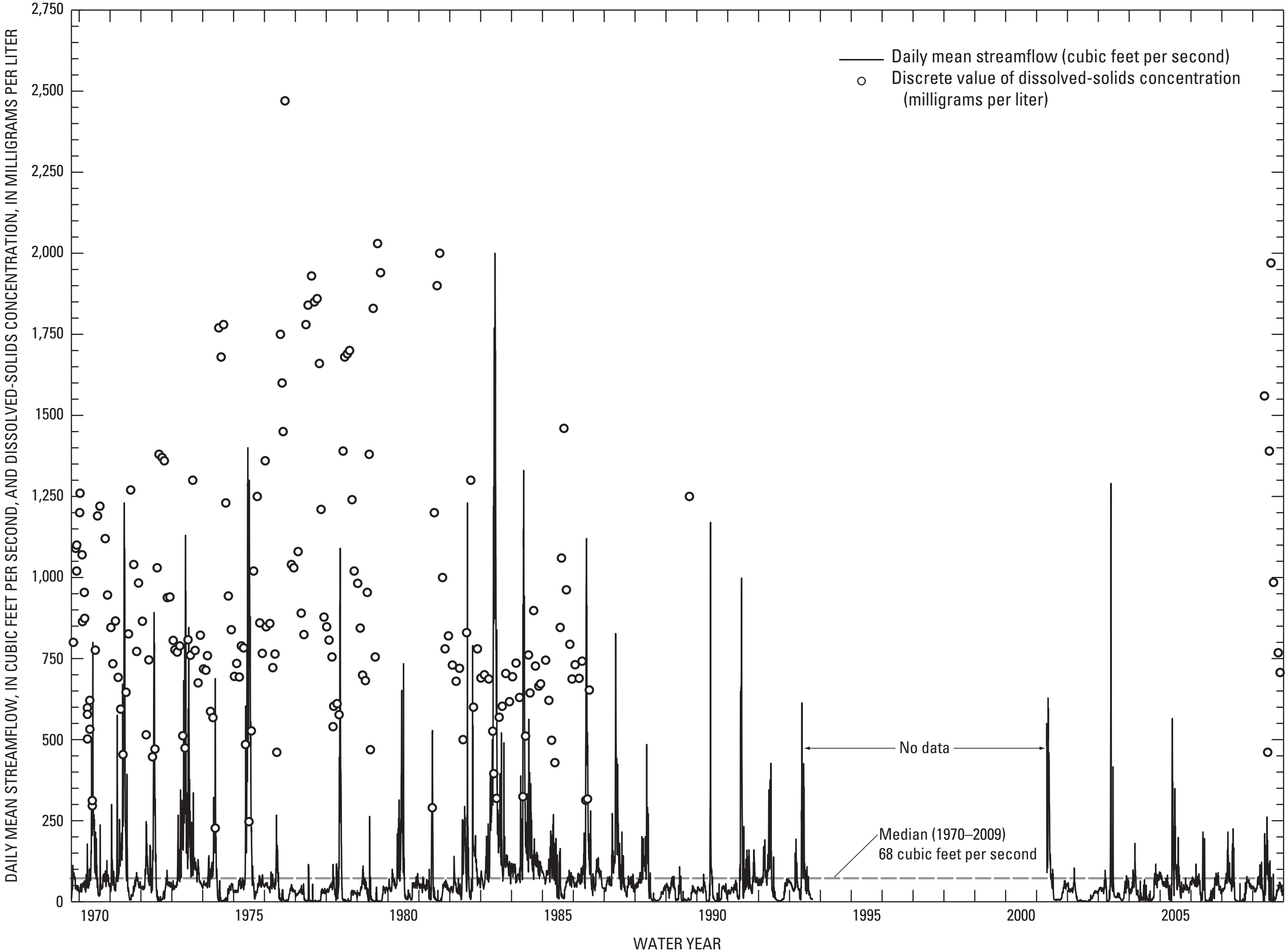

Figure 2. Daily mean streamflow and discrete values of dissolved-solids concentration during water-quality sampling at U.S. Geological Survey streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009.

the root mean square error is 17 percent. The model shown in equation 1 was determined to be the most appropriate model for the available data because the period of dissolved-solid load estimation (October 1, 1969, to September 30, 1993, and May 1, 2001, to November 20, 2008) was extended substantially beyond the period containing calibration data (October 24, 1969 to July 9, 1986 and May 19, 2008 to November 20, 2008). Therefore, no models with annual time terms were considered.

Estimated annual dissolved-solids load from the S-LOADEST program for each water year are shown in table 1 and figure 3. The mean annual mean daily dissolved-solids load for water years 1970–2009 is 133 tons. The 95-percent confidence interval for this value ranges from 127 to 139 tons. The mean annual dissolved-solids load for water years 1970–2009 is 48,700 tons, and the median annual dissolved-solids load for the same period is 45,400 tons (table 1; fig. 3). Annual streamflow ranged from 14,100 acre-ft in 1977 to 197,500 acre-ft in 1983.

