Analysis of Annual Dissolved-Solids Loading from Selected Natural and Irrigated Catchments in the Upper Colorado River Basin, 1974–2003

Prepared in cooperation with the U.S. Department of the Interior, Bureau of Reclamation

Scientific Investigations Report 2012–5090

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

Cover: Photo on left: Irrigated agricultural lands near Antelope Wash, Uinta Mountains, Utah. Photo on right: Ashley Creek near Vernal, Utah, looking upstream.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter (cm)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Mass	
ton	0.9072	metric ton

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

°F=(1.8×°C)+32

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

°C=(°F-32)/1.8

Abbreviations

AAOTMax annual average monthly (April through October) maximum temperature
ENSO El Niño-Southern Oscillation
IQR interquartile range
PDO Pacific Decadal Oscillation
PRISM Parameter-elevation Regressions on Independent Slopes Model
Reclamation Bureau of Reclamation
SPARROW Spatially Referenced Regressions on Watershed Attributes
UCRB Upper Colorado River Basin
USGS U.S. Geological Survey

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Abstract

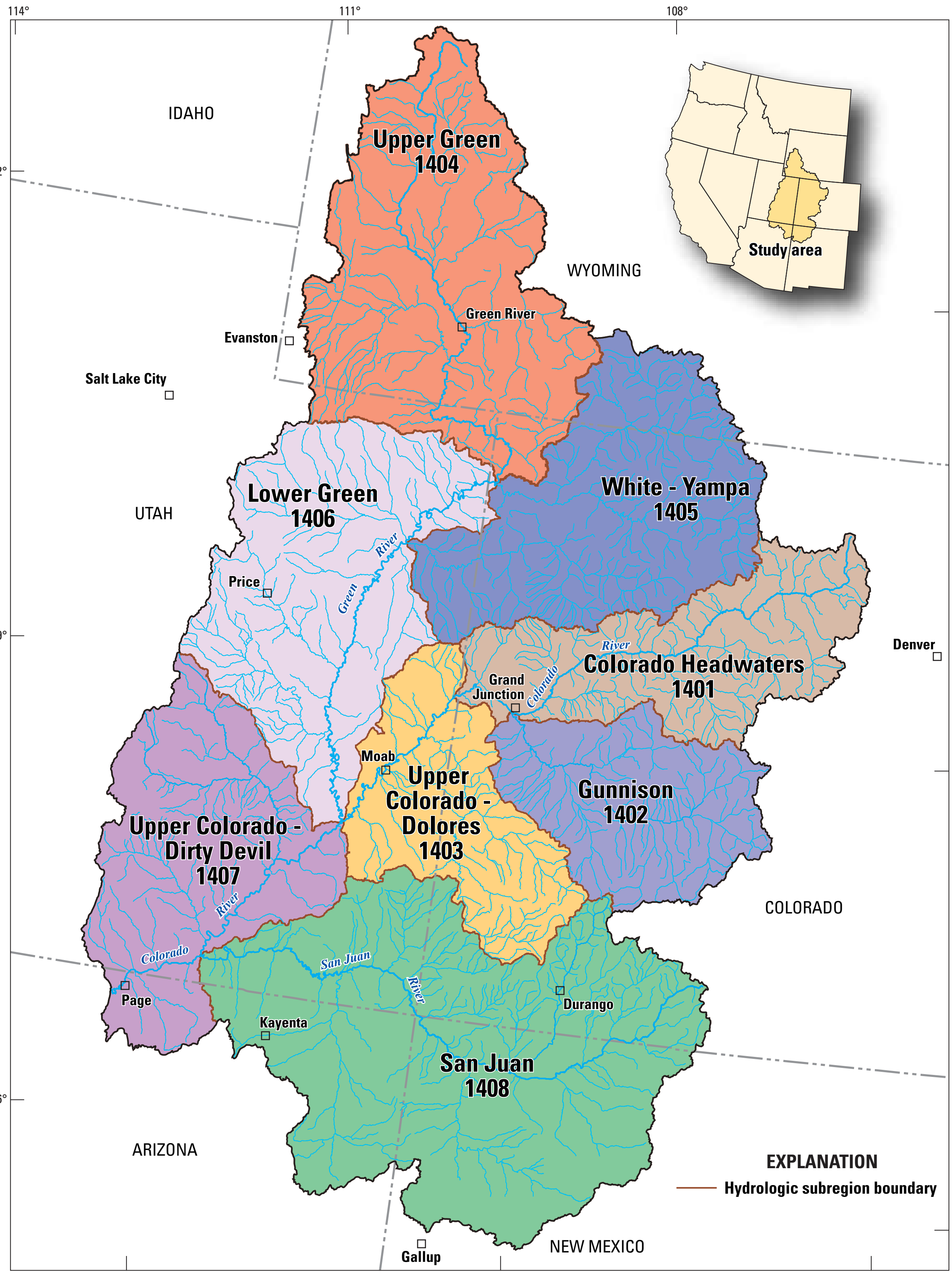
Dissolved-solids loading from 17 natural catchments and 14 irrigated catchments in the Upper Colorado River Basin was examined for the period from 1974 through 2003. In general, dissolved-solids loading increased and decreased concurrently in natural and irrigated catchments but at different magnitudes. Annually, the magnitude of loading in natural catchments changed about 10 percent more, on average, than in irrigated catchments. Measures of variability, or spread, indicate that natural catchments had 35 percent greater annual variability in loading than irrigated catchments. Precipitation and dissolved-solids loads were positively correlated in natural catchments, and a weak positive correlation was determined for irrigated catchments. A weak negative correlation between temperature and dissolved-solids load was determined for both natural and irrigated catchments. In irrigated catchments, the dissolved-solids load response to an above-average precipitation period from 1982 through 1987 generally lagged behind that in the natural catchments. On average, irrigated catchments with reservoir storage had the largest normalized maximum annual loads during the wet period.

Introduction

The 108,000 square mile (mi^2) drainage area of the Upper Colorado River Basin (UCRB) includes portions of Wyoming, Colorado, Utah, New Mexico, and Arizona (fig. 1). For this report, the UCRB is defined as the contributing drainage area upstream of U.S. Geological Survey (USGS) streamflow-gaging station 09380000, Colorado River at Lees Ferry, Arizona. The landscape in the UCRB is varied and includes alpine forests, arid badlands, and slickrock canyonlands. The major rivers of the UCRB are the Colorado, Green, and San Juan, and the headwaters of these rivers generally are located within highly-deformed crustal blocks of the Central Rocky Mountains. The geology of these headwater areas stands in distinct contrast to the undeformed rocks of the Colorado Plateau, which generally compose the lower one-third of the UCRB. During the past 30 years, the UCRB, on average, annually discharged about 7 million tons of dissolved solids, as computed at Lees Ferry, Arizona (Anning and others, 2007). It is estimated that between 40 and 45 percent of the dissolved-solids load at Lees Ferry, Arizona, is attributable to irrigated agriculture in the UCRB (Iorns and others, 1965; Kenney and others, 2009).

Dissolved-solids concentrations and loads in streams in the UCRB have been measured or estimated at numerous locations for various surface-water-quality assessments during the past century. These and other investigations have developed a solid conceptual understanding of the sources, transport mechanisms, and the ultimate fate of dissolved solids in the UCRB (fig. 2). The major sources of dissolved solids in UCRB streams are categorized as natural, which includes geologic formations and saline springs, or anthropogenic, which includes irrigated agricultural lands (Iorns and others, 1965; Kenney and others, 2009; U.S. Department of the Interior, 2009).

The conceptual understanding of dissolved-solids loading to streams in the UCRB has been applied to the framework of the USGS Spatially Referenced Regressions on Watershed Attributes (SPARROW) surface-water-quality model (Anning and others, 2007; Kenney and others, 2009) and other models to obtain estimates of dissolved-solids loads at unmonitored locations as well as to provide a more comprehensive basin-wide perception of salinity in the UCRB. These models have verified the conceptual understanding of the sources of dissolved solids in the basin and have enhanced the understanding of a variety of the transport mechanisms. For example, precipitation and evapotranspiration were among seven statistically significant landscape transport characteristics in the UCRB dissolved-solids SPARROW model (Kenney and others, 2009). Interestingly, precipitation and evapotranspiration are the only time-specific independent parameters in the UCRB SPARROW model that vary year-to-year (Kenney and others, 2009; Kenney and Buto, 2012). Estimated SPARROW model coefficients for precipitation and evapotranspiration show that increases in either parameter lead to an increase in dissolved-solids load (Kenney and others, 2009).



Base from U.S. Census Bureau digital data, 1:100,000-scale, 2000
Hydrography from 1:1,000,000-scale Enhanced River Reach File 1.2, 2002
Hydrologic subregions from 1:250,000-scale USGS digital data
Albers Equal Area Conic projection, North American Datum of 1983

Figure 1. Upper Colorado River Basin study area.

