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Estimates of Dissolved-Solids Load of the Dolores River in the Paradox Valley, Montrose County, Colorado, 1988 through 2009

Administrative Report

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

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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)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	28.32	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Mass	
ton, short (2,000 lb)	9.0718474×10^8	milligram (mg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per year (ton/yr)	0.9072	metric ton per year

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

°F=(1.8×°C)+32

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

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

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

Estimates of Dissolved-Solids Load of the Dolores River in the Paradox Valley, Montrose County, Colorado, 1988 through 2009

By Kenneth R. Watts

Introduction

Saline groundwater discharge to the Dolores River substantially increases the dissolved-solids load of the Dolores River as it crosses the Paradox Valley (fig. 1). In July 1996, the Bureau of Reclamation (BOR) began production operation of a salinity control project, the Paradox Valley Unit (PVU), to reduce discharge of saline groundwater (brine) to the Dolores River in the Paradox Valley. The PVU pumps brine from an alluvial aquifer, which is hydraulically connected to the Dolores River, at a rate of about 230 gal/min (about 0.5 ft^3/s). The brine-production wells are completed near the base of the alluvial aquifer and below the freshwater/brine interface. Pumping the brine-production wells lowers the freshwater/brine interface, which reduces or reverses the vertical hydraulic gradient between the freshwater/brine interface and the river. As a result of changes in position of the freshwater/brine interface and the magnitude and (or) direction of the vertical hydraulic gradient, discharge of brine and the dissolved-solids load of the Dolores River decreases. The BOR evaluates the performance of the PVU based on estimates of the dissolved-solids load contributed to the Dolores River in the Paradox Valley. Specific conductance and concentrations of dissolved solids of water samples collected from the Dolores River at U.S. Geological Survey (USGS) streamgaging stations 09169500 and 09171100 (fig. 1) and continuous streamflow and specific-conductance data previously have been used to estimate the dissolved-solids load of the Dolores River in the Paradox Valley (Watts, 2000; and Chafin, 2003). An update of estimated dissolved-solids load of the Dolores River was done because much additional data have been collected at the gaging stations since the previous estimates.

Figure 1. Locations of streamgaging stations 09169500 and 09171100 and the Paradox Valley Unit brine-production wells, injection well, and water-quality monitors, Montrose County, Colorado, 2010.

Purpose and Scope

The purpose of this report is to describe the data and methods used to estimate the dissolved-solids load of the Dolores River in the Paradox Valley, Montrose County, Colorado, and to present estimates of dissolved-solids loads of the Dolores River in the Paradox Valley for the period January 1, 1988, through December 31, 2009.

Data

Streamflow and water-quality data used in this analysis were collected at USGS stations 09169500 (Dolores River at Bedrock, Colorado) and 09171100 (Dolores River near Bedrock, Colorado) (fig. 1) during August 27, 1987, through December 31, 2009. The data includes mean-daily discharge and specific conductance, during 1988 through 2009, and measurements of specific conductance and concentrations of dissolved solids in samples collected from the Dolores River at the stations during August 27, 1987, through December 1, 2009. Station 09169500, the Dolores River at Bedrock, Colorado, is located upstream from the PVU and near upstream side of the valley; and station 09171100, the Dolores River near Bedrock, Colorado, is located downstream from the PVU and the Paradox Valley (fig. 1).

Stream stage and specific conductance are monitored continuously (15-minute intervals) at the stations. Stream discharge is estimated from the stage measurements and the relation between discharge and stage, as determined by measurements of instantaneous discharge (Carter and Davidian, 1968). Water-quality samples have been collected approximately monthly since August 27, 1987, to determine concentrations of major ions (bicarbonate, calcium, carbonate, chloride, magnesium, potassium, sodium, and sulfate) and dissolved solids and to measure specific conductance. The concentrations of bicarbonate and carbonate are estimated from sample alkalinity and pH (Rounds, 2003).

Mean daily discharge (ft^3/s) and mean-daily specific conductance (μS/cm) of the Dolores River at Bedrock (station 09169500) and near Bedrock (station 09171100) were retrieved from the Web interface of the National Water Information System (NWIS) (accessed at http://waterdata.usgs.gov/co/nwis/) for the period January 1, 1988, through December 31, 2009.

Concentration of dissolved solids in and specific conductance of water samples collected from the Dolores River at stations 09169500 and 09171100 were retrieved from the NWIS Web interface for the period August 27, 1987, through December 1, 2009 (table 1, Supplemental Data). Data for two samples collected in 1978 at both stations that were used by Chafin (2003) were not included in this analysis because about 9 years separated the date of their collection from the beginning of periodic sampling during August 1987 and because the flow of the Dolores River upstream from the Paradox Valley has been regulated by McPhee Reservoir (not shown in figure 1) since March 19, 1984 (U.S. Geological Survey, 2009).

Concentration of dissolved solids in water-quality samples collected from the Dolores River at Bedrock (station 09169500) during August 27, 1987, through December 1, 2009, ranged from 158 to 2,260 mg/L and specific-conductance values ranged from 283 to 2,490 μS/cm (Appendix 1, table 1). Mean-daily specific conductance of the Dolores River at Bedrock ranged from 185 to 2,860 μS/cm during 1988 through 2009 (data available from the National Water Information System Web interface at http://waterdata.usgs.gov/co/nwis/). Concentration of dissolved solids in water-quality samples collected from the Dolores River near Bedrock (station 09171100) during August 27, 1987, through December 1, 2009, ranged from 174 to 14,900 mg/L and specific-conductance values ranged from 304 to 25,700 μS/cm (Appendix 1, table 1). Mean-daily specific conductance of the Dolores River near Bedrock ranged from 262 to 33,200 μS/cm during 1988 through 2009 (data available from the National Water Information System Web interface at http://waterdata.usgs.gov/co/nwis/).