The annual dissolved-solids load decreased from water years 1970–93 to water years 2002–09 (fig. 3). This decrease probably is because the period 2002–09 is characterized by dry years, whereas the period 1970–93 is characterized by wet and dry years (fig. 2). The median streamflow for water years 1970–93 is 76 cubic feet per second (ft^3/s), whereas the median streamflow for water years 2002–09 is 47 ft^3/s, which is less than the median streamflow of 68 ft^3/s for water years 1970–2009. Other possible reasons for the decrease in dissolved-solids load include changes in land management practices, changes in water use, or a combination of these and unknown factors.

When data are highly varied, calculation of mean values can be more valid when several of the largest and smallest values are “trimmed.” The most common method of trimming is removing 25 percent of the largest and smallest values, resulting in a “trimmed mean” or “25-percent trimmed mean” (Helsel and Hirsch, 2002). Values for the annual dissolved-solids load data were first ranked largest to smallest (table 2). The 25-percent trimmed mean was then computed on the middle 50 percent of the values. This approach resulted in the best estimate of annual load because such estimates are not influenced by the most extreme (and perhaps anomalous) values (Helsel and Hirsch, 2002). The calculated 25-percent trimmed mean is 44,300 tons per year and is used as the best estimate of annual dissolved-solids load for water years 1970–2009.

A Case Study Using the Upper Colorado River Basin SPARROW Model, Henrys Fork, Wyoming and Utah

The USGS, in cooperation with the BOR and the Bureau of Land Management, developed a dissolved-solids SPARROW model specific to the Upper Colorado River Basin (Kenney and others, 2009). The SPARROW model uses a mass-balance approach to examine the production and transport of instream constituent mass, or flux, on the basis of a nonlinear weighted least-squares regression technique. Coefficients for defined contaminant sources, landscape transport characteristics, and aquatic transport characteristics are determined through iterative calibration with contaminant load from streamflow and water-quality data at stream-monitoring sites. The coefficients represent an average condition of the role each source term and characteristic play throughout the basin of interest, assuming an unbiased distribution of the monitoring sites used in model calibration (Kenney and others, 2009). These coefficients are then applied to the SPARROW model, and contaminant load estimates can be generated for each of the incremental stream reaches that describe the basin of interest.

The SPARROW model was calibrated by using dissolved-solids load for water year 1991 at 218 stream-monitoring sites throughout the Upper Colorado River Basin (Kenney and others, 2009). The prediction error is approximately 51 percent (Kenney and others, 2009). The 11 defined sources for the model were 7 geologic source groups, 3 irrigated agricultural land groups, and 1 point-source associated with 7 large saline springs and 6 reservoirs. Six landscape transport characteristics and terms associated with climate, soils, vegetation, and elevation were found to be statistically significant in describing the transport of dissolved solids to streams in the Upper Colorado River Basin (Kenney and others, 2009).

Simulation results from the SPARROW model for the Upper Colorado River Basin include estimates of dissolved-solids load for water year 1991 at more than 10,000 unique stream reaches throughout the Upper Colorado River Basin. In the model, the 520 mi^2 of the Henrys Fork drainage is represented by 57 unique stream reaches. Although the Henrys Fork drainage basin was included in the SPARROW model, estimated dissolved-solids load results for reaches in that basin

Table 1. Annual streamflow and annual dissolved-solids load at U.S. Geological Survey streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009.

Water year	Annual streamflow (acre-feet)	Dissolved-solids load			
		Lower 95-percent confidence limit for the estimated mean daily load (tons/day)	Estimated mean daily load (tons/day)	Upper 95-percent confidence limit for the estimated mean daily load (tons/day)	Estimated annual load (tons)
1970	61,900	144	150	156	54,900
1971	98,000	190	199	208	72,600
1972	64,600	138	144	151	52,800
1973	115,000	221	232	243	84,600
1974	54,800	129	135	140	49,100
1975	114,100	195	207	219	75,400
1976	33,400	93	97	101	35,500
1977	14,100	48	50	52	18,300
1978	47,500	99	104	109	38,000
1979	19,100	58	60	63	22,000
1980	55,000	122	127	133	46,700
1981	35,400	92	96	100	35,000
1982	55,100	132	138	144	50,200
1983	197,500	319	338	358	123,300
1984	132,600	258	271	284	99,000
1985	63,400	156	162	169	59,200
1986	88,300	182	190	199	69,400
1987	75,600	168	175	182	63,900
1988	47,600	116	121	126	44,200
1989	19,700	62	65	67	23,600
1990	28,200	73	76	79	27,700
1991	55,900	125	130	136	47,600
1992	51,000	123	128	134	47,000
1993	47,600	116	120	125	44,000
2002	16,300	53	55	58	20,200
2003	34,100	83	87	90	31,600
2004	20,600	64	67	70	24,500
2005	54,200	133	138	144	50,400
2006	30,800	88	91	95	33,400
2007	33,400	90	93	97	34,100
2008	35,400	96	100	104	36,600
2009	45,000	111	115	120	42,100
Mean	**57,700**	**127**	**133**	**139**	**48,700**
Median	**49,300**	**119**	**124**	**129**	**45,400**