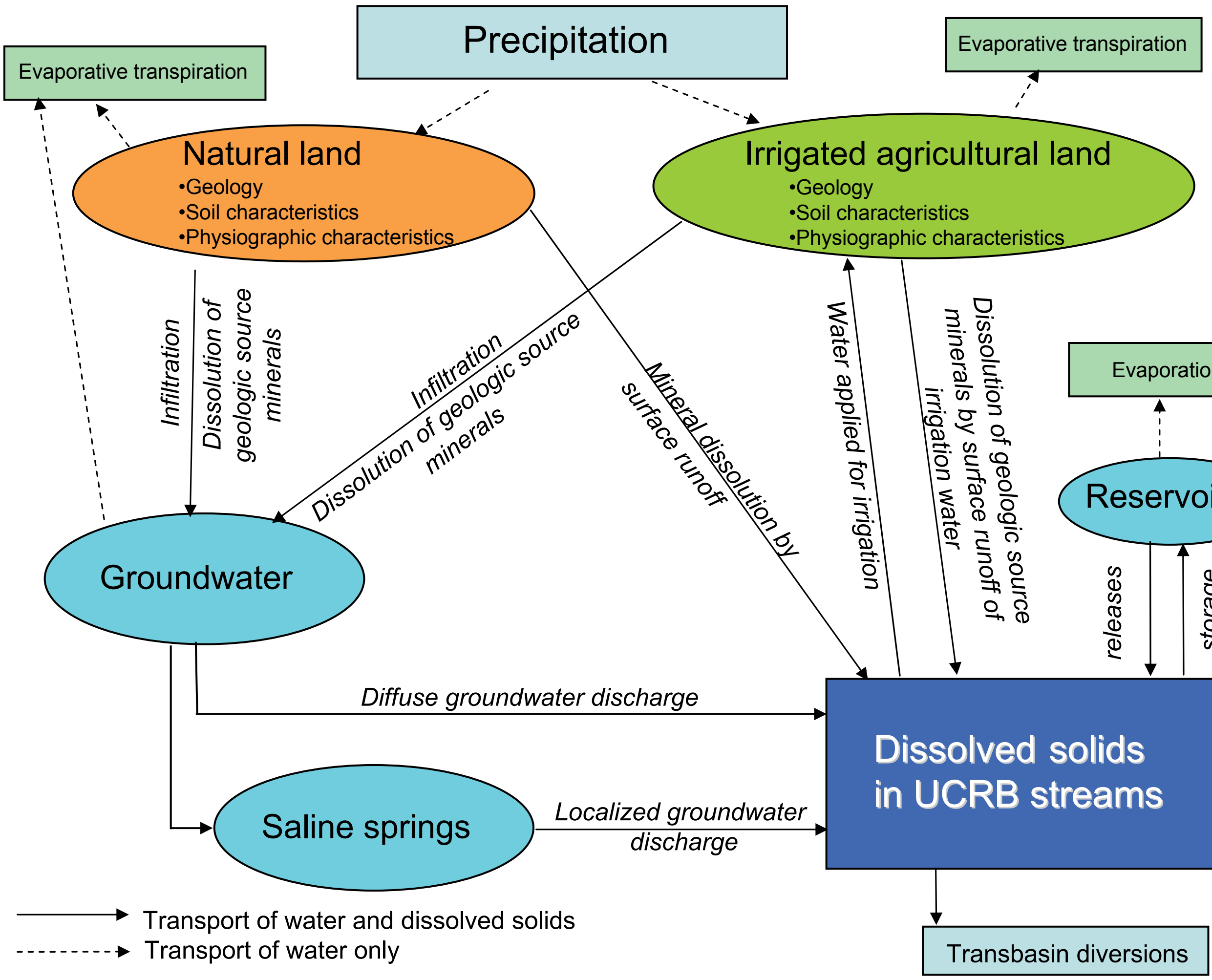


Figure 2. Conceptual model illustrating the processes by which dissolved solids are generated and transported to streams in the Upper Colorado River Basin (UCRB; modified from Kenney and others, 2009).

When constructing the UCRB SPARROW model, conceptually, the effects of precipitation and evapotranspiration as transport mechanisms were assumed to be associated only with the natural, geologic sources of dissolved solids and not the anthropogenic, irrigated-land sources. This assumption implies that dissolved solids are derived from agricultural lands in the UCRB as a result of the application of irrigation water, soil disturbance, and, to a lesser degree, the application of soluble fertilizers (Kenney and others, 2009). Thus, for irrigated lands, precipitation and evapotranspiration were not designated as landscape transport characteristics in the effort to model sources of dissolved solids from irrigated lands. Elevation was the only landscape transport characteristic assigned to sources from irrigated lands because it represents a distinguishing characteristic affecting the amount of water used for irrigated crops in different locations within the UCRB (Kenney and others, 2009).

The construct of the UCRB SPARROW model and other dissolved-solids modeling exercises undertaken in the UCRB, incorporates the general assumption that loads associated with agricultural lands vary minimally year-to-year. This report, which was prepared in cooperation with the U.S. Department of the Interior’s Bureau of Reclamation (Reclamation), tests this assumption by examining the variability in salt loading from catchments dominated by natural sources compared to catchments dominated by anthropogenic or irrigated agricultural sources. It also examines the correlation between precipitation and dissolved-solids load and between temperature and dissolved-solids load for the two catchment types. In this report, “year” refers to “water year,”—the period spanning October of the previous year through September of the current year. Annual dissolved-solids loads, annual precipitation, and annual temperature values were computed for every water year where data were available. For example, the annual dissolved-solids load for 1983 represents the computed load for the months October 1982 through September 1983.

Purpose and Scope

The purpose of this report is to present an understanding of how dissolved-solids loading in catchments dominated by natural sources differs from loading in catchments dominated by irrigated agricultural lands and how loads from irrigated and natural catchments relate to precipitation and temperature. It also presents an examination of the variability of dissolved-solids loads computed for a selection of catchments that have monitoring stations in the UCRB. Catchments were classified by their dominant dissolved-solids load source: natural geologic or irrigated agricultural lands. Expanding on this assessment of variability, climatic drivers, specifically precipitation and temperature, and their relation to loading from both source types also are examined. Furthermore, currently, it is not clear what effect multi-year wet or dry periods have on dissolved-solids loads discharged from natural and irrigated catchments. A qualitative discussion of the dissolved-solids loading response to wet and dry periods between 1974 and 2003, from both natural and irrigated catchments in the UCRB, is included. Limitations and uncertainties in the analysis, including how the results should be interpreted, are outlined explicitly.

Site Selection

Catchments chosen for this study (fig. 3; appendix 1) were a subset of the calibration reaches with outlet water-quality monitoring stations that had been used in the calibration of both the southwestern dissolved-solids SPARROW model presented in Anning and others (2007) and the UCRB dissolved-solids SPARROW model presented in Kenney and others (2009). Most of the catchments chosen for the study were incremental and did not represent entire upstream watersheds because they were bound upstream by water-quality monitoring stations, or water-quality monitoring stations and headwaters. To define catchments that met specified criteria for this analysis, dissolved-solids loads associated with upstream monitoring sites were subtracted from the loads associated with the monitoring site at the catchment outlet using available data. A total of 31 catchments met criteria for two groups: (1) natural catchments, where 10 percent or less of the dissolved solids originating and discharging from the catchment were derived from irrigated lands, and (2) agricultural catchments, where 70 percent or more of the dissolved solids originating and discharging from the catchment were derived from irrigated lands (fig. 3). The percentage of dissolved solids associated with irrigated lands discharged from the catchments was determined from the results of the UCRB dissolved-solids SPARROW model (Kenney and others, 2009), which represented conditions during 1991. Because of limited data for irrigated lands throughout the UCRB, the dataset used in Kenney and others (2009), which was provided by Reclamation, "Potentially irrigated lands in Colorado, New Mexico, Utah, and Wyoming" (David Eckhart, Bureau of Reclamation, written commun., September 28, 2006), and the results of Kenney and others (2009) concerning the proportional amount of dissolved-solids loading from irrigated lands, were assumed to be representative of the catchments in most years. To simplify the analysis, catchments in which a substantial portion of the salt load was associated with natural point sources, such as large saline springs, were not included. Because of limited long-term dissolved-solids monitoring data in the UCRB for the years 1974–2003, the periods of record of computed annual dissolved-solids loads for the selected catchments ranged from 10 to 26 years and averaged 16.6 years.

Annual Dissolved-Solids Loads

Annual dissolved-solids loads from all monitoring stations bounding catchments meeting the criteria described previously were taken from Anning and others (2007). Annual dissolved-solids loads for each catchment were calculated by subtracting loads associated with upstream monitoring stations from computed loads at the catchment outlet monitoring station. For this reason, dissolved-solids loads provided in Anning and others (2007) for most monitoring stations located at selected catchment outlets are larger than those assigned to many of the catchments (appendix 2). Annual dissolved-solids loads were mean-normalized by dividing each annual load by the average annual load of the respective catchment. Normalizing ensures that differences in the magnitudes of the loads, as well as differences in catchment size, do not influence the analysis, and it allows for equal comparisons among all catchments. All loads discussed in this report, unless stated otherwise, were mean-normalized.

Annual Precipitation and Annual Average Monthly Maximum Temperature

The current conceptual understanding of dissolved-solids load transport in the UCRB indicates that precipitation and temperature explain much of the variability in loading in UCRB streams (Anning and others, 2007; Kenney and others, 2009). Estimates of monthly precipitation and air temperature from the 4-kilometer resolution Parameter-elevation Regressions on Independent Slopes Model (PRISM) product (PRISM Group, 2007) were used to compute annual (water year) precipitation (appendix 3) and annual average monthly (April through October) maximum temperature (AAOTMax) for each defined catchment (appendix 4). Catchment annual precipitation and AAOTMax were mean-normalized by dividing each annual value by the average annual value of the respective catchment. This was done in order to make equal comparisons among catchments located at different elevations because higher elevations generally have more precipitation and cooler temperatures than lower elevations.

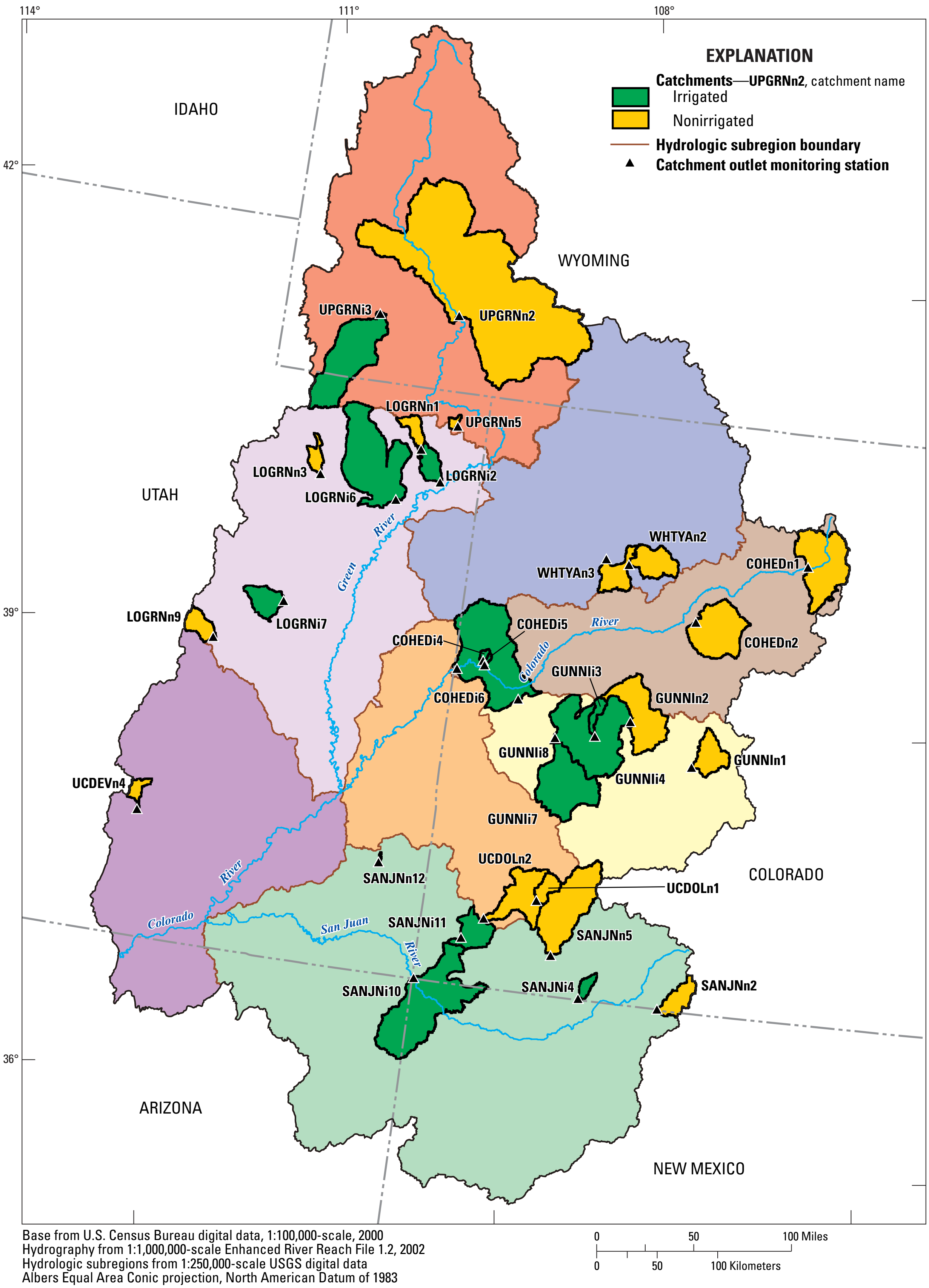


Figure 3. Selected natural and agricultural catchments in the Upper Colorado River Basin.