The large increases in maximum concentration of dissolved solids and maximum specific-conductance values of the Dolores River between stations 09169500 and 09171100 result from the inflow of a relatively small volume of sodium-chloride brine. Concentration of dissolved solids in brine from the alluvial aquifer near the PVU ranges from 220,200 to 296,000 mg/L and averages about 258,000 mg/L; specific conductance of the brine ranges from about 197,000 to 229,000 μS/cm (Bureau of Reclamation, 1978). Groundwater in the alluvial aquifer is density stratified, with fresh groundwater, which has a relative density of about 1 g/cm^3, overlying brine with a relative density of about 1.164 g/cm^3. Brine discharge to the river varies seasonally and from year to year in response to changes in the position of the water table and freshwater/brine interface.

During 1988 through 2009, there were 882 missing values for mean-daily specific conductance at station 09169500 and 527 missing values for mean-daily specific conductance at station 09171100. Missing values for mean-daily specific conductance during 1988 through 1992 were not estimated. Estimates of missing mean-daily specific-conductance values during 1993 through 2009 were provided by Andrew Nicholas (Bureau of Reclamation, Bedrock, Colorado, electronic commun., June 10, 2010).

Estimating Concentration of Dissolved Solids from Specific Conductance

The relation between ionic concentration and specific conductance is fairly simple for dilute solutions of single salts. Natural waters generally are not simple solutions but contain a variety of both ionic and undissociated species, and the amounts and proportions of each may range widely. Specific conductance of water primarily is a result of the concentrations of dissolved solids, primarily the major anions and cations (bicarbonate, calcium, carbonate, chloride, magnesium, potassium, sodium, and sulfate) (Hem, 1985). Although specific conductance of water cannot be expected simply to be related to ion concentrations or to concentrations of dissolved solids, it can display relatively well defined relations (Hem, 1985). The ratio of the concentration of dissolved solids (mg/L) with specific conductance (µS/cm) in natural waters ranges from about 0.54 to 0.96 but mostly is between 0.55 to 0.75, and larger values are associated with water having larger sulfate concentrations (Hem, 1985). Brine associated with halite may contain as much as 10 times the dissolved-solids content as seawater (about 350,000 mg/L), and at these high concentrations the correlation between dissolved solids and specific conductance is not well defined (not linear) (Hem, 1985).

The relation of concentration of dissolved solids and specific conductance of the Dolores River over the range of concentrations of dissolved solids and specific-conductance values observed during August 27, 1987, through December 1, 2009, is approximately linear. Previously, Watts (2000) and Chafin (2003) used linear regression to estimate the concentration of dissolved solids from specific-conductance values for the Dolores River at stations 09169500 and 09171100. Chafin (2003) combined the water-quality data from 315 discrete samples collected at the stations from January 4, 1978, through February 27, 2002, to develop a regression equation ($DS = 0.5653 \times SC - 13$) to predict concentration of dissolved solids (DS, in milligrams per liter) from specific conductance (SC, in microsiemens per centimeter at 25 degrees Celsius).

Because of differences in ionic proportions between water from the Dolores River at stations 09169500 and 09171100 (fig. 2), it was expected that the relation between specific conductance and concentration of dissolved solids in the Dolores River would be different at the two gages; therefore, for this analysis, a regression equation was developed to predict concentration of dissolved solids from specific conductance for each gaging station.

Figure 2. Piper diagrams showing proportions of major cations and anions, as percentage of milliequivalents per liter, in the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (station 09171100), August 27, 1987, through December 1, 2009.

Least-squares regression analysis, as implemented in SYSTAT® for Windows®, version 11.00.01, © SYSTAT Software, Inc. (2004), was used to estimate concentration of dissolved solids from the approximately linear relation with specific conductance for 218 samples collected from the Dolores River at Bedrock (station 09169500) and for 218 samples collected from the Dolores River near Bedrock (station 09171100) (fig. 3).

Figure 3. Relation of concentration of dissolved solids and specific conductance of the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (station 09171100), August 27, 1987, through December 1, 2009. [DS = concentration of dissolved solids; SC = specific conductance]

The coefficient of determination, R^2, for the regression model of concentration of dissolved solids with specific conductance for the Dolores River at Bedrock (station 09169500) was 0.928 and for the Dolores River near Bedrock (station 091171100) was 0.995. The coefficient of determination is the proportion of variance of the dependent variable (concentration of dissolved solids) related with the variance of the independent variable (specific conductance) (Montgomery and Peck, 1982). The p-values (probability values) for the regression coefficients for both regression models were less than

0.001. The p-value is the probability of seeing a result as extreme in a collection of random data in which the independent variable has no effect on the dependent variable. The regression model (equation) for predicting concentration of dissolved solids from specific conductance for the Dolores River at Bedrock, Colorado (station 09169500), was

$$DS = 0.6945 \times SC - 81.4 \quad (1)$$

and for the Dolores River near Bedrock, Colorado (station 09171100) was

$$DS = 0.5809 \times SC - 48.7 \quad (2)$$

where DS is the concentration of dissolved solids (in milligrams per liter) and SC is the specific conductance (in microsiemens per centimeter at 25 degrees Celsius).