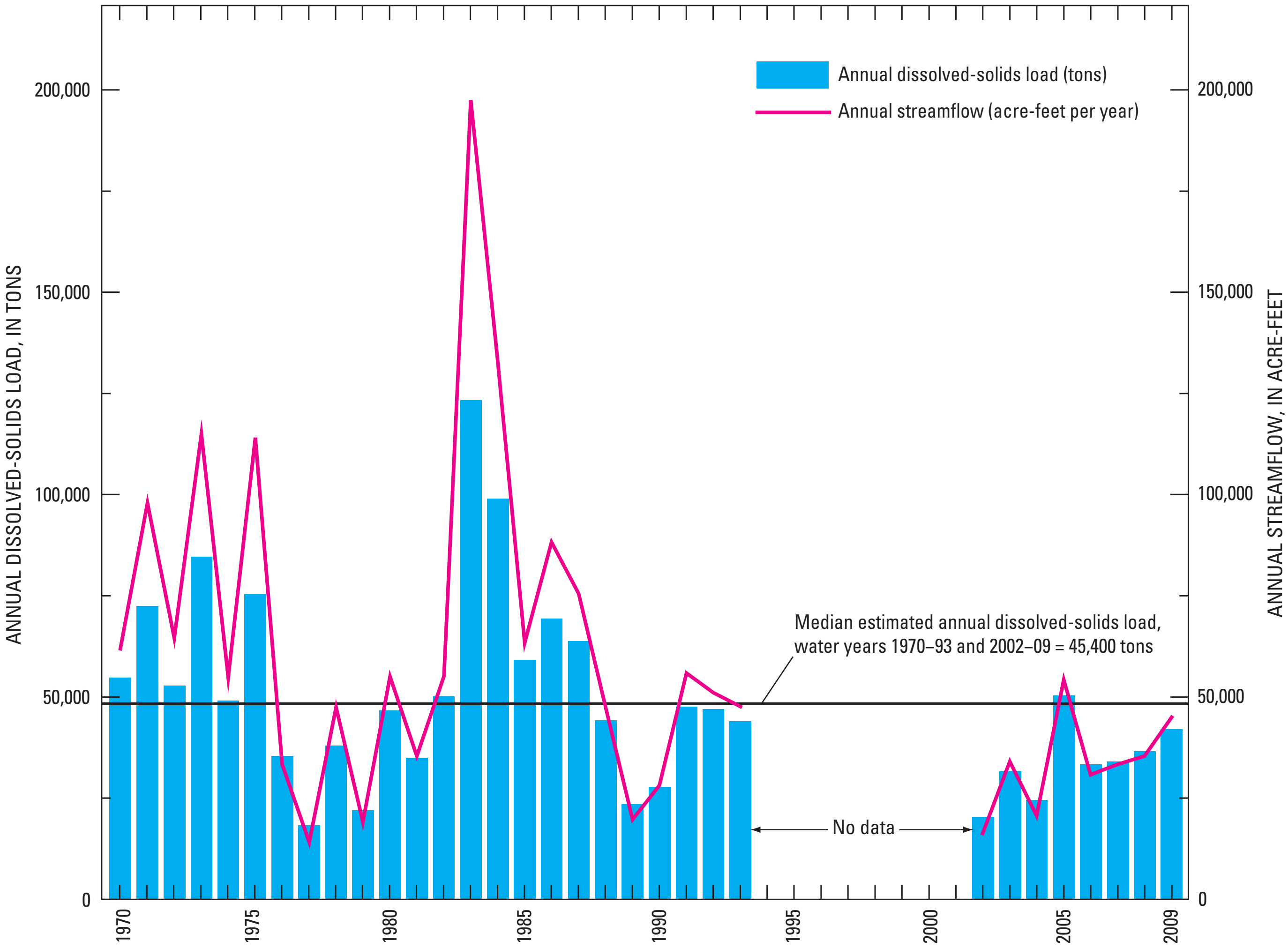

Figure 3. Annual streamflow and annual dissolved-solids load at streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009.

were not included in the final report by Kenney and others (2009). Those results are published as part of this report and are shown in table 3. All methods for determining the model results are described in Kenney and others (2009).

The dissolved-solids load predicted by using the SPARROW model for Henrys Fork near Manila, Utah, for water year 1991 was 29,600 tons. Considering the prediction error (51 percent) associated with the model, the predicted dissolved-solid load has a range of uncertainty of 14,500 tons to 44,700 tons (table 3). The results generated by the model represent basin-averaged conditions. Water developments and local point sources of dissolved solids, such as springs, can cause differences between predicted dissolved-solids load and actual dissolved-solids load because local influences on dissolved-solids loading to streams are not represented in the model at finer scales (Kenney and others, 2009).

Table 2. Ranked annual streamflow and annual dissolved-solids load from streamflow-gaging station 09229500, Henrys Fork near Manila, Utah, water years 1970–2009.