Variability of Dissolved-Solids Loads

The average annual dissolved-solids load for natural and irrigated catchments was computed for each year from 1974 through 2003 (fig. 4). The time series shows a similar pattern of change in loading for both the natural and irrigated catchments in this study. The two catchment types show concurrent increases and decreases in dissolved-solids loads for all years but 1987, 1999, 2001, and 2003. However, the magnitude of change is generally lower for irrigated catchments.

To illustrate how the averaged annual dissolved-solids loads changed from one year to the next, the annual change, as a percent, in the average load (fig. 4) was computed by using the equation:

$$\delta_{percent} = \left[\frac{\left(\overline{L}_{i+1} - \overline{L}_i \right)}{\overline{L}_i} \right] 100 \qquad (1)$$

where

$\delta_{percent}$ is the annual change in the average normalized dissolved-solids load from year i to year i+1 (in percent),

$\overline{L}_i$ is the average normalized annual dissolved-solids load of year i (dimensionless), and

$\overline{L}_{i+1}$ is the average normalized annual dissolved-solids load of year i+1 (dimensionless).

The annual change in average dissolved-solids loads for the natural and irrigated catchments is shown in figure 5. Loading associated with both natural and irrigated catchments varied annually; however, the magnitude of change from one year to the next for irrigated catchments generally was lower than for the natural catchments. The average of the absolute values of the percent of annual change in loading for natural catchments was 29 percent, compared to 19 percent for irrigated catchments. The maximum of the absolute values of the percent of annual change in loading in natural catchments was

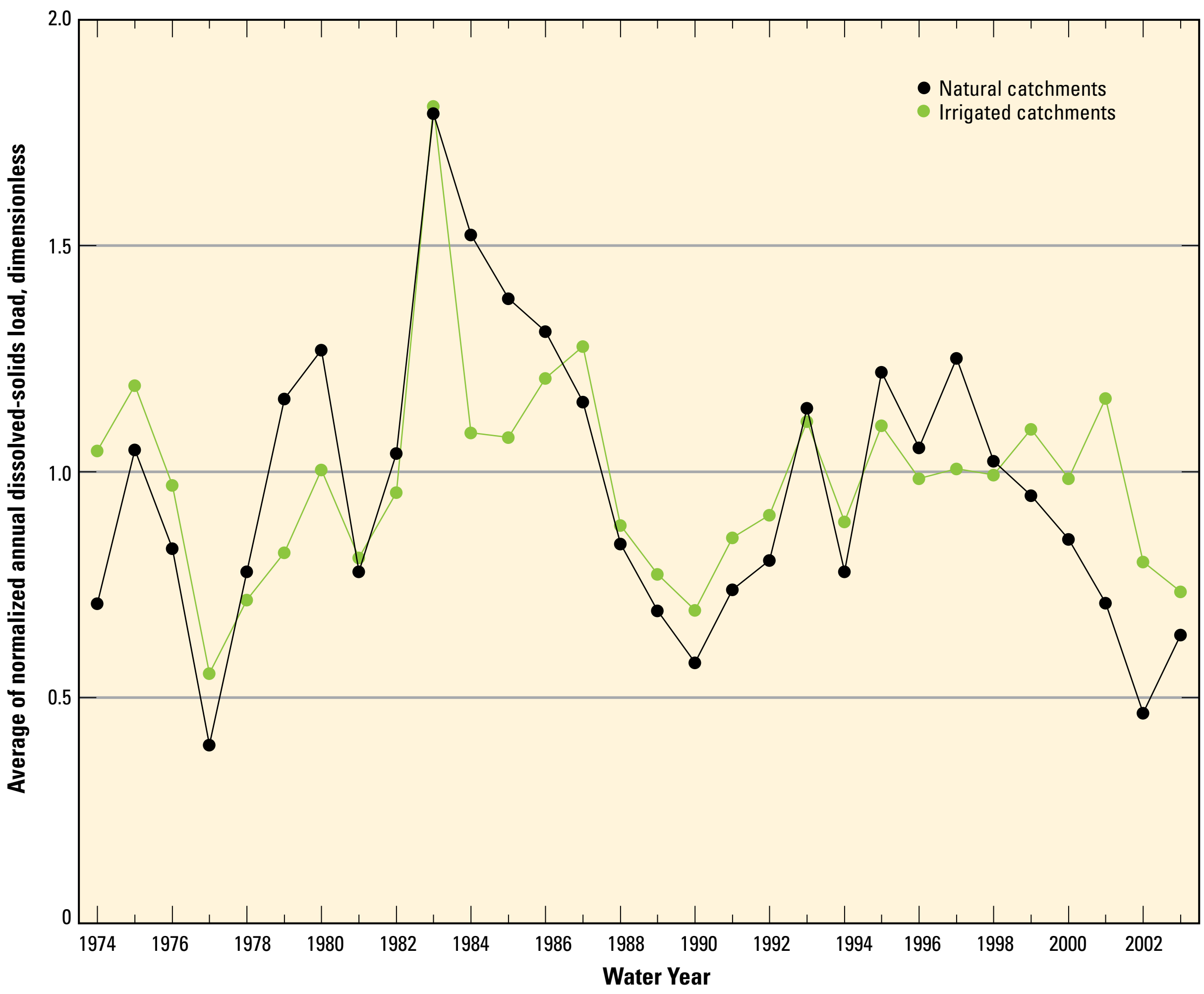


Figure 4. Average normalized annual dissolved-solids loads for selected natural and irrigated catchments in the Upper Colorado River Basin.

97 percent and was 90 percent for irrigated catchments; the minima were 5 percent and less than 1 percent for natural and irrigated catchments, respectively.

When evaluating variability, statistical metrics that provide a measurement of the population spread, such as standard deviation and interquartile range (IQR) are often used. The standard deviation is computed by using the squares of the deviations of data from the mean, so that outliers influence the magnitude (Helsel and Hirsch, 1992). The IQR is the range of the central 50 percent of the population, which is computed by subtracting the 25th percentile from the 75th percentile. The IQR is not influenced by outliers because the highest and lowest 25 percent of the population are not considered. The IQR is the most commonly used outlier-resistant measure of spread (Helsel and Hirsch, 1992). The outlier-resistant properties of the IQR were ideal for this analysis because of the small sample sizes available for the individual catchments. The IQR was computed for the normalized annual dissolved-solids load of each catchment for its available period of record (table 1). The average IQR for natural catchments was 0.51, and the IQR for irrigated catchments was 0.38. The sample sizes for the catchments ranged from 10 to 26 years for dissolved-solids loads and averaged 16.6 years. The variability of dissolved-solids loads in natural catchments, as determined by the average IQR, was about 35 percent greater than the variability in irrigated catchments. Three of the five irrigated catchments with the highest IQRs also had the greatest amounts of in-catchment storage. This could indicate that greater variability in normalized annual dissolved-solids loads is associated with in-catchment reservoir storage in irrigated catchments. The natural catchments did not appear to differ in variability relative to in-catchment reservoir storage.

Relation between Dissolved-Solids Loads and Climatic Variables

Dissolved-solids loads at all monitoring sites, in both natural and irrigated catchments in the UCRB showed annual variability. Climate, specifically precipitation and temperature, appears to be the major causal mechanism of this variability (Anning and others, 2007; Kenney and others, 2009). The presence or absence of upstream reservoirs also could play a role in the variability of dissolved-solids loading in the UCRB.

Correlation analyses between dissolved-solids loads and precipitation, and between dissolved-solids loads and temperature, were done for each of the 31 catchments studied. Correlation provides a measure of observed co-variation, but it is not evidence of a causal relation between two variables. Attribution of a causal relation comes from understanding processes involving the variables (Helsel and Hirsch, 1992). The correlation analyses for this study evaluated how load varied with the climatic variables, precipitation, and temperature. For example, if precipitation increases, then how does load respond? These analyses, by means of determined correlation coefficients, also provide a measure of the strength of the relation between the variables.

Most of the catchment sample populations of annual dissolved-solids loads were small (less than 20), skewed, and not distributed normally (appendix 1). Further, the relations between precipitation and load, and temperature and load, do not appear to be linear. Because of these characteristics, the nonparametric Kendall's rank correlation test was selected to measure the strength of the assumed monotonic relation between dissolved-solids loads and precipitation, and between

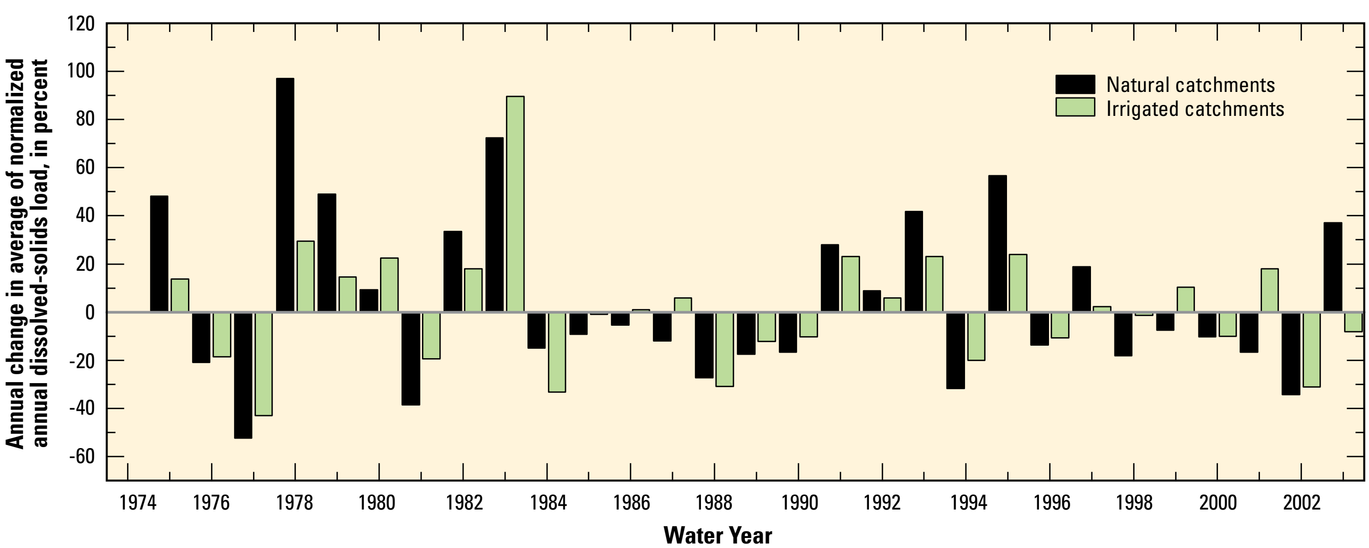


Figure 5. Annual change in average normalized dissolved-solids loads for selected natural and irrigated catchments in the Upper Colorado River Basin.