The fit of the regression model also is judged on the basis of the distribution of model error (the difference between the observed and predicted value) plotted against the predicted value. The least-squares regressions method is based on the assumption that the error is randomly distributed. If the points in a residual plot, a plot of error against either the predicted value (or the independent variable), are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; otherwise, a nonlinear model may be more appropriate. Residual plots for the regression models are included in the *SYSTAT output* (table 2, Supplemental data) and in table 3 (worksheet *SampleData* in spreadsheet *DoloresRiverLoad_1988-2009.xlsx*). The residuals (errors) appear to be proportional to the predicted values (independent variables) in the residual plots (shown on worksheet *SampleData*), indicating that nonlinear models might improve estimates of concentrations of dissolved solids.

Estimates of Dissolved-Solids Load of the Dolores River in the Paradox Valley, 1988 through 2009

Mean-daily concentration of dissolved solids of the Dolores River at station 09169500 and at station 09171100 (fig. 4) was estimated from the mean-daily specific-conductance value, using either equation 1 or 2, as appropriate, for the period January 1, 1988, through December 31, 2009. Mean-daily concentration of dissolved solids was not estimated for those days during 1988 through 1992 when the mean-daily specific-conductance value was not reported in the NWIS database (295 days for station 09169500 and 235 days for station 09171100). Estimates of mean-daily specific conductance, which were provided by Andrew Nicholas (Bureau of Reclamation, Bedrock, Colorado, electronic commun., June 10, 2010), were used to estimate concentrations of dissolved solids for the 1993 through 2009 period, when the mean-daily specific-conductance value was not reported in NWIS (587 days for station 09169500 and 292 days for station 09171100).

Figure 4. Estimated mean-daily concentration of dissolved solids of the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (09171100), 1988 through 2009.

Daily dissolved-solids loads of the Dolores River at Bedrock (station 09169500) and near Bedrock (station 09171100) (fig. 5) were estimated as the product of mean-daily discharge (ft^3/s), estimated mean-daily concentration of dissolved solids (mg/L), and a factor to convert from load in ($mg/L\cdot ft^3/s$) to load in tons per day (the conversion factor: 0.0026969 = 86,400 seconds/day × 28.3168 L/ft^3 ⁄ 907,184,740 mg/ton). [Note: The horizontal dashed lines in figure 5 are equal to a dissolved-solids load of 274 tons/day or about 100,000 tons/year.]

Figure 5. Estimated daily dissolved-solids load of the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (09171100), 1988 through 2009.

The increase in dissolved-solids load of the Dolores River between stations 09169500 and 09171100 (fig. 6) primarily results from discharge of brine from the alluvial aquifer but also includes an unknown amount of load from “fresh” groundwater, surface runoff, and irrigation return flow. The ultimate source of the brine is from the collapse-breccia aquifer that underlies the alluvial aquifer. The collapse-breccia aquifer was formed as salt (halite) and other evaporite minerals were dissolved and removed from the Paradox Member of the Hermosa Formation (Gutiérrez, 2004). Computed differences in dissolved-solids load ranged from about –920 to 1,885 tons/day. The average difference in dissolved-solids load prior to production operation of the PVU (prior to July 1996) was about 336 tons/day or about 122,700 tons/year. The average difference in dissolved-solids load after production operation of the PVU began in July 1996 was about 128 tons/day or 46,750 tons/year.

Figure 6. Estimated difference in dissolved-solids load of the Dolores River between gaging stations 09169500 and 09171100, Paradox Valley, Montrose County, Colorado, 1988 through 2009. [Notes: 442 missing values prior to January 1, 1993, and 437 values with difference in loads less than 1 ton per day not shown.]

Decreases in dissolved-solids load (negative load differences) were computed for 419 days in the 8,036 day period from January 1, 1988, through December 31, 2009, and positive load differences less than 1 ton/day were computed for 18 days. Differences in dissolved-solids load less than 1 ton/day are not shown in figure 6. Chafin (2003) also noted negative load differences and attributed them largely to streamflow losses that recharge the alluvial aquifer of the Paradox Valley during the rise in river stage in early spring. Other causes of negative load differences include errors in measurement of streamflow and specific conductance and errors in the regression models. Errors in measurement of streamflow and specific conductance probably are randomly distributed and on average do not bias estimates of load differences. Because the relation between dissolved solids and specific conductance varies with the proportions of major cations and anions in the water, errors in the estimated concentrations of dissolved solids from the regression models likely result from variability of dissolved cations and anions contributed by various sources within the drainage. An additional source of error occurs when there are rapid changes in streamflow and the peak flow occurs on different days at the two gages, which could result in apparent gains or losses in streamflow when mean-daily discharge is used to estimate dissolved-solids load.

The annual increase in dissolved-solids load of the Dolores River as it crosses the Paradox Valley ranged from an estimated 16,790 ton in 2002 to 206,424 tons in 1988 (table 3, worksheet *Annual Dissolved-Solids Load* in spreadsheet *DoloresRiverLoad_1988-2009.xlsx*). The average increase in dissolved-solids load during 1988 through 1996 (production operation of the PVU began in July 1996) was about 120,000 tons per year and during 1997 through 2009 was about 46,000 tons per year. Some of the load reduction during 2001 and 2002 likely is related to effects of drought on groundwater levels within the Paradox Valley.

Applicability of the regression equations for estimating concentrations of dissolved solids and dissolved-solids loads should be reviewed periodically, particularly when (1) streamflow and water-quality conditions are much different than those that occurred during 1988–2009, (2) results from continued water-quality sampling at the stations indicate a substantial change in water chemistry at either site, or (3) operations of the Paradox Valley Unit are modified substantially.

Acknowledgments

Andrew Nicholas, BOR Facility Operations Specialist for the Paradox Valley Unit, provided estimates of mean-daily specific conductance for the Dolores River and brine injection rates for the Paradox Valley Unit for the period January 1, 1993, through December 31, 2009. Roderick Ortiz and Katie Walton-Day, USGS Colorado Water Science Center, provided technical reviews of the report.