Rank	Water year	Annual streamflow (acre-feet)	Annual dissolved-solids load (tons)
1	1983	197,500	123,300
2	1984	132,600	99,000
3	1973	115,000	84,600
4	1975	114,100	75,400
5	1971	98,000	72,600
6	1986	88,300	69,400
7	1987	75,600	63,900
8	1985	63,400	59,200
75th percentile			**55,900**
9	1970	61,900	54,900
10	1972	64,600	52,800
11	2005	54,200	50,400
12	1982	55,100	50,200
13	1974	54,800	49,100
14	1991	55,900	47,600
15	1992	51,000	47,000
16	1980	55,000	46,700
50th percentile (median)			**45,400**
17	1988	47,600	44,200
18	1993	47,600	44,000
19	2009	45,000	42,100
20	1978	47,500	38,000
21	2008	35,400	36,600
22	1976	33,400	35,500
23	1981	35,400	35,000
24	2007	33,400	34,100
25th percentile			**33,900**
25	2006	30,800	33,400
26	2003	34,100	31,600
27	1990	28,200	27,700
28	2004	20,600	24,500
29	1989	19,700	23,600
30	1979	19,100	22,000
31	2002	16,300	20,200
32	1977	14,100	18,300
25-percent trimmed mean			**44,300**

Adjustment of Predicted Dissolved-Solids Load from SPARROW Model for Henrys Fork near Manila, Utah

Consideration of local hydrology is needed to reasonably compare results generated by the model with observed dissolved-solids load. Two features, Antelope Springs in Antelope Wash and Peoples Canal, which diverts water from Henrys Fork, were not represented in the SPARROW model and needed to be considered in order to compare results generated by the model with observed dissolved-solids load.

The dissolved-solid load associated with Antelope Springs was evaluated by using monitoring data collected in Antelope Wash. Water-quality data were collected in Antelope Wash (site 410244109454901) from August 2004 to September 2009 and analyzed as described by Gerner and others (2006). These data may be obtained from the NWIS (*http://nwis.waterdata.usgs.gov*). Ten samples were analyzed for dissolved-solids concentrations using the ROE method. A regression equation between ROE and specific conductance was determined by using the results from the 10 samples. This equation was then used to estimate the dissolved-solids concentrations in the remaining 20 samples for which only specific-conductance data were available. On the basis of these sampling results, the annual dissolved-solids load discharged from Antelope Wash was estimated to be 9,200 tons (table 4).

The annual dissolved-solids load for Antelope Wash was predicted to be 2,700 tons by using the SPARROW model (table 3). The SPARROW model underestimated the dissolved-solids load in this reach because the effect of the point-source dissolved-solids load associated with Antelope Springs was not represented in the model. The predicted dissolved-solids load (2,700 tons) for Antelope Wash was subtracted from the estimated annual dissolved-solids load (9,200 tons) determined from sampling in Antelope Wash. The difference of 6,500 tons, representing the contribution from Antelope Springs, was added to the SPARROW prediction of 29,600 tons for the Henrys Fork near Manila, Utah, resulting in an adjusted dissolved-solids load of 36,100 tons for the Henrys Fork near Manila, Utah, for water year 1991.

In contrast to Antelope Springs, the Peoples Canal diverts water and therefore dissolved-solids load from Henrys Fork. Water is diverted upstream from the streamflow-gaging station on Henrys Fork near Manila, Utah. Because Peoples Canal was not represented in the SPARROW model, the predicted dissolved-solids load for Henrys Fork includes the dissolved-solids load associated with the canal. In order to make the comparison with the dissolved-solids load estimated for Henrys Fork near Manila, Utah (site 09229500), from the LOADEST program, the SPARROW results need to be

Table 3. Predicted and adjusted dissolved-solids load from SPARROW model for selected locations in the Henrys Fork Basin, Wyoming, water year 1991.

[LOADEST, LOAD ESTimator computer program; NA, not applicable; SPARROW, SPAtially Referenced Regression On Watershed attributes]

	Henrys Fork upstream from Antelope Wash		Antelope Springs, Antelope Wash, and Peoples Canal				Henrys Fork near Manila, Utah			
	Predicted 1991 dissolved-solids load, from SPARROW model (tons)	Adjusted mean annual dissolved-solids load[1] (tons)	Predicted 1991 dissolved-solids load for Antelope Wash, from SPARROW model (tons)	Annual dissolved-solids load for Antelope Wash (tons)	Adjusted dissolved-solid load for Antelope Springs[2] (tons)	Annual dissolved-solids load diverted into Peoples Canal (tons)	Predicted 1991 dissolved-solids loads, from SPARROW model (tons)	Adjusted 1991 dissolved-solid load, from SPARROW model[3] (tons)	Estimated 1991 annual dissolved-solids load, from LOADEST (tons)	25-percent trimmed mean annual dissolved-solids load, from LOADEST (tons)
Prediction with 51-percent positive error[4]	37,800	56,200	4,100	NA	NA	NA	44,700	41,100	NA	NA
Actual, predicted, estimated or adjusted value	25,000	37,200	2,700	9,200	6,500	8,900	29,600	27,200	47,600	44,300
Prediction with 51-percent negative error[4]	12,200	18,200	1,300	NA	NA	NA	14,500	13,300	NA	NA

[1]25-percent trimmed mean annual dissolved-solids load adjusted by using the percent difference (84 percent) between SPARROW-model predicted dissolved-solids loads at Henry Fork near Manila, Utah, and Henrys Fork upstream from Antelope Wash.

[2]The difference between annual dissolved-solids load for Antelope Wash and the 1991 predicted dissolved-solids load from the SPARROW model for Antelope Wash.

[3]Adjusted SPARROW-model predicted dissolved-solids load with the addition of Antelope Springs dissolved-solids load and the subtraction of Peoples Canal dissolved-solids load.