Table 1. Variability of normalized annual dissolved-solids loads for selected catchments in the Upper Colorado River Basin.

[na, not applicable]

Catchment name	Interquartile range of normalized annual dissolved-solids loads	[1]Percentage of dissolved-solids load associated with irrigated lands	Storage within catchment, in acre-feet	Storage upstream of catchment, in acre-feet
Natural catchments				
COHED2n	0.15	5	0	43,600
WHTYA2n	0.18	0	0	0
UPGRN2n	0.29	8	0	392,500
SANJN05n	0.33	1	23,250	0
UCDOL1n	0.36	0	21,710	0
LOGRN03n	0.39	2	0	0
GUNNI1n	0.43	1	0	106,200
LOGRN01n	0.45	0	0	0
SANJN02n	0.47	8	0	0
COHED1n	0.51	7	574,750	0
UCDOL2n	0.58	5	0	0
LOGRN09n	0.60	0	0	0
GUNNI2n	0.63	9	26,940	0
UCDEV4n	0.70	0	0	0
UPGRN5n	0.70	0	0	0
WHTYA3n	0.81	6	7,660	0
SANJN12n	1.11	0	0	0
Average	0.51	3	na	na
Minimum	0.15	0	na	na
Maximum	1.11	9	na	na
Average of catchments without in-catchment storage	0.50	2	na	na
Average of catchments with in-catchment storage	0.53	5	na	na
Irrigated catchments				
COHED5i	0.07	100	0	0
COHED4i	0.10	100	0	0
GUNNI8i	0.14	84	5,750	0
COHED6i	0.20	98	0	621,500
GUNNI4i	0.28	98	23,400	1,097,000
GUNNI7i	0.28	100	0	0
LOGRN07i	0.30	93	0	0
SANJN11i	0.30	98	0	0
SANJN04i	0.33	97	0	0
LOGRN2i	0.45	94	38,170	0
UPGRN3i	0.50	81	46,470	0
LOGRN06i	0.61	90	29,900	0
SANJN10i	0.78	77	0	0
GUNNI3i	0.93	72	0	0
Average	0.38	92	na	na
Minimum	0.07	72	na	na
Maximum	0.93	100	na	na
Average of catchments without in-catchment storage	0.37	93	na	na
Average of catchments with in-catchment storage	0.40	89	na	na

[1]From Kenney and others, 2009.

dissolved-solids loads and temperature. Kendall's correlation coefficient, tau, can range from +1 to –1. The strength of the correlation depends on the closeness of the coefficient to either +1 or –1. Positive values indicate that as one variable increases, the second variable increases; a negative coefficient indicates that as one variable increases, the other decreases; and a zero value indicates no correlation between variables. In general, a strong positive correlation is indicated with tau values of 0.7 and higher, and similarly, a strong negative correlation is indicated with tau values of –0.7 or lower.

Dissolved-Solids Loads and Precipitation

Conceptually, a causal relation exists between precipitation and dissolved-solids load because an increase in precipitation increases the capacity to dissolve and transport solids from sources to streams. Kendall's tau was computed for each catchment on pairs of dissolved-solids load and precipitation, as well as for all pairs from the two catchment types (table 2, figs. 6 and 7). For the 17 natural catchments, tau indicated 15 positive correlations that were significant at the $p < 0.05$ level, and Kendall's tau for all pairs of dissolved-solids load and corresponding catchment annual precipitation was 0.48, which is significant at the $p < 0.05$ level. A *p*-value less than 0.05 represents a statistically significant correlation. For the 14 irrigated catchments, 7 were found to have positive correlations that were significant at the $p < 0.05$ level. When using all pairs of normalized dissolved-solids load and corresponding catchment annual precipitation, tau was 0.27 and indicated a weak positive correlation significant at the $p < 0.05$ level.

The results of the correlation analyses provide verification of the conceptual understanding that higher precipitation generally leads to larger dissolved-solids loads in natural basins. For the correlation tests, only 2 of the 17 natural catchments, LOGRN9n and UPGRN2n, showed no significant correlation between load and precipitation. A weak positive correlation and a large *p*-value were determined for catchment LOGRN9n. For catchment UPGRN2n, the correlation

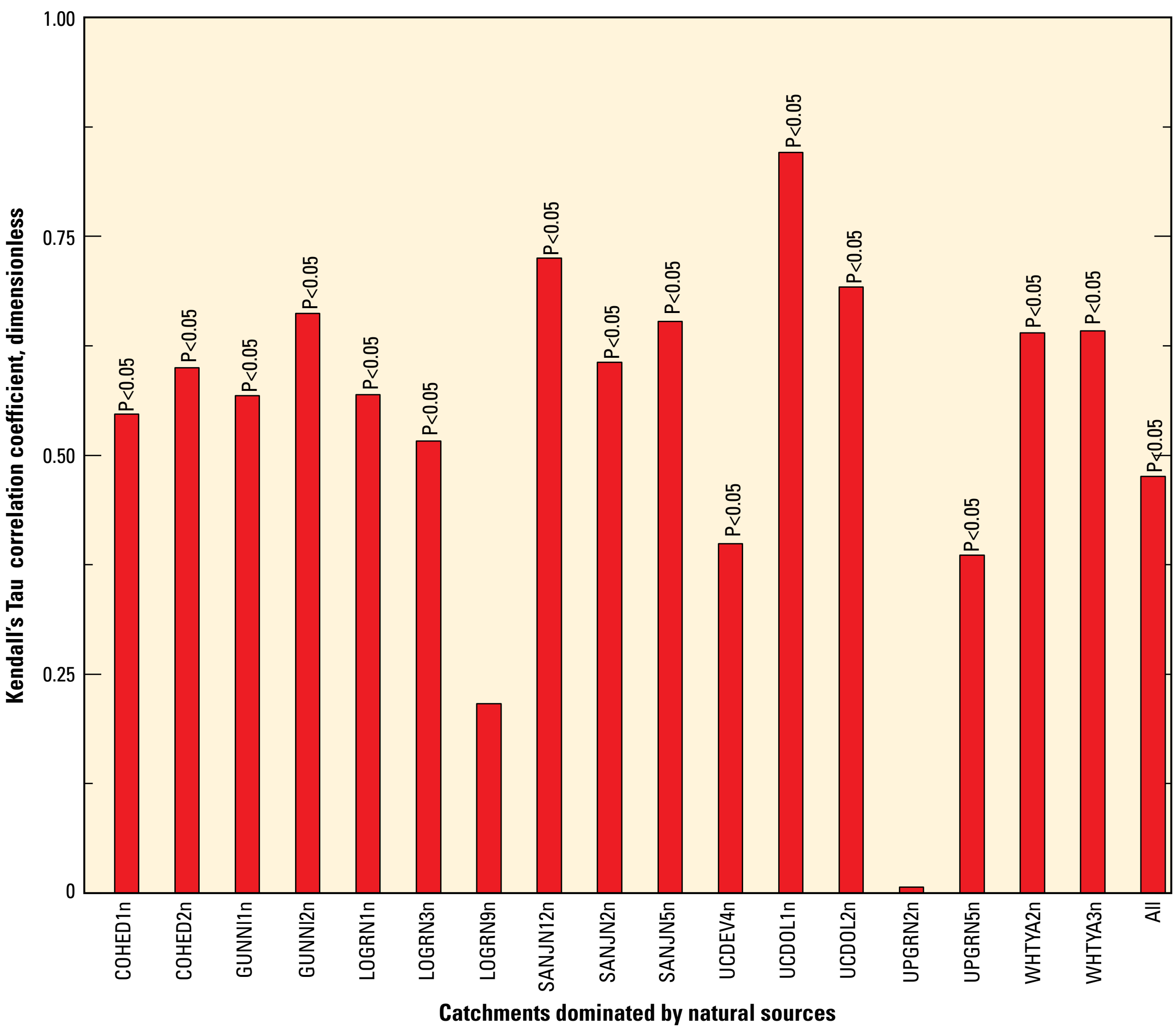


Figure 6. Correlation coefficients computed between normalized annual dissolved-solids loads and normalized annual precipitation for natural catchments in the Upper Colorado River Basin. A p-value less than 0.05 represents a statistically significant correlation.

Table 2. Correlation coefficients computed between normalized annual dissolved-solids loads and normalized annual precipitation for selected catchments in the Upper Colorado River Basin.

[na, not applicable; <, less than]

Catchment name	Kendall's tau correlation coefficient	Kendall's tau correlation coefficient p-value	Period of annual dissolved-solids loads	Number of annual dissolved-solids loads	Storage within catchment, in acre-feet	Storage upstream of catchment, in acre-feet
Natural catchments						
COHED1n	0.55	<0.05	1984–2003	20	574,750	0
COHED2n	0.60	<0.05	1989–1999	11	0	43,600
GUNNI1n	0.57	<0.05	1984–2003	20	0	106,200
GUNNI2n	0.66	<0.05	1978–2003	26	26,940	0
LOGRN1n	0.57	<0.05	1974–1991	18	0	0
LOGRN3n	0.52	<0.05	1974–1991	18	0	0
LOGRN9n	0.22	0.23	1974–1991	18	0	0
SANJN12n	0.73	<0.05	1974–1991	18	0	0
SANJN2n	0.61	<0.05	1984–1995	12	0	0
SANJN5n	0.65	<0.05	1984–2003	20	23,250	0
UCDEV4n	0.40	<0.05	1974–1991	18	0	0
UCDOL1n	0.85	<0.05	1984–1996	13	21,710	0
UCDOL2n	0.69	<0.05	1984–1996	13	0	0
UPGRN2n	0.01	1.00	1975–1999	25	0	392,500
UPGRN5n	0.39	<0.05	1974–1991	18	0	0
WHTYA2n	0.64	<0.05	1977–2001	25	0	0
WHTYA3n	0.64	<0.05	1978–1997	20	7,660	0
All pairs	0.48	<0.05	na	na	na	na
Irrigated catchments						
COHED4i	–0.09	0.65	1974–1983	10	0	0
COHED5i	–0.33	0.21	1974–1983	10	0	0
COHED6i	0.26	0.25	1986–2003	18	0	621,500
GUNNI3i	0.51	<0.05	1984–1996	13	0	0
GUNNI4i	0.67	<0.05	1986–1996	11	23,400	1,097,000
GUNNI7i	0.56	<0.05	1984–2003	20	0	0
GUNNI8i	–0.05	0.77	1984–2003	20	5,750	0
LOGRN2i	0.29	0.28	1974–1983	10	38,170	0
LOGRN6i	0.42	<0.05	1974–1994	21	29,900	0
LOGRN7i	0.56	<0.05	1974–1986	13	0	0
SANJN10i	–0.04	0.83	1984–2002	19	0	0
SANJN11i	0.30	0.19	1982–1993	12	0	0
SANJN4i	0.41	<0.05	1984–2003	20	0	0
UPGRN3i	0.51	<0.05	1974–1983	10	46,470	0
All pairs	0.27	<0.05	na	na	na	na

coefficient was near 0, indicating no relation. This catchment covers a portion of the main stem Green River, defined by the outlet monitoring station 09217000, Green River near Green River, Wyoming. This catchment has the largest drainage area of all the selected catchments and also has the greatest amount of regulation upstream of the catchment. The analysis indicates that another process has a greater effect on dissolved-solids loads in this catchment than precipitation.