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Supplemental Data

Table 1. Specific conductance, concentration of dissolved solids, and discharge of the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (station 09171100), August 27, 1987, through December 1, 2009.

[Note: Dissolved-solids values in red are reported as estimated. Specific-conductance values in red are laboratory values of specific conductance, other values are from filed measurements. Discharge is instantaneous discharge at time of sample collection. --, instantaneous discharge not reported]

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
Dolores River at Bedrock, Colorado – Station 09169500				
1987/08/27	10:30	1,460	1,050	252
1987/10/05	10:30	782	446	78
1987/11/17	11:00	800	500	109
1988/01/13	12:00	880	444	99
1988/03/01	11:30	808	502	253
1988/04/05	12:30	690	440	378
1988/05/11	12:05	380	238	618
1988/05/24	11:50	389	242	673
1988/06/09	14:25	361	211	625
1988/06/28	11:40	762	404	285
1988/08/02	13:15	425	251	151
1988/09/21	17:15	837	513	79
1988/09/22	8:45	841	500	78
1988/10/06	15:10	691	379	80
1988/11/22	11:40	842	486	84
1988/12/09	9:50	620	370	89
1989/01/04	15:00	627	368	85
1989/04/20	9:30	409	236	991
1989/05/17	12:40	460	258	242
1989/06/12	12:30	679	368	72
1989/07/06	14:00	650	328	60
1989/08/17	8:00	585	315	65
1989/09/05	16:30	594	310	59

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1989/10/02	13:40	540	320	63
1989/11/14	12:30	556	294	80
1990/01/02	11:30	562	307	83
1990/03/06	14:40	660	369	66
1990/04/11	14:00	1,200	645	32
1990/05/16	12:10	1,560	964	26
1990/06/01	12:00	1,430	939	32
1990/06/06	20:00	1,590	950	8
1990/07/17	13:30	760	440	45
1990/08/08	10:00	618	327	31
1990/09/05	12:30	670	396	193
1990/09/06	9:15	842	552	400
1990/10/11	9:30	1,280	859	42
1990/11/19	12:30	998	583	34
1991/01/08	14:10	970	521	--
1991/03/05	14:00	1,540	1,020	64
1991/04/10	13:00	460	290	405
1991/05/07	12:00	1,140	737	65
1991/05/22	9:30	360	213	924
1991/06/11	9:00	897	564	72
1991/06/19	14:15	1,110	735	70
1991/07/26	11:50	790	456	68
1991/07/30	15:15	468	280	56
1991/08/20	16:50	600	334	71
1991/10/30	12:00	703	420	50
1991/11/18	15:20	1,720	1,440	73
1991/12/04	15:45	1,060	643	39
1992/01/13	12:30	1,060	624	41
1992/03/10	14:25	1,400	1,060	66
1992/03/23	12:30	1,110	733	76
1992/04/20	12:35	398	254	987
1992/05/05	13:15	355	198	1,250
1992/05/28	10:15	444	283	3,100
1992/06/17	13:45	420	247	392
1992/07/22	13:45	894	547	62
1992/08/26	10:00	544	319	76
1992/10/06	14:10	651	358	53

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1992/11/12	12:00	810	426	49
1992/12/22	11:00	1,240	641	24
1993/01/26	12:00	1,140	739	66
1993/03/22	12:30	460	281	825
1993/05/19	14:00	360	229	4,410
1993/06/15	7:00	386	223	932
1993/07/07	16:00	500	284	215
1993/08/09	12:00	644	339	135
1993/09/07	14:05	738	433	105
1993/10/05	11:00	571	291	50
1993/11/16	13:00	758	417	55
1993/12/28	15:45	925	499	38
1994/01/27	9:50	935	490	52
1994/03/09	13:00	1,180	718	98
1994/04/26	14:30	752	454	167
1994/05/10	13:10	332	193	1,210
1994/05/22	12:35	283	162	2,060
1994/06/23	7:00	610	325	99
1994/07/27	7:30	623	338	56
1994/08/09	10:50	660	367	65
1994/08/18	10:00	547	300	80
1994/10/11	15:40	820	464	48
1994/11/15	15:45	600	326	71
1995/02/22	13:55	805	429	57
1995/04/06	10:20	603	363	425
1995/04/25	13:20	374	214	1,060
1995/05/22	15:15	307	172	2,940
1995/06/15	10:10	310	173	1,330
1995/06/28	8:20	301	167	1,370
1995/07/12	8:05	287	158	752
1995/07/25	12:45	547	301	160
1995/08/17	8:10	498	253	101
1995/08/29	9:25	629	365	101
1995/10/11	10:10	639	383	54
1995/12/13	12:10	970	577	51
1996/01/24	12:55	989	535	35
1996/02/28	10:30	894	506	46

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1996/04/16	10:05	870	488	63
1996/05/07	12:00	907	549	96
1996/05/30	15:10	898	527	53
1996/06/19	14:05	578	303	55
1996/07/11	9:40	796	428	56
1996/08/07	10:40	471	250	56
1996/08/21	14:05	498	272	56
1996/08/28	14:50	471	247	108
1996/10/24	9:45	868	486	42
1996/12/10	12:50	1,010	621	72
1997/02/24	14:15	1,390	927	96
1997/04/07	13:10	566	359	652
1997/05/06	9:45	348	205	2,870
1997/06/05	6:20	321	178	2,050
1997/07/22	12:35	513	276	117
1997/07/28	14:50	450	234	129
1997/08/05	15:15	911	559	171
1997/08/20	8:45	564	316	130
1997/08/26	12:55	460	245	161
1997/09/03	13:15	525	296	135
1997/10/07	10:20	825	474	61
1997/11/18	12:25	858	510	53
1998/01/15	9:40	932	550	49
1998/03/03	12:25	1,010	615	52
1998/05/27	9:45	304	178	1,570
1998/07/08	14:00	533	283	127
1998/09/03	13:45	395	206	181
1998/10/15	9:00	855	502	47
1998/12/14	14:15	1,040	618	48
1999/03/10	15:05	1,140	718	61
1999/05/04	10:50	790	517	406
1999/05/26	11:45	302	176	3,000
1999/06/23	11:45	401	240	699
1999/08/04	11:45	993	644	343
1999/08/18	14:30	642	373	111
1999/08/31	13:00	1,340	974	124
1999/10/27	12:30	555	303	77