[4]Standard error of estimate from Kenney and others (2009).

Table 4. Dissolved-solids concentration and estimated mean dissolved-solids load in streamflow from Antelope Wash, Wyoming, August 2004 to September 2009.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ROE, residue on evaporation at 180°C; mg/L, milligrams per liter; --, no data]

Date	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm at 25°C)	Dissolved-solids concentration, ROE (mg/L)	Estimated daily dissolved-solids concentration[1] (mg/L)	Estimated daily dissolved-solids load[2] (tons)
8/10/2004	4.3	3,640	3,580	3,580	15,150
9/14/2004	3.0	4,160	4,080	4,080	12,000
10/26/2004	4.1	4,140	--	4,120	16,600
11/22/2004	3.8	4,320	4,450	4,450	16,600
1/19/2005	2.6	4,150	--	4,130	10,600
2/24/2005	2.3	4,030	4,080	4,080	9,200
4/5/2005	1.6	4,560	--	4,490	7,100
6/1/2005	1.3	4,470	4,250	4,250	5,400
6/13/2007	1.9	3,690	--	3,720	7,000
7/10/2007	1.2	3,670	--	3,700	4,400
8/14/2007	2.2	3,840	3,950	3,950	8,600
9/27/2007	2.2	3,860	--	3,870	8,400
11/8/2007	2.1	4,100	--	4,080	8,400
12/13/2007	1.5	4,310	--	4,270	6,300
2/13/2008	1.4	3,930	3,970	3,970	5,500
3/19/2008	1.9	3,750	--	3,770	7,100
4/10/2008	1.6	3,870	--	3,880	6,100
5/20/2008	1.0	4,180	--	4,150	3,900
6/9/2008	1.4	4,200	--	4,010	5,500
7/17/2008	3.4	3,460	3,450	3,450	11,500
8/25/2008	3.1	3,750	--	3,770	11,500
9/30/2008	1.8	3,900	3,990	3,990	7,100
12/3/2008	2.5	4,020	--	4,010	9,900
2/19/2009	1.5	4,190	4,090	4,090	6,000
4/6/2009	3.1	3,810	--	3,830	11,700
5/20/2009	1.2	4,220	--	4,190	4,900
6/4/2009	1.6	3,980	--	3,980	6,300
7/9/2009	7.5	2,890	--	3,010	22,200
8/4/2009	4.2	3,270	--	3,350	13,800
9/3/2009	2.3	3,720	--	3,750	8,500
Mean	**2.5**			**3,900**	**9,200**

[1]Values were determined from analysis of residue on evaporation at 180°C (ROE) or by using regression equation developed from relation between ROE and specific conductance (SC): *Dissolved solids concentration* = 0.8881SC + 441.9.

[2]Individual average dissolved-solids concentrations (DS_{conc}) were extrapolated to average daily dissolved-solids load (DS_{load}) values by using the equation $DS_{load} = DS_{conc} \times 0.002697 \times streamflow \times 365$, where *streamflow* is the instantaneous streamflow.

adjusted to remove the dissolved-solids load associated with the canal.

The dissolved-solids load associated with Peoples Canal was determined from monitoring data. Water-quality data were collected at two sites on the canal (site 410233109440901 and 410044109405601) from June 2004 to September 2009 and analyzed as described in Gerner and others (2006). These data may be obtained from the NWIS (*http://nwis.waterdata.usgs.gov*). The ROE method was used for dissolved-solids analysis of 11 of the 23 samples collected during water years 2004–09. A regression equation was determined for the relation between ROE and specific conductance. This equation was then used to estimate dissolved-solids concentrations for the remaining 12 samples for which only specific conductance data were available (table 5).

On the basis of monitoring data, the annual dissolved-solids load for Peoples Canal was estimated to be 8,900 tons (table 6). This value was subtracted from the adjusted dissolved-solids load (36,100 tons) determined for the Henrys Fork near Manila, Utah. The final adjusted dissolved-solids load (27,200 tons) determined for the Henrys Fork near Manila, Utah (using the SPARROW model and monitoring data for Antelope Wash and Peoples Canal) was similar to the original dissolved-solids load of 29,600 tons predicted by using the SPARROW model. These data indicate that the inclusion of Antelope Springs point source and water diversion in Peoples Canal did not substantially change the SPARROW prediction; therefore, the SPARROW predictions of dissolved-solids load were used for further analysis as discussed in subsequent sections of this report.

The dissolved-solids load (29,600 tons) determined by using the SPARROW model for Henrys Fork near Manila, Utah, is 38 percent less than the estimated dissolved-solids load from the LOADEST model (47,600 tons) for the streamflow-gaging station at Henrys Fork near Manila, Utah (site 09229500) for water year 1991 (table 3). These data indicate that overall the SPARROW model underpredicted the dissolved-solids load by about 38 percent. Models like SPARROW are valuable for large-basin analyses and predicting dissolved-solids load in ungaged reaches; however, site-specific data are important for local managers and decision-making with regard to small watersheds.