Positive values of tau that were significant at the $p < 0.05$ level were found in 7 of the 14 irrigated catchments, indicating that higher precipitation correlated to larger dissolved-solids loads. A weak positive correlation for all pairs of load and precipitation was determined as well. Qualitatively, it appears that years with higher precipitation usually generated larger dissolved-solids loads in irrigated basins. For irrigated catchments, tau for all pairs of loads and precipitation was 78 percent greater than tau for all pairs associated with the irrigated catchments. This indicates that precipitation was more strongly related to dissolved-solids loading in natural catchments than in irrigated ones.

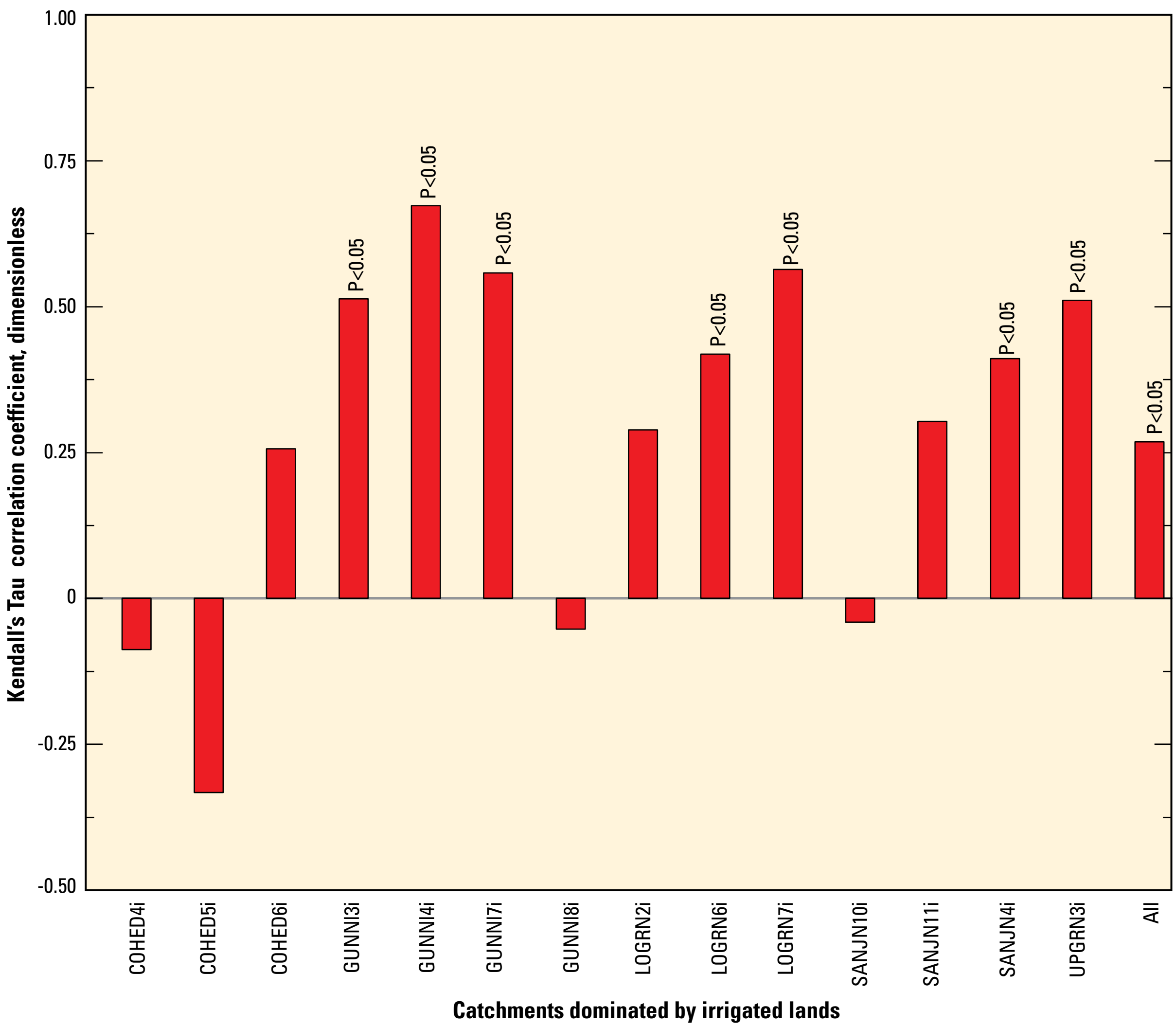


Figure 7. Correlation coefficients computed between normalized annual dissolved-solids loads and normalized annual precipitation for irrigated catchments in the Upper Colorado River Basin. A *p*-value less than 0.05 represent a statistically significant correlation.

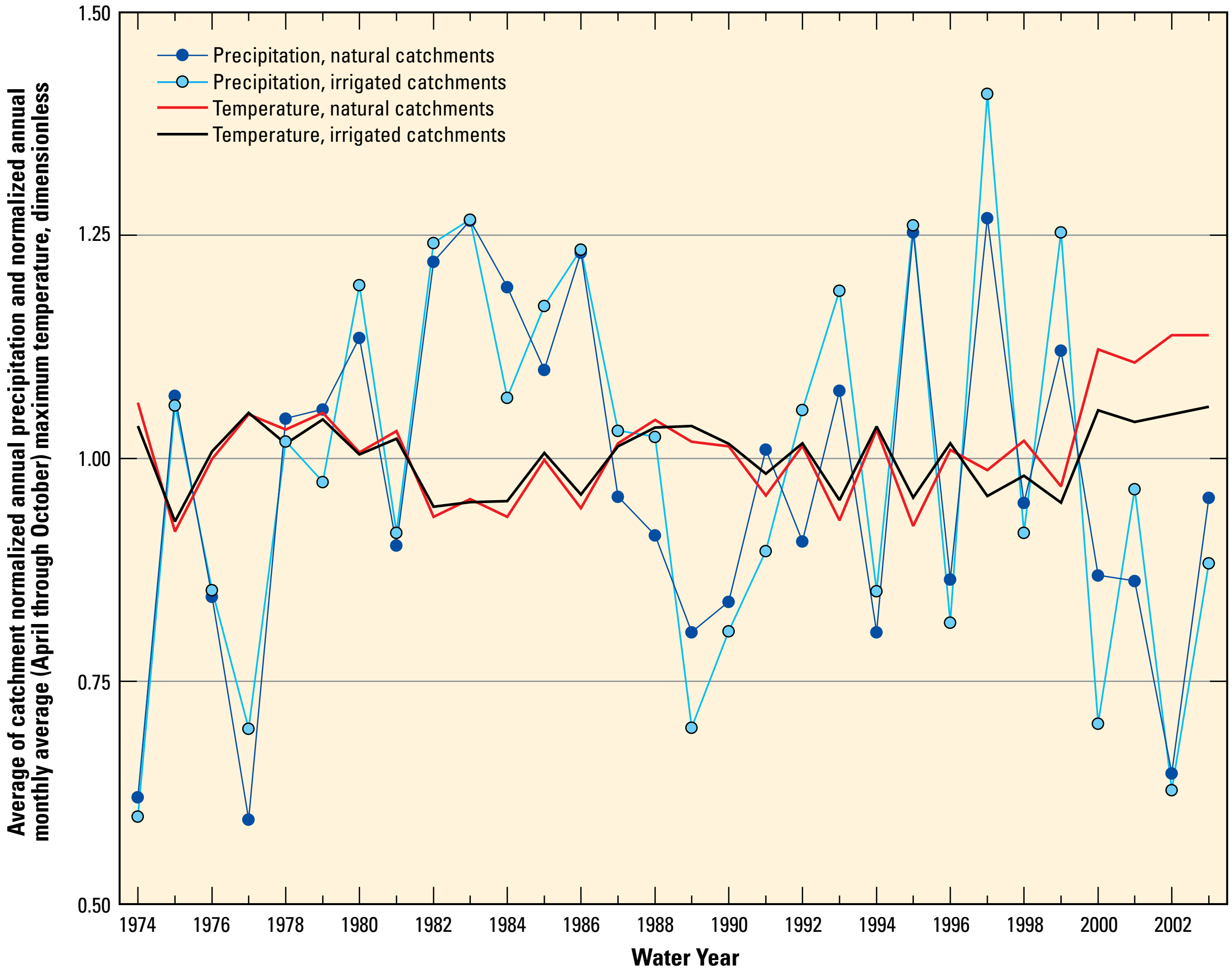


Figure 8. Normalized precipitation and temperature for selected irrigated and natural catchments in the Upper Colorado River Basin.

Dissolved-Solids Loads and Temperature

A causal relation between temperature and dissolved-solids load is not as clear in the literature as it is between precipitation and load. In the UCRB, cooler temperatures are related to wetter periods and vice versa (fig. 8), which indicates that a negative correlation exists between temperature and dissolved-solids load; cooler temperatures correlate with larger loads. However, depending on the availability of irrigation water and irrigation practices, the relation between temperature and load from irrigated lands likely varies from one catchment to the next.

Kendall's tau values were computed for each catchment and AAOTMax as well as for all pairs of dissolved-solids load and AAOTMax for all natural and irrigated catchments (table 3, figs. 9 and 10). For the 17 natural catchments, Kendall's tau indicated 8 negative correlations that were significant at the $p < 0.05$ level, and correlation coefficients computed for all pairs of normalized dissolved-solids load and corresponding AAOTMax indicated a weak negative correlation (tau equal to −0.27) at the $p < 0.05$ level. For the 14 irrigated catchments, 4 were found to have negative correlations significant at the $p < 0.05$ level by using Kendall's rank correlation. When using all pairs of dissolved-solids load and corresponding catchment AAOTMax, tau was –0.28, indicating a weak negative correlation significant at the $p < 0.05$ level for all irrigated catchments.

Table 3. Correlation coefficients computed between normalized annual dissolved-solids loads and normalized annual monthly (April through October) average maximum temperature for selected catchments in the Upper Colorado River Basin.