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1999/12/17	10:30	806	445	45
2000/03/01	11:45	1,010	590	52
2000/04/06	13:45	1,100	691	163
2000/04/24	15:00	351	204	947
2000/05/15	13:45	342	199	716
2000/06/01	9:45	661	370	98
2000/07/06	7:15	645	339	55
2000/08/17	8:30	594	310	113
2000/11/02	12:00	685	396	87
2000/12/13	14:15	805	431	49
2001/02/15	15:00	791	431	44
2001/03/14	15:00	1,010	577	56
2001/04/26	9:15	657	398	154
2001/06/04	14:15	1,000	581	53
2001/07/03	8:15	641	326	45
2001/07/30	13:00	633	328	48
2001/08/30	8:00	755	446	53
2001/10/04	8:45	708	361	37
2001/11/20	9:30	858	463	32
2002/02/27	9:30	983	522	38
2002/04/23	9:30	1,060	571	29
2002/05/30	8:15	1,710	886	12
2002/06/19	7:45	1,350	724	2
2002/06/27	10:00	785	426	2
2002/08/05	12:15	545	296	3
2002/09/26	11:30	1,790	987	10
2002/11/19	9:45	1,340	751	22
2002/12/12	10:15	1,320	686	38
2003/02/13	9:30	1,280	699	31
2003/04/02	8:45	698	387	55
2003/04/23	9:45	776	452	59
2003/05/28	8:45	998	568	40
2003/06/19	8:45	1,980	1,120	12
2003/07/09	8:45	1,090	563	16
2003/08/21	11:45	2,490	2,260	30
2003/10/02	10:00	1,520	801	14
2003/12/02	9:00	1,180	635	22

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
2004/01/27	13:00	1,320	744	16
2004/03/30	9:15	637	386	117
2004/04/12	14:00	662	405	140
2004/05/20	8:00	930	571	74
2004/06/23	8:00	622	337	46
2004/07/23	8:30	655	369	57
2004/08/25	7:30	513	277	53
2004/10/27	9:15	770	416	42
2004/12/09	10:00	972	538	42
2005/02/03	9:00	954	574	62
2005/03/02	9:15	893	542	93
2005/04/19	13:30	347	205	834
2005/06/01	9:45	384	220	1,040
2005/06/29	11:20	413	234	458
2005/07/28	10:15	585	311	87
2005/08/17	10:00	531	313	282
2005/10/06	11:20	1,650	1,140	38
2006/02/09	8:30	1,190	616	20
2006/04/12	10:00	543	307	141
2006/05/31	9:20	963	539	49
2006/07/19	8:30	697	374	56
2006/08/17	10:00	357	185	186
2006/08/24	7:15	444	236	86
2006/09/20	9:15	2,070	1,640	47
2006/11/08	10:00	1,150	642	40
2006/12/06	10:00	1,550	910	28
2007/01/09	9:00	1,450	828	29
2007/03/07	9:45	1,480	880	43
2007/05/23	9:00	790	519	438
2007/06/12	13:45	490	273	205
2007/07/31	9:15	785	500	83
2007/09/18	11:00	318	174	272
2007/10/01	15:30	1,380	916	31
2007/12/04	12:30	1,780	1,340	66
2008/02/21	10:45	1,170	769	65
2008/03/04	10:45	1,300	844	92
2008/04/01	14:30	305	185	1,500

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
2008/05/06	10:15	359	199	1,010
2008/06/17	12:45	325	181	874
2008/08/20	9:30	596	321	78
2008/11/19	9:15	795	424	41
2009/01/13	11:15	827	466	33
2009/03/11	10:45	1,020	630	64
2009/06/16	10:30	785	448	81
2009/07/28	14:00	550	296	59
2009/09/15	11:10	688	381	33
2009/12/01	15:40	860	471	41
		Dolores River near Bedrock, Colorado – Station 09171100		
1987/08/27	12:30	2,380	1,620	285
1988/01/13	13:00	5,100	3,060	130
1988/03/01	14:30	2,330	1,350	282
1988/04/05	15:00	1,710	987	393
1988/05/11	16:30	442	328	630
1988/05/24	14:30	538	335	698
1988/06/09	11:20	648	358	658
1988/06/28	15:45	5,550	3,100	135
1988/08/03	8:00	1,880	992	123
1988/09/21	16:30	3,700	2,040	81
1988/09/22	11:30	3,770	2,040	79
1988/10/06	17:20	4,840	2,630	86
1988/11/22	16:30	5,080	2,960	112
1988/12/09	11:30	8,310	5,180	65
1989/01/04	12:20	4,720	2,620	94
1989/02/13	14:00	4,500	2,350	112
1989/04/19	14:45	485	274	985
1989/05/17	16:30	1,550	818	246
1989/06/12	14:30	5,100	2,640	74
1989/07/07	8:30	3,920	2,000	57
1989/08/17	10:30	2,250	1,220	62
1989/09/05	14:00	2,240	1,130	62
1989/10/02	15:00	2,300	1,180	62
1989/11/14	14:00	3,700	2,050	81