Determination of Dissolved-Solids Load for Upper Henrys Fork Basin

A principle objective of this investigation was to estimate the annual dissolved-solids load for normal (mean) conditions in the upper Henrys Fork Basin, the 485-mi^2 drainage upstream from the confluence with Antelope Wash (fig. 1). Dissolved-solids and streamflow monitoring data do not exist for this location, and Henrys Fork near Manila, Utah, is the nearest monitoring site. SPARROW model simulations for the Upper Colorado River Basin were used to predict dissolved-solids loads for water year 1991 at 57 locations throughout the Henrys Fork Basin, including Henrys Fork upstream from Antelope Wash. The dissolved-solids load predicted by using the SPARROW model for the Henrys Fork upstream from Antelope Wash (25,000 tons) for water year 1991 was 84 percent of the dissolved-solids load predicted by using the SPARROW model for Henrys Fork near Manila, Utah (29,600 tons) for water year 1991. The application of this coefficient (0.84) to the 25-percent trimmed mean of the annual dissolved-solids load at Henrys Fork near Manila, Utah, estimated by LOADEST (44,300 tons), yielded an estimated annual dissolved-solids load in Henrys Fork upstream from Antelope Wash of 37,200 tons (± 2,800 tons at the 95-percent confidence level; table 3).

The 25-percent trimmed mean was used because it represents a mean value less affected by extremes. The scientific objective for this study was to estimate the dissolved-solids load for the study area for mean conditions. By adjusting, and later comparing, the SPARROW results to the trimmed mean, a dissolved-solids load more representative of the mean dissolved-solids load was obtained. If the objective had been to compare SPARROW results for water year 1991, then the dissolved-solids load representative of 1991 rather than the mean dissolved-solids load would be presented. The 25-percent trimmed mean of the LOADEST estimated annual dissolved-solids load for Henrys Fork near Manila, Utah, of 44,300 tons is within the range of uncertainty of the SPARROW model prediction of 29,600 tons for the Upper Colorado River Basin.

Distribution of Dissolved-Solids Load by Source at Selected Locations in Henrys Fork Basin

In addition to providing estimates of dissolved-solids load at locations of interest, the SPARROW model for the Upper Colorado River Basin apportions the total dissolved-solids load associated with each of the 11 defined sources. An objective of this investigation was to estimate the dissolved-solids load associated with irrigated agricultural lands in the upper Henrys Fork Basin. As determined by the SPARROW model simulations, approximately 56 percent (14,000 tons) of the dissolved-solids load at Henrys Fork upstream from Antelope Wash (25,000 tons) is associated with the 21,500 acres of irrigated agricultural lands (fig. 1). For comparison, at Henrys Fork near Manila, Utah, the 24,800 acres of irrigated agricultural lands in this 520-mi^2 drainage area (David Eckhart, Bureau of Reclamation Remote Sensing and Geographic Information Group, written commun., September 28, 2006) contribute approximately 47 percent (17,000 tons) of the adjusted dissolved-solids load (36,100 tons) for the Henrys Fork near Manila, Utah, after adding in the contribution of Antelope Springs, which was not represented in the SPARROW model. No adjustments were made to the contributions of the 11 defined sources predicted by using the SPARROW model, except for the addition of the dissolved-solids load from Antelope Springs.

Table 5. Dissolved-solids concentration and estimated daily dissolved-solids load in Peoples Canal, Wyoming, June 2004 to September 2009.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ROE, residue on evaporation at 180°C; mg/L, milligrams per liter; --, no data]

Site number	Site name	Sample date	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm at 25°C)	Dissolved-solids concentration, ROE (mg/L)	Estimated daily dissolved-solids concentration[1] (mg/L)	Estimated daily dissolved-solids load[2] (tons)
410233109440901	Peoples Canal at Henrys Fork	6/29/2004	50.0	1,130	808	808	109
410233109440901	Peoples Canal at Henrys Fork	7/22/2004	40.0	1,100	--	827	89
410233109440901	Peoples Canal at Henrys Fork	8/10/2004	23.0	1,110	802	802	50
410233109440901	Peoples Canal at Henrys Fork	9/14/2009	24.0	1,540	1,210	1,210	78
410233109440901	Peoples Canal at Henrys Fork	10/26/2004	24.0	1,080	--	811	52
410233109440901	Peoples Canal at Henrys Fork	11/22/2004	1.6	1,210	904	904	4
410233109440901	Peoples Canal at Henrys Fork	6/1/2005	41.0	390	265	265	29
410044109405601	Peoples Canal at Washam, WY	7/10/2007	4.8	1,190	--	901	12
410044109405601	Peoples Canal at Washam, WY	8/14/2007	13.0	1,040	772	772	27
410044109405601	Peoples Canal at Washam, WY	9/27/2007	20.0	1,210	--	917	49
410044109405601	Peoples Canal at Washam, WY	10/16/2007	27.0	902	661	661	48
410044109405601	Peoples Canal at Washam, WY	11/7/2007	2.6	840	--	615	4
410044109405601	Peoples Canal at Washam, WY	5/20/2008	39.0	463	326	326	34
410044109405601	Peoples Canal at Washam, WY	6/10/2008	40.0	641	--	452	49
410044109405601	Peoples Canal at Washam, WY	7/17/2008	28.0	1,060	784	784	59
410044109405601	Peoples Canal at Washam, WY	8/25/2008	15.0	1,460	1,170	1,170	47
410044109405601	Peoples Canal at Washam, WY	9/30/2008	14.0	1,250	--	950	36
410044109405601	Peoples Canal at Washam, WY	4/29/2009	7.2	796	--	579	11
410044109405601	Peoples Canal at Washam, WY	5/19/2009	24.0	357	--	220	14
410044109405601	Peoples Canal at Washam, WY	6/5/2009	32.0	537	368	368	32
410044109405601	Peoples Canal at Washam, WY	7/9/2009	26.0	932	--	690	48
410044109405601	Peoples Canal at Washam, WY	8/4/2009	25.0	1,270	--	966	65
410044109405601	Peoples Canal at Washam, WY	9/1/2009	21.0	1,420	--	1,089	62