[A p-value less than 0.05 represents a statistically significant correlation. na, not applicable; <, less than]

Catchment name	Kendall's tau correlation coefficient	Kendall's tau correlation coefficient p-value	Period of annual dissolved-solids loads	Number of annual dissolved-solids loads	Storage within catchment, in acre-feet	Storage upstream of catchment, in acre-feet
Natural catchments						
COHED1n	–0.44	<0.05	1984–2003	20	574,750	0
COHED2n	–0.13	0.64	1989–1999	11	0	43,600
GUNNI1n	–0.51	<0.05	1984–2003	20	0	106,200
GUNNI2n	–0.38	<0.05	1978–2003	26	26,940	0
LOGRN1n	–0.21	0.24	1974–1991	18	0	0
LOGRN3n	–0.20	0.26	1974–1991	18	0	0
LOGRN9n	–0.10	0.60	1974–1991	18	0	0
SANJN12n	–0.19	0.29	1974–1991	18	0	0
SANJN2n	–0.39	0.09	1984–1995	12	0	0
SANJN5n	–0.52	<0.05	1984–2003	20	23,250	0
UCDEV4n	–0.14	0.45	1974–1991	18	0	0
UCDOL1n	–0.46	<0.05	1984–1996	13	21,710	0
UCDOL2n	–0.38	0.08	1984–1996	13	0	0
UPGRN2n	–0.01	1.00	1975–1999	25	0	392,500
UPGRN5n	–0.37	<0.05	1974–1991	18	0	0
WHTYA2n	–0.41	<0.05	1977–2001	25	0	0
WHTYA3n	–0.46	<0.05	1978–1997	20	7,660	0
All pairs	–0.27	<0.05	na	na	na	na
Irrigated catchments						
COHED4i	0.06	0.77	1974–1983	10	0	0
COHED5i	0.42	0.11	1974–1983	10	0	0
COHED6i	–0.28	0.20	1986–2003	18	0	621,500
GUNNI3i	–0.38	0.08	1984–1996	13	0	0
GUNNI4i	–0.45	0.06	1986–1996	11	23,400	1,097,000
GUNNI7i	–0.68	<0.05	1984–2003	20	0	0
GUNNI8i	–0.04	0.82	1984–2003	20	5,750	0
LOGRN2i	–0.42	0.11	1974–1983	10	38,170	0
LOGRN6i	–0.37	<0.05	1974–1994	21	29,900	0
LOGRN7i	–0.49	<0.05	1974–1986	13	0	0
SANJN10i	–0.09	0.62	1984–2002	19	0	0
SANJN11i	–0.15	0.54	1982–1993	12	0	0
SANJN4i	–0.24	0.14	1984–2003	20	0	0
UPGRN3i	–0.64	<0.05	1974–1983	10	46,470	0
All pairs	–0.28	<0.05	na	na	na	na

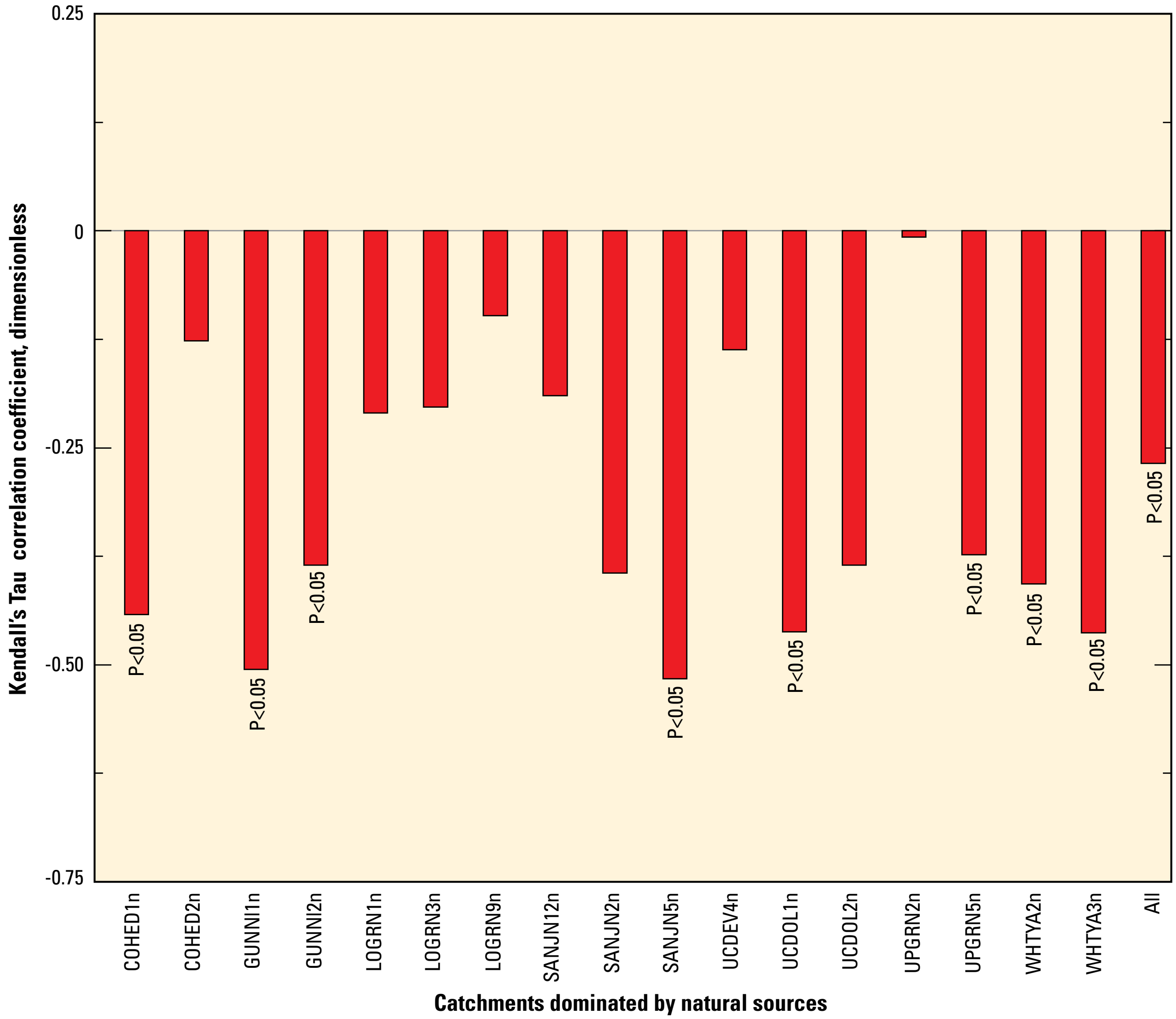


Figure 9. Correlation coefficients computed between normalized annual dissolved-solids loads and normalized annual monthly (April through October) average maximum temperature for natural catchments in the Upper Colorado River Basin. A *p*-value less than 0.05 represents a statistically significant correlation.

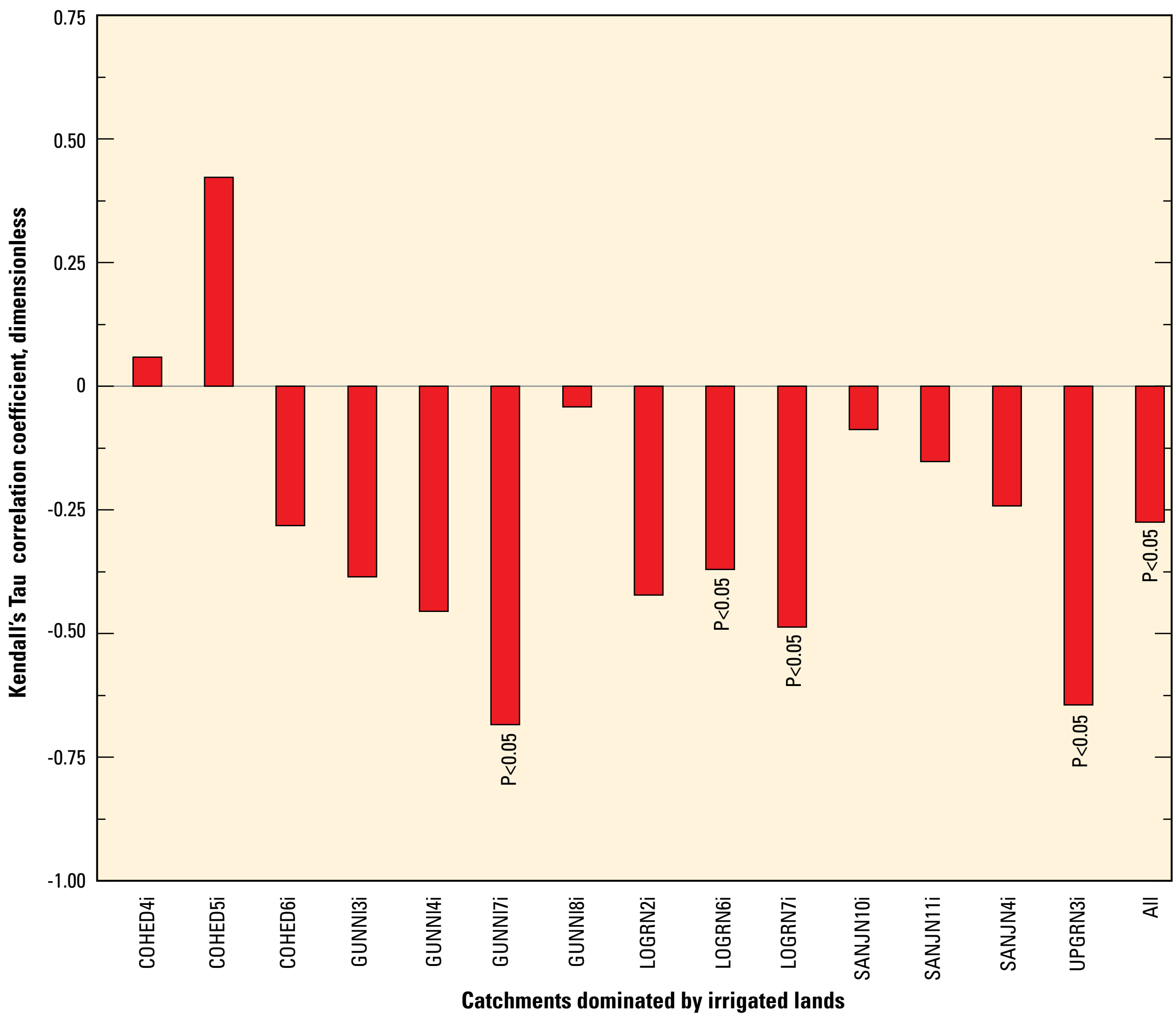


Figure 10. Correlation coefficients computed between normalized annual dissolved solids-loads and normalized annual monthly (April through October) average maximum temperature for irrigated catchments in the Upper Colorado River Basin. A *p*-value less than 0.05 represents a statistically significant correlation.

Response to Wet and Dry Periods

Precipitation in the UCRB varies year-to-year in response to fluctuations in global climate patterns. Ocean temperature patterns, such as the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) can be associated with periods of above- and below-average precipitation and streamflow in the Colorado River (Hidalgo, 2004; U.S. Geological Survey, 2004). The precipitation record for the UCRB from 1974 through 2003 shows a period of above-average precipitation from 1982 through 1986, and a period of below-average precipitation from 2000 through 2003 (fig. 8). The highest 3-year average streamflow volume at Lees Ferry, Arizona since 1895, occurred from 1983 through 1985, and the lowest 3-year average occurred from 2000 through 2002 (U.S. Geological Survey, 2004). Dissolved-solids loading in the UCRB is most often evaluated annually (by water years) without consideration for the antecedent conditions in the basin. The effects of consecutive above- or below- average precipitation years on dissolved-solids loading in the basin have not been studied. Understanding differences in loading from irrigated and natural lands in response to wet or dry periods is of particular interest to this investigation.