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1990/01/02	13:00	4,030	2,140	104
1990/03/06	16:40	6,320	3,390	72
1990/04/11	16:00	9,850	5,590	30
1990/05/16	16:55	8,790	5,250	29
1990/06/01	10:45	6,480	3,990	31
1990/06/06	18:30	18,100	11,100	12
1990/07/17	16:30	2,550	1,370	46
1990/08/09	10:00	2,870	1,520	32
1990/09/05	15:00	1,130	627	82
1990/09/06	12:00	657	371	468
1990/10/12	8:30	4,890	2,900	37
1990/11/19	15:00	5,180	2,960	38
1991/01/08	16:00	6,310	3,290	
1991/04/10	15:00	694	412	417
1991/05/07	14:00	5,660	3,250	68
1991/05/21	14:30	441	251	851
1991/06/11	10:50	3,460	2,230	74
1991/06/19	13:15	3,850	2,420	69
1991/07/26	10:30	1,300	759	87
1991/07/31	9:15	2,140	1,130	53
1991/08/20	17:55	1,890	1,000	64
1991/10/30	16:10	2,810	1,720	48
1991/11/18	13:45	2,580	1,940	86
1991/12/04	12:15	20,300	12,000	20
1992/01/13	14:00	12,600	7,410	38
1992/03/10	13:30	5,770	3,780	76
1992/03/23	14:00	5,160	3,160	77
1992/04/20	16:15	474	279	998
1992/05/05	16:45	387	219	1,260
1992/05/28	15:00	468	299	3,210
1992/06/18	8:30	830	467	379
1992/07/23	9:30	3,630	2,210	63
1992/08/26	14:25	1,830	984	80
1992/10/07	9:30	2,720	1,490	52
1992/11/12	14:00	4,500	2,330	51
1992/12/21	16:15	11,400	6,550	50
1993/01/26	15:00	17,900	9,910	59

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1993/03/22	17:00	705	392	770
1993/04/20	15:15	334	192	3,300
1993/05/19	17:50	352	208	4,560
1993/06/15	13:15	480	270	1,220
1993/07/08	10:00	700	396	457
1993/08/09	13:50	1,940	996	114
1993/09/07	15:35	2,360	1,270	108
1993/10/05	13:00	3,380	1,720	55
1993/11/15	15:45	4,780	2,790	68
1993/12/28	13:30	7,500	3,890	46
1994/01/27	11:35	5,710	3,050	60
1994/03/09	15:30	3,670	1,760	101
1994/04/26	15:35	2,360	1,270	175
1994/05/10	16:00	378	215	1,220
1994/05/22	16:15	304	174	1,990
1994/06/23	10:00	2,800	1,500	98
1994/07/27	9:30	3,170	1,620	57
1994/08/09	12:30	2,560	1,400	63
1994/08/18	9:35	1,900	1,000	69
1994/10/12	9:15	3,310	1,760	51
1994/11/16	14:30	2,680	1,400	63
1995/02/22	10:15	4,810	2,540	60
1995/04/06	13:30	925	529	445
1995/04/24	16:30	448	251	992
1995/05/23	9:50	320	177	2,870
1995/06/14	13:45	352	195	1,300
1995/06/27	15:45	349	193	1,270
1995/07/12	14:15	449	238	827
1995/07/25	10:40	3,150	1,650	169
1995/08/16	17:35	2,950	1,500	108
1995/08/29	11:20	2,450	1,280	120
1995/10/11	11:45	6,670	3,610	56
1995/12/12	14:25	8,600	4,970	63
1996/01/24	8:55	8,530	4,720	25
1996/02/28	13:55	7,410	4,140	55
1996/04/16	13:20	5,070	2,790	70
1996/05/06	15:15	3,330	1,840	95

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
1996/05/30	8:45	5,200	2,940	51
1996/06/19	9:15	3,460	1,820	51
1996/07/11	14:45	2,670	1,410	62
1996/08/07	7:15	1,480	760	59
1996/08/21	9:45	1,820	944	54
1996/08/28	11:35	1,230	603	145
1996/10/24	15:05	3,350	1,750	42
1996/12/10	14:55	5,480	3,200	75
1997/02/25	9:20	4,100	2,450	82
1997/04/08	8:45	728	463	643
1997/05/06	14:15	353	209	2,830
1997/06/04	11:20	312	174	2,450
1997/07/22	8:20	1,900	988	125
1997/07/28	11:25	1,060	546	180
1997/08/05	12:20	1,530	816	145
1997/08/20	11:55	1,470	766	123
1997/08/26	15:15	938	476	165
1997/09/03	15:30	1,290	676	131
1997/10/07	12:30	3,770	2,010	69
1997/11/18	14:35	4,440	2,470	55
1998/01/15	11:15	7,300	4,120	41
1998/03/03	13:50	4,780	2,740	60
1998/05/27	14:00	317	186	1,600
1998/07/08	8:30	1,870	963	119
1998/08/05	7:45	2,210	1,230	95
1998/09/03	16:00	592	314	169
1998/10/15	12:45	2,680	1,490	43
1998/12/14	11:15	7,090	4,060	34
1999/03/11	11:30	4,880	2,750	74
1999/05/04	13:20	898	575	387
1999/05/26	8:30	318	182	3,140
1999/06/23	8:00	427	257	765
1999/08/04	9:00	2,230	1,370	94
1999/08/18	12:30	1,550	851	99
1999/08/31	15:30	1,780	1,230	123
1999/10/27	15:45	2,010	1,070	76
1999/12/16	16:45	2,010	1,090	78