[1]Values were determined from analysis of residue on evaporation at 180°C (ROE) or by using regression equation developed from relation between ROE and specific conductance (SC): *Dissolved solids concentration* = 0.8176SC – 72.19.

[2]Individual average dissolved-solids concentrations (DS_{conc}) were extrapolated to average daily dissolved-solids load (DSload) values by using the equation $DS_{load} = DS_{conc}$ x 0.002697 x *streamflow*, where *streamflow* is the instantaneous streamflow.

Table 6. Estimated dissolved-solids load in Peoples Canal, Wyoming, June 2004 to September 2009.

[No samples were collected during December through March. --, not applicable]

Period	Number of samples[1]	Estimated mean daily dissolved-solids load[2] (tons)	Estimated mean dissolved-solids load for period[3] (tons)
April 15–30	1	11	180
May	2	24	740
June	4	55	1,650
July	4	52	1,600
August	4	47	1,400
September	4	56	1,700
October	2	50	1,550
November 1–15	2	4	60
April 15 – November 15	--	--	8,900

[1]Samples collected at either U.S. Geological Survey site 410233109440901 or 410044109405601.

[2]Values were determined from the mean value for the period from the estimated daily dissolved-solids load in table 5.

[3]Value was determined by multiplying days in period by the estimated mean daily dissolved-solids load in tons.

Summary

The Colorado River Salinity Control Forum has a goal of reducing dissolved-solids load in the Colorado River drainage system, including Henrys Fork. Irrigated agriculture has been the focal point of many projects because changes to infrastructure and irrigation practices can yield substantial reductions in dissolved-solids load. The Henrys Fork Basin upstream from Antelope Wash (drainage area of 485 square miles) includes about 21,500 acres of irrigated lands. The U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation, conducted an investigation to estimate the dissolved-solids load associated with irrigated agricultural lands upstream from Antelope Wash. Streamflow and water-quality data collected at Henrys Fork near Manila, Utah (USGS streamflow-gaging station 09229500), downstream from Antelope Wash were used to estimate annual dissolved-solids loads that were then compared to the dissolved-solids load for water year 1991 estimated by the SPAtially Referenced Regression On Watershed attributes (SPARROW) model for the Upper Colorado River Basin.

Annual dissolved-solids loads at Henry Fork near Manila, Utah, were estimated by using the LOAD ESTimator (LOADEST) computer program run as an add-on to S-PLUS. The annual dissolved-solids load for water years 1970–2009 ranged from 18,300 tons in 1977 to 123,300 tons in 1983. Annual streamflows for this period ranged from 14,100 acre-feet in 1977 to 197,500 acre-ft in 1983. The estimated mean annual dissolved-solids load for water years 1970–2009 was 48,700 tons, and the estimated median annual dissolved-solids load for the same period was 45,400 tons. The annual dissolved-solids loads were ranked from largest to smallest, and 25 percent of the highest and lowest values were removed. Then the 25-percent trimmed mean of 44,300 tons was used as the best estimate of annual dissolved-solids load.

The predicted dissolved-solids load from the Upper Colorado River Basin SPARROW model at Henrys Fork near Manila, Utah, was 29,600 tons for water year 1991. Two features, Antelope Springs in Antelope Wash and Peoples Canal, which diverts water from Henrys Fork, were not represented in the SPARROW model and needed to be considered in order to compare results generated by the model with observed dissolved-solids load. The dissolved-solids load associated with Antelope Springs (6,500 tons) was added to the SPARROW prediction and the dissolved-solids load diverted by Peoples Canal (8,900 tons) was subtracted from the SPARROW prediction for an adjusted dissolved-solids load of 27,200 tons for water year 1991. The final adjusted dissolved-solids load (27,200 tons) determined for the Henrys Fork near Manila, Utah (using the SPARROW model prediction and monitoring data for Antelope Wash and Peoples Canal), was similar to the original SPARROW predicted dissolved-solids load of 29,600 tons. Therefore, the SPARROW predictions of dissolved-solids load were used for subsequent analyses.

A principle objective of this investigation was to estimate the annual dissolved-solids load in the upper Henrys Fork Basin for mean conditions. The dissolved-solids load predicted by using the SPARROW model for Henrys Fork upstream from Antelope Wash (25,000 tons) was 84 percent of the dissolved-solids load predicted by using the SPARROW model for Henrys Fork near Manila, Utah (29,600 tons). The application of this coefficient (0.84) to the 25-percent trimmed mean of annual dissolved-solids load at Henrys Fork near

Manila, Utah, estimated by LOADEST (44,300 tons) yielded an estimated annual dissolved-solids load in Henrys Fork upstream from Antelope Wash of 37,200 tons (± 2,800 tons at the 95-percent confidence level).