Antecedent Precipitation

Antecedent precipitation conditions likely play a role in the delivery of dissolved solids to streams in the UCRB in subsequent years. For example, an above-average precipitation year can flush accumulated salts from the landscape, thereby reducing available salts for subsequent above-average precipitation years. In this example, if the above-average years were equal in precipitation, loads associated with the first year are likely to be greater. Above-average precipitation years often result in a rise in water tables as well. Both natural and irrigated basins with shallow groundwater tables or short groundwater flow paths can have continued or lagged dissolved-solids loading to streams in a subsequent average or below-average precipitation year.

Dissolved-Solids Load Response to Wet Period

In the UCRB, water years 1982 through 1987 defined one of the wetter periods in the precipitation record (fig. 8). Similarly, in most cases, the largest annual dissolved-solids loads for the study period were measured at monitoring stations throughout the basin during these years. The maximum normalized annual dissolved-solids load associated with this wet period for each of the catchments, along with the corresponding year, is shown in table 4. The available periods of record for 1974 through 2003 for the catchments differed (table 4). Therefore, annual dissolved-solids loads data did not cover the entire wet period for some catchments but began in the middle or terminated before the end of the period. Natural catchments had a larger average annual maximum normalized dissolved-solids load during the wet period (1.85) than irrigated catchments (1.63). Natural catchments with in-catchment reservoir storage had a smaller average annual maximum normalized dissolved-solids load than natural catchments without storage, whereas the opposite was the case for irrigated catchments. Irrigated catchments with in-catchment storage had the largest average annual maximum normalized dissolved-solids load (2.05) of all catchment types examined.

From the limited dataset available for the wet period from 1982 through 1987, the year with the largest normalized dissolved-solids load appeared earlier in natural catchments than in irrigated catchments. The maximum normalized dissolved-solids load for natural catchments with storage occurred, on average, 0.8 year before that in irrigated catchments with storage, and natural catchments without storage responded 0.7 year earlier than irrigated catchments without storage. Further, in-catchment storage in both natural and irrigated catchments is associated with an average response lag of 0.7 and 0.8 year, respectively.

Dissolved-Solids Load Response to Dry Period

A dry period from about 2000 through 2003 is evident in the precipitation record for the UCRB (fig. 8). Unfortunately, annual loads are only available for this entire dry period for 9 of the 31 study catchments. With data from such a small number of catchments, a comparable analysis to that of the dissolved-solids load response to a wet period presented in the previous section cannot be made here. Of the nine catchments that have data spanning this period, five are irrigated and four are natural. For the irrigated catchments, the average minimum annual dissolved-solids load was 0.61. For the natural catchments, the average was 0.47. As was the case in the dissolved-solids load response to a wet period, the irrigated catchments generally showed a response similar to the natural catchments but of lower magnitude. Minimum normalized loads in irrigated catchments were greater than those for the natural catchments. There was only one irrigated catchment with in-catchment storage and only one natural catchment without in-catchment storage. Consequently, an examination of the annual dissolved-solids loads for catchments with and without in-catchment storage was not done.

Reservoir Storage and Water Availability

Reservoirs and water availability add to the complexity of factors affecting dissolved-solids loading in natural and irrigated catchments. One of the main purposes for most reservoirs in the UCRB is agricultural irrigation. Reservoirs are used to store water during the high-flow, spring snowmelt runoff period to augment base flows during the dry, summer growing season. Many of these reservoirs have the capacity to augment flows into the next year, if needed. Agricultural areas fortunate enough to have upstream storage generally have a similar amount of water available for irrigation in

Table 4. Maximum normalized dissolved-solids loads during the wet period from 1982 through 1987 for selected catchments in the Upper Colorado River Basin.

[na, not applicable]

Catchment name	Catchment outlet monitoring site number	Period of annual dissolved-solids loads	Storage within catchment, in acre-feet	Storage upstream of catchment, in acre-feet	Maximum normalized dissolved-solids load during period 1982–1987	Year of maximum normalized dissolved-solids load during period 1982–1987
Natural catchments						
COHED1n	09034250	1984–2003	574,750	0	2.54	1984
COHED2n	09070000	1989–1999	0	43,600	na	na
GUNNI1n	09110000	1984–2003	0	106,200	1.69	1984
GUNNI2n	09132500	1978–2003	26,940	0	1.65	1986
LOGRN1n	09266500	1974–1991	0	0	1.65	1983
LOGRN3n	09279100	1974–1991	0	0	1.32	1986
LOGRN9n	9326500	1975–1992	0	0	1.93	1985
SANJN12n	09378630	1974–1991	0	0	3.15	1983
SANJN2n	09346000	1984–1995	0	0	1.54	1985
SANJN5n	09361500	1984–2003	23,250	0	1.29	1985
UCDEV4n	09337000	1974–1991	0	0	2.12	1983
UCDOL1n	9165000	1984–1996	21,710	0	1.27	1986
UCDOL2n	09166500	1984–1996	0	0	1.46	1987
UPGRN2n	09217000	1982–1999	0	392,500	1.55	1983
UPGRN5n	9235600	1974–1991	0	0	3.09	1983
WHTYA2n	09303000	1977–2001	0	0	1.34	1985
WHTYA3n	09304200	1978–1997	7,660	0	2.06	1984
Average					1.85	1984.5
Average for catchments with in-catchment storage					1.76	1985.0
Average for catchments without in-catchment storage					1.89	1984.3
Irrigated catchments						
COHED4i	09153290	1974–2000	0	0	1.09	1986
COHED5i	09153300	1974–1983	0	0	0.96	1978
COHED6i	09163500	1991–2003	0	621,500	na	na
GUNNI3i	09135900	1984–1996	0	0	1.72	1984
GUNNI4i	09144250	1986–1996	23,400	1,097,000	1.72	1986
GUNNI7i	09149500	1984–2003	0	0	1.43	1984
GUNNI8i	09152500	1984–2003	5,750	0	1.22	1994
LOGRN2i	09271500	1974–1983	38,170	0	2.76	1983
LOGRN6i	09302000	1974–1994	29,900	0	1.97	1983
LOGRN7i	09314280	1974–1986	0	0	1.41	1983
SANJN10i	09371010	1984–2002	0	0	1.55	1985
SANJN11i	09371500	1982–1993	0	0	1.32	1993
SANJN4i	09355000	1984–2003	0	0	1.45	1987
UPGRN3i	09222000	1974–1983	46,470	0	2.59	1983
Average					1.63	1985.3
Average for catchments with in-catchment storage					2.05	1985.8
Average for catchments without in-catchment storage					1.36	1985.0

most years. This would indicate that dissolved-solids loads from irrigated lands with upstream storage are not likely to decrease during short periods of below-average precipitation because, in general, the same amount of water is available and applied to the land. However, under a persistent dry period, such as one lasting more than a couple of years, the availability of this water source can decline because of finite storage capacity and preferential water rights. In this case, less water is applied to agricultural lands, which, intuitively, should lead to smaller dissolved-solids loads. Further, loads associated with agricultural lands having shallow groundwater systems are likely to be larger during periods of elevated water tables. Assuming that a similar amount of water is applied to crops, given its continued availability, more water is likely to be discharged from these lands to streams as both irrigation return flow and groundwater discharge. Irrigated catchments with in-catchment storage had the largest average annual maximum dissolved-solids loads during the wet period from 1982 through 1987, compared with any other catchment type studied. The reason for the increased variability and large annual maximum loads for irrigated catchments with reservoir storage is not clear, but one reason for this could be related to the constant supply of water provided by reservoirs which in turn, allows for about the same amount of water to be applied to crops each year. With high water tables, the application of the same amount of water as would be applied in a dry year could generate an exceptional amount of load. On average, the annual loads associated with irrigated catchments with in-catchment storage showed the greatest positive skew of the studied catchment types (appendix 1). This could indicate that the largest loads, likely from wet years, associated with irrigated catchments with storage could be amplified as a result of irrigation practices. Natural catchments with and without reservoir storage showed similar variability to one another (table 1). The reservoirs in the natural catchments did not appear to create much of a lag in dissolved-solids transport over an annual time frame.

Limitations

The analyses presented in this report have limitations that must be considered when interpreting the results. The 31 selected catchments used throughout this analysis fall short of adequately representing the variety of catchments in the UCRB. The periods of record for the selected catchments generally do not span the entire 1974 through 2003 period of study. The periods of record vary from one catchment to another, and the selection criteria were set at a minimum of 10 consecutive years of annual dissolved-solids loads. The average period of record was 16.6 years. On the basis of the results presented in Kenney and others (2009), a criterion for the natural catchments was that no more than 10 percent of the dissolved-solids load was attributed to irrigated lands. Similarly, a criterion for the irrigated catchments was that at least 70 percent of the dissolved-solids load was attributed to irrigated lands. Using these criteria, for each catchment type, there is some portion of the load associated with the other, less desirable, dissolved-solids source. Further, in the irrigated catchments, the amount of irrigated land makes up only a small portion of the defined catchment area (appendix 1), even though at least 70 percent of the load was attributed to irrigated lands. The sample size used in this study (31 catchments, with 14 irrigated agricultural catchments and 17 natural catchments) is a small population for a robust analysis. With such a small sample size, the ability to draw conclusions applicable throughout the UCRB is limited.

There is uncertainty in the computed dissolved-solids loads at the monitoring stations, related to various sources of measurement error (Kenney and others, 2009). Dissolved-solids loads are derived from analyses of dissolved-solids concentrations, specific-conductance measurements, daily mean streamflow computations, and statistical modeling. These data were measured and analyzed by USGS personnel in accordance with USGS standards and techniques as outlined in Rantz and others (1982), U.S. Geological Survey (variously dated), and Fishman and Friedman (1989). By using the measurements and lab analyses obtained at the monitoring stations, annual loads were computed by using statistical load models as described in Anning and others (2007). The amount of uncertainty associated with measurement error is difficult to quantify; however, because standard procedures were followed for the measurements and lab analyses, measurement errors were assumed to be generally equivalent for each site.

This analysis of catchment types is based on subtracting an upstream dissolved-solids load from the load computed at the catchment outlet monitoring station. Loads from upstream monitoring stations can be orders of magnitude less than the loads at the catchment outlet monitoring station, or these upstream loads can make up a large percentage of the outlet station loads. The uncertainties, or range of likely values, as well as the rounding precision of computed loads, were not considered when these calculations were made. These issues are particularly important when evaluating the results associated with the catchments located on the main stems of the larger rivers, such as the Green, San Juan, and Colorado Rivers.

It is well-known that irrigation practices, specifically sprinkler irrigation and flood irrigation, have an effect on dissolved-solids loading. Sprinkler irrigation is more efficient than flood irrigation in terms of the amount of water applied and consumed. Mitigation of dissolved-solids loading from irrigated lands often consists of replacing flood-irrigation infrastructure with sprinklers. It is likely that in some catchments, both irrigation practices existed, and it is conceivable that irrigation practices on many irrigated lands changed from flood to sprinkler during the period of study. For this analysis, however, no distinction among irrigation practices on irrigated lands was made and all irrigated lands were treated the same.