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
2000/03/01	14:00	4,130	2,290	60
2000/04/06	10:15	2,110	1,200	119
2000/04/24	16:45	372	213	1,030
2000/05/15	15:45	376	217	740
2000/06/01	7:30	2,260	1,190	101
2000/07/06	10:00	2,640	1,390	57
2000/08/16	15:00	1,350	691	68
2000/11/02	8:45	1,530	840	92
2000/12/13	16:00	2,650	1,500	54
2001/02/15	17:15	5,780	3,280	70
2001/03/14	17:00	2,160	1,200	58
2001/04/26	12:45	857	502	162
2001/06/04	16:15	2,010	1,120	50
2001/07/03	10:30	1,400	730	47
2001/07/30	15:30	1,090	559	47
2001/08/30	10:30	1,570	860	51
2001/10/04	11:15	1,330	679	36
2001/11/20	12:00	1,520	798	32
2002/02/27	12:00	1,930	1,020	32
2002/04/23	13:00	2,650	1,420	29
2002/05/30	11:15	4,570	2,490	14
2002/06/19	11:30	25,700	14,900	2
2002/06/27	7:00	20,800	12,200	2
2002/08/05	14:15	9,960	5,540	2
2002/09/26	14:45	3,990	2,230	10
2002/11/19	12:15	2,470	1,350	22
2002/12/12	12:45	3,530	1,950	34
2003/02/13	12:00	2,850	1,560	38
2003/04/02	11:00	3,110	1,680	50
2003/04/23	12:45	2,720	1,500	65
2003/05/28	11:45	2,750	1,490	38
2003/06/19	10:45	9,430	5,280	12
2003/07/09	11:00	2,050	1,060	15
2003/08/22	11:30	2,610	2,170	23
2003/10/02	15:00	2,130	1,560	14
2003/12/02	11:15	3,930	2,150	28
2004/01/26	13:30	11,800	6,940	51

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
2004/03/30	12:15	953	571	124
2004/04/12	15:45	919	550	151
2004/05/20	10:45	1,360	795	78
2004/06/23	11:15	832	467	47
2004/07/23	10:45	889	534	54
2004/08/25	9:30	583	324	53
2004/10/27	12:30	1,060	565	40
2004/12/09	12:45	2,410	1,280	40
2005/02/03	11:45	2,630	1,490	68
2005/03/02	12:00	2,300	1,290	103
2005/04/19	16:00	377	221	1,050
2005/05/31	16:15	384	224	1,330
2005/06/29	8:15	599	336	443
2005/07/28	13:30	1,440	749	82
2005/08/17	12:45	698	410	282
2005/10/05	16:30	5,450	3,370	46
2006/02/09	12:15	6,490	3,410	36
2006/04/12	13:00	1,590	860	153
2006/05/31	14:45	2,660	1,420	52
2006/07/19	11:00	1,550	801	50
2006/08/17	14:15	496	260	159
2006/08/24	9:30	621	325	90
2006/09/20	12:45	2,870	2,080	48
2006/11/08	12:30	4,900	2,670	45
2006/12/06	12:30	5,210	3,040	57
2007/01/09	11:30	7,080	3,980	59
2007/03/07	12:30	2,810	1,540	48
2007/05/23	12:45	831	528	419
2007/06/12	18:10	561	313	194
2007/07/31	12:30	1,060	664	81
2007/09/18	13:30	328	177	353
2007/10/01	17:15	2,370	1,450	34
2007/12/04	15:00	2,020	1,280	70
2008/02/21	14:00	3,470	1,980	80
2008/03/04	13:30	3,540	2,090	97
2008/04/01	10:45	318	188	1,460
2008/05/06	14:45	355	205	1,110

Sample date (yyyy/mm/dd)	Sample time (hh:mm)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius	Dissolved solids (milligrams per liter)	Discharge (cubic feet per second)
2008/06/17	9:30	344	190	840
2008/08/19	14:15	1,100	586	73
2008/11/18	15:15	2,010	1,090	41
2009/01/13	14:15	2,790	1,480	50
2009/03/11	15:15	3,770	2,140	68
2009/06/16	14:15	2,120	1,160	75
2009/07/28	15:30	1,540	801	59
2009/09/15	13:00	1,590	839	38
2009/12/01	11:45	3,550	1,910	46

Table 2. SYSTAT output regression analysis of dissolved-solids concentration and specific-conductance values for the Dolores River at Bedrock, Colorado (station 09169500) and near Bedrock, Colorado (station 09171100), 1987 through 2009.

The following results are for station 09169500, August 27, 1987 through December 1, 2009. This regression model predicts concentration of dissolved solids (DS) from specific-conductance values (SC) for water samples collected at the upstream gaging station, station 09169500, the Dolores River at Bedrock, Colorado.

[N = number of samples, P(2 Tail) = the probability that an equivalent coefficient would be obtained if the variables were unrelated, Std = standard, df = degrees of freedom, F-ratio = , P = probability of a larger F-ratio if the variables were unrelated, df = degrees of freedom]

Eigenvalues of unit scaled X'X

1	2
1.90425	0.09575

Condition indices

1	2
1.00000	4.45958

Variance proportions

	1	2
CONSTANT	0.04787	0.95213
SC	0.04787	0.95213

Dependent Variable: DS N: 218 Multiple R: 0.96312 Squared multiple R: 0.92759

Adjusted squared multiple R (R^2): 0.92726 Standard error of estimate: 73.92915

Effect	Coefficient	Std Error	Std Coefficient	Tolerance	t	P(2 Tail)
CONSTANT	-81.36411	11.72620	0.00000	.	-6.93866	0.00000
SC	0.69447	0.01320	0.96312	1.00000	52.60348	0.00000