The SPARROW model predicted that approximately 56 percent (14,000 tons per year) of the dissolved-solids load for water year 1991 at Henrys Fork upstream from Antelope Wash (25,000 tons) is associated with the 21,500 acres of irrigated agricultural lands. For comparison, at Henrys Fork near Manila, Utah, the 24,800 acres of irrigated agricultural lands in this 520-square-mile drainage area contributes approximately 47 percent (17,000 tons per year) of the adjusted dissolved-solids load (36,100 tons), after adding in the contribution of Antelope Springs, which was not represented in the SPARROW model.

References Cited

Cohn, T.A., 1988, Adjusted maximum likelihood estimation of the moments of lognormal populations from type I censored samples: U.S. Geological Survey Open-File Report 88–350, 34 p.

Colorado River Basin Salinity Control Forum, 1975, Proposed water quality standards for salinity including numerical criteria and plan of implementation for salinity control, Colorado River system: Denver, Colo., 134 p.

Colorado River Basin Salinity Control Forum, 2002, 2002 Review of water quality standards for salinity—Colorado River System: Denver, Colo., 188 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Gerner, S.J., Spangler, L.E., Kimball, B.A., and Naftz, D.L., 2006, Characterization of dissolved solids in water resources of agricultural lands near Manila, Utah, 2004–05: U.S. Geological Survey Scientific Investigations Report 2006–5211, 36 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.

Iorns, W.V., Hembree, C.H., and Oakland, G.L., 1965, Water resources of the Upper Colorado River Basin—technical report: U.S. Geological Survey Professional Paper 441, 370 p.

Kenney, T.A., Gerner, S.J., Buto, S.G., and Spangler, L.E., 2009, Spatially referenced statistical assessment of dissolved-solids load sources and transport in streams of the Upper Colorado River Basin: U.S. Geological Survey Scientific Investigations Report 2009–5007, 70 p., accessed August 17, 2009, at *http://pubs.usgs.gov/sir/2009/5007.*

Koenig, K.J., 1960, Bridger Formation in the Bridger Basin, Wyoming, *in* McGookey, D.P., and Miller, D.N., Jr., eds., Overthrust belt of southwestern Wyoming and adjacent areas: Wyoming Geological Association, 15th Annual Field Conference Guidebook, p. 163–168.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey Map, scale 1:500,000.

Lowham, H.W., Peterson, D.A., Larson, L.R., Zimmerman, E.A., Ringen, B.E., and Mora, K.L., 1985, Hydrology of area 52, Rocky Mountain coal province, Wyoming, Colorado, Idaho, and Utah: U.S. Geological Survey Open-File Report 83–761, 96 p.

Mason, J.P., and Miller, K.A., 2004, Water resources of Sweetwater County, Wyoming: U.S. Geological Survey Scientific Investigations Report 2004–5214, 188 p.

Natural Resources Conservation Service, 2006, Plan and environmental assessment, Manila-Washam project area of the Colorado River Salinity Control Program, final draft, Sweetwater and Daggett Counties: United States Department of Agriculture, 112 p.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load estimator (LOADEST)—a FORTRAN program for estimating constituent load in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p.

Schwarz, G.E., and Alexander, R.B, 1995, State Soil Geographic (STATSGO) data base for the conterminous United States: U.S. Geological Survey Open-File Report 95–449, digital map, scale 1:250,000, accessed September 16, 2009, at *http://water.usgs.gov/lookup/getspatial?ussoils.*

TIBCO Software, Inc., 2008, TIBCO Spotfire S+ 8.1 for Windows: Palo Alto, Calif., TIBCO Software, Inc., 572 p.

U.S. Department of Agriculture, 2004a, Ecological site descriptions, Agricultural Research Service, accessed January 29, 2010, at *http://usda-ars.nmsu.edu/esd/esdIntro.html.*

U.S. Department of Agriculture, 2004b, Soil survey of Henrys Fork Area, Utah-Wyoming—Part of Daggett and Summit Counties, Utah and Sweetwater and Uinta Counties, Wyoming: Natural Resource Conservation Service, 282 p., accessed January 7, 2010, at *http://soildatamart.nrcs.usda.gov/Survey.aspx?State=WY.*

U.S. Department of the Interior, 1999, Quality of water—Colorado River Basin: Bureau of Reclamation Progress report no. 19, 93 p. plus appendix.

U.S. Department of the Interior, 2003, Quality of water—Colorado River Basin: Salt Lake City, Utah, Progress Report 21, 95 p.

Publishing support provided by:
Denver Publishing Service Center

For more information concerning this publication, contact:
Director, Wyoming Water Science Center
U.S. Geological Survey
2617 East Lincolnway, Suite B
Cheyenne, Wyoming 82001
(307) 778-2931

Or visit the Wyoming Water Science Center Web site at:
http://wy.water.usgs.gov/

USGS

Foster and Kenney—**Dissolved-Solids Load in Henrys Fork Upstream from the Confluence with Antelope Wash, Wyoming**—SIR 2010–5048