Effect	Coefficient	Lower 95%	Upper 95%
CONSTANT	-81.36411	-104.47654	-58.25168
SC	0.69447	0.66845	0.72049

Correlation matrix of regression coefficients

	CONSTANT	SC
CONSTANT	1.00000	
SC	-0.90425	1.00000

Analysis of Variance

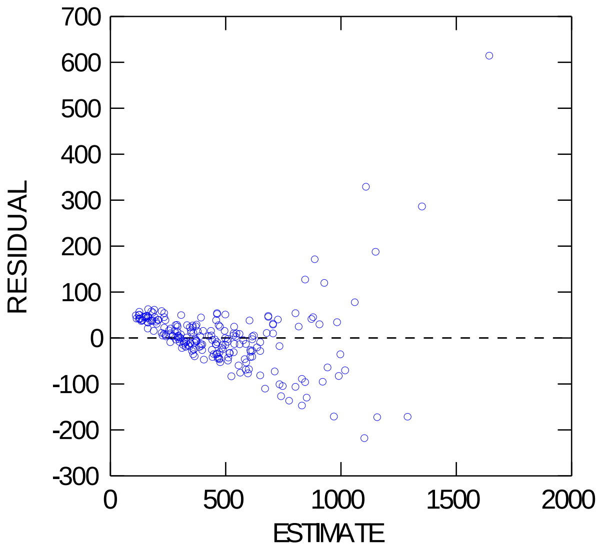
Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	1.51238E+07	1	1.51238E+07	2767.12627	0.00000
Residual	1.18055E+06	216	5465.51885		

*** WARNING ***
Case 49 is an outlier (Studentized Residual = 4.70748)
Case 169 has large leverage (Leverage = 0.09533)
Case 169 is an outlier (Studentized Residual = 10.77962)
Case 195 is an outlier (Studentized Residual = 4.09218)

Durbin-Watson D Statistic 1.83803
First Order Autocorrelation 0.07429

NOTE: The following residual (error) plot indicates a slight bias in the regression model for dissolved-solids concentrations less than about 200 milligrams per liter.

Plot of residuals against predicted values



The following results are for station 09171100, August 27, 1987 through December 1, 2009. This regression model predicts concentration of dissolved solids (DS) from specific-conductance values for water samples collected at the downstream gaging station (09171100), the Dolores River near Bedrock, Colorado.

[N = number of samples, P(2 Tail) = the probability that a an equivalent coefficient would be obtained if DS and SC were unrelated, df = degrees of freedom]

Eigenvalues of unit scaled X'X

	1	2
	1.67439	0.32561

Condition indices

	1	2
	1.00000	2.26767

Variance proportions

	1	2
CONSTANT	0.16280	0.83720
SC	0.16280	0.83720

Dependent Variable: DS   N: 218   Multiple R: 0.99756   Squared multiple R: 0.99512

Adjusted squared multiple R (R^2): 0.99510   Standard error of estimate: 145.78972

Effect	Coefficient	Std Error	Std Coefficient	Tolerance	t	P(2 Tail)
CONSTANT	-48.72852	13.37279	0.00000	.	-3.64386	0.00034
SC	0.58089	0.00277	0.99756	1.00000	2.09E02	0.00000

Effect	Coefficient	Lower 95%	Upper 95%
CONSTANT	-48.72852	-75.08640	-22.37065
SC	0.58089	0.57544	0.58635

Correlation matrix of regression coefficients

	CONSTANT	SC
CONSTANT	1.00000	
SC	-0.67439	1.00000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	9.37072E+08	1	9.37072E+08	44087.87788	0.00000
Residual	4.59100E+06	216	21254.64333		

*** WARNING ***

Case 248 has large leverage (Leverage = 0.08389)

Case 248 is an outlier (Studentized Residual = 4.77102)

Case 266 has large leverage (Leverage = 0.10915)

Case 279 has large leverage (Leverage = 0.08177)

Case 375 has large leverage (Leverage = 0.18592)

Case 376 has large leverage (Leverage = 0.11537)

Case 387 is an outlier (Studentized Residual = 5.10304)

Durbin-Watson D Statistic 1.35156

First Order Autocorrelation 0.31413

NOTE: The following residual (error) plot indicates a slight bias in the regression model for dissolved-solids concentrations less than about 1,000 milligrams per liter.

Plot of residuals against predicted values

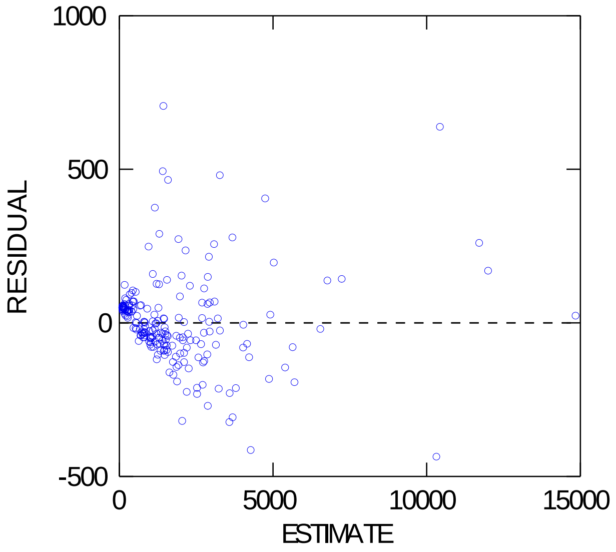


Table 3. *DoloresRiverLoad_1988-2009.xlsx*

Table 3 is an attached MicroSoft Excel 2007 ® spreadsheet.