Physical processes related to dissolved-solids loading in streams of the UCRB generally are less complicated when viewed on a regional scale. This analysis was conducted at a very local scale, where processes can be very complex, including such things as local groundwater-surface-water interactions, small-scale water development, and other human activities and behaviors, such as crop irrigation. While the annual time scale mitigates some of these issues, local processes can affect the annual loading of dissolved solids differently in each catchment. When considering local processes, it is important to understand that dissolved-solids yield (the amount of load per area) in a given basin is not static in time. Trends in dissolved-solids concentrations related either to salinity control projects or natural processes have been identified during the period of study (Liebermann and others, 1989; Chafin, 2002; Anning and others, 2007; Leib and Bauch, 2008).

The results presented in this report are specific to the period of study and the catchments included in this analysis. At this point, the conclusions drawn are not meant to apply to the entire UCRB; rather, they should be used to guide further investigation and monitoring of salinity loading from irrigated and natural catchments. In general, more data are needed to accurately distinguish loading characteristics for irrigated and natural basins, both with and without in-catchment storage.

Summary

Dissolved-solids loads in natural and irrigated catchments generally increased and decreased concurrently during the period of study from 1974 through 2003 in the Upper Colorado River Basin (UCRB). The average magnitude of these changes, computed from the average annual dissolved-solids load, from one year to the next, indicated that the magnitude of change in dissolved-solids loads in natural catchments was about 10 percent greater than in irrigated catchments. Statistical measurements of variability, or spread, computed using the time series of dissolved-solids loads for each catchment, indicated that the average variability of the natural catchments was about 35 percent greater than the variability of the irrigated catchments.

Dissolved-solids loads from natural catchments were positively correlated to precipitation. Significant positive correlations were found in 15 of the 17 natural catchments examined, whereas, 7 of the 14 irrigated catchments had a significant positive correlation. Using all pairs of available dissolved-solids load and precipitation data, a positive correlation between them was determined for natural catchments, and a weak positive correlation was found between them in irrigated catchments. These results indicated that precipitation was related to dissolved-solids loading from natural catchments more strongly than from irrigated catchments. The correlation between temperature and dissolved-solids loads in this study was generally negative. Kendall's rank correlation test indicated that 8 of the 17 natural catchments had a significant negative correlation, and 7 of the 14 irrigated catchments had a significant negative correlation. Using all pairs of available dissolved-solids loads and temperature, weak negative correlations were determined for both irrigated and natural catchments.

The years from 1982 through 1987 define one of the wettest periods in the UCRB. On the basis of the maximum normalized annual dissolved-solids load associated with these years, the response of loading to the above-average precipitation in irrigated catchments generally lagged behind the response in natural catchments, and normalized annual loads generally were smaller than in natural catchments. On average, however, irrigated catchments with in-catchment reservoir storage had the largest normalized maximum annual loads.

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Appendix 1.

Appendix 1. Catchment characteristics and annual load statistics for catchments examined in the Upper Colorado River Basin.

[Shading denotes irrigated agricultural catchments]

Catchment designation	Catchment outlet monitoring station number	Catchment outlet monitoring station name	Hydrologic subregion	Period of annual dissolved-solids loads	Catchment characteristics: Dominant source[1]
COHED1n	09034250	Colorado River at Windy Gap near Granby, Colorado	Colorado Headwaters	1984–2003	High-yield sedimentary Cenozoic rocks
COHED2n	09070000	Eagle River below Gypsum, Colorado	Colorado Headwaters	1989–1999	High-yield sedimentary Paleozoic and Precambrian rocks
COHED4i	09153290	Reed Wash near Mack, Colorado	Colorado Headwaters	1974–2000	Irrigated sedimentary-clastic Mesozoic lands
COHED5i	09153300	Reed Wash near Loma, Colorado	Colorado Headwaters	1974–1983	Irrigated sedimentary-clastic Mesozoic lands
COHED6i	09163500	Colorado River near Colorado-Utah state line	Colorado Headwaters	1991–2003	Irrigated sedimentary-clastic Mesozoic lands
GUNNI1n	09110000	Taylor River at Almont, Colorado	Gunnison	1984–2003	High-yield sedimentary Paleozoic and Precambrian rocks
GUNNI2n	09132500	North Fork Gunnison River near Somerset, Colorado	Gunnison	1978–2003	High-yield sedimentary Mesozoic rocks
GUNNI3i	09135900	Leroux Creek at Hotchkiss, Colorado	Gunnison	1984–1996	Irrigated sedimentary-clastic Mesozoic lands
GUNNI4i	09144250	Gunnison River at Delta, Colorado	Gunnison	1986–1996	Irrigated sedimentary-clastic Mesozoic lands
GUNNI7i	09149500	Uncompahgre River at Delta, Colorado	Gunnison	1984–2003	Irrigated sedimentary-clastic Mesozoic lands
GUNNI8i	09152500	Gunnison River near Grand Junction, Colorado	Gunnison	1984–2003	Irrigated sedimentary-clastic Mesozoic lands
LOGRN1n	09266500	Ashley Creek near Vernal, Utah	Lower Green	1974–1991	Low-yield sedimentary Cenozoic rocks
LOGRN2i	09271500	Ashley Creek near Jensen, Utah	Lower Green	1974–1983	Irrigated sedimentary-clastic Tertiary lands
LOGRN3n	09279100	Rock Creek near Talmage, Utah	Lower Green	1974–1991	Low-yield sedimentary Cenozoic rocks
LOGRN6i	09302000	Duchesne River near Randlett, Utah	Lower Green	1974–1994	Irrigated sedimentary-clastic Tertiary lands
LOGRN7i	09314280	Desert Seep Wash near Wellington, Utah	Lower Green	1974–1986	Irrigated sedimentary-clastic Mesozoic lands
LOGRN9n	09326500	Ferron Creek (Upper Station) near Ferron, Utah	Lower Green	1975–1992	High-yield sedimentary Cenozoic rocks
SANJN10i	09371010	San Juan River at Four Corners, Colorado	San Juan	1984–2002	Irrigated sedimentary-clastic Tertiary lands
SANJN11i	09371500	McElmo Creek near Cortez, Colorado	San Juan	1982–1993	Irrigated sedimentary-clastic Mesozoic lands
SANJN12n	09378630	Recapture Creek near Blanding, Utah	San Juan	1974–1991	Low-yield sedimentary Mesozoic rocks
SANJN2n	09346000	Navajo River at Edith, Colorado	San Juan	1984–1995	Low-yield sedimentary Cenozoic rocks
SANJN4i	09355000	Spring Creek at La Boca, Colorado	San Juan	1984–2003	Irrigated sedimentary-clastic Mesozoic lands
SANJN5n	09361500	Animas River at Durango, Colorado	San Juan	1984–2003	High-yield sedimentary Paleozoic and Precambrian rocks
UCDEV4n	09337000	Pine Creek near Escalante, Utah	Upper Colorado-Dirty Devil	1974–1991	Low-yield sedimentary Cenozoic rocks
UCDOL1n	9165000	Dolores River below Rico, Colorado	Upper Colorado-Dolores	1984–1996	High-yield sedimentary Paleozoic and Precambrian rocks
UCDOL2n	09166500	Dolores River at Dolores, Colorado	Upper Colorado-Dolores	1984–1996	High-yield sedimentary Mesozoic rocks
UPGRN2n	09217000	Green River near Green River, Wyoming	Upper Green	1982–1999	High-yield sedimentary Cenozoic rocks
UPGRN3i	09222000	Blacks Fork near Lyman, Wyoming	Upper Green	1974–1983	Irrigated sedimentary-clastic Tertiary lands
UPGRN5n	9235600	Pot Creek above Diversions near Vernal, Utah	Upper Green	1974–1991	Low-yield sedimentary Cenozoic rocks
WHTYA2n	09303000	North Fork White River at Buford, Colorado	White-Yampa	1977–2001	Low-yield sedimentary Cenozoic rocks
WHTYA3n	09304200	White River above Coal Creek near Meeker, Colorado	White-Yampa	1978–1997	High-yield sedimentary Paleozoic and Precambrian rocks

Appendix 1. Catchment characteristics and annual load statistics for catchments examined in the Upper Colorado River Basin.—Continued

[Shading denotes irrigated agricultural catchments]

Catchment designation	Catchment outlet monitoring station number	Catchment outlet monitoring station name	Catchment characteristics—Continued						
			Reservoir storage within catchment, in acre-feet	Reservoir storage upstream of catchment, in acre-feet	Mean elevation, in feet	Average annual precipitation, 1974–2003, in inches	Catchment area, in acres	Irrigated acres	Percentage of dissolved-solids load associated with irrigated lands[1]
COHED1n	09034250	Colorado River at Windy Gap near Granby, Colorado	574,750	0	9,587	24.39	418,401	14,720	7
COHED2n	09070000	Eagle River below Gypsum, Colorado	0	43,600	8,797	18.46	351,585	10,444	5
COHED4i	09153290	Reed Wash near Mack, Colorado	0	0	4,702	9.53	11,315	6,189	100
COHED5i	09153300	Reed Wash near Loma, Colorado	0	0	4,668	9.53	18,478	10,316	100
COHED6i	09163500	Colorado River near Colorado-Utah state line	0	621,473	5,740	12.42	752,563	70,403	98
GUNNI1n	09110000	Taylor River at Almont, Colorado	0	106,200	10,386	20.33	142,822	602	1
GUNNI2n	09132500	North Fork Gunnison River near Somerset, Colorado	26,940	0	8,882	29.36	336,210	8,250	9
GUNNI3i	09135900	Leroux Creek at Hotchkiss, Colorado	0	0	8,598	28.37	42,846	2,956	72
GUNNI4i	09144250	Gunnison River at Delta, Colorado	23,395	1,096,656	7,096	18.94	608,331	80,827	98
GUNNI7i	09149500	Uncompahgre River at Delta, Colorado	0	0	6,909	13.48	426,783	65,879	103
GUNNI8i	09152500	Gunnison River near Grand Junction, Colorado	5,752	0	7,093	17.88	748,014	20,351	84
LOGRN1n	09266500	Ashley Creek near Vernal, Utah	0	0	9,451	26.42	64,831	0	0
LOGRN2i	09271500	Ashley Creek near Jensen, Utah	38,170	0	5,741	9.15	92,412	19,766	94
LOGRN3n	09279100	Rock Creek near Talmage, Utah	0	0	8,037	20.48	53,264	102	2
LOGRN6i	09302000	Duchesne River near Randlett, Utah	29,900	0	7,130	15.70	644,139	95,010	90
LOGRN7i	09314280	Desert Seep Wash near Wellington, Utah	0	0	5,822	9.07	123,475	13,179	93
LOGRN9n	09326500	Ferron Creek (Upper Station) near Ferron, Utah	0	0	8,836	24.63	90,349	0	0
SANJN10i	09371010	San Juan River at Four Corners, Colorado	0	0	5,780	9.63	738,479	5,644	77
SANJN11i	09371500	McElmo Creek near Cortez, Colorado	0	0	6,531	14.61	147,511	34,751	98
SANJN12n	09378630	Recapture Creek near Blanding, Utah	0	0	8,480	25.58	2,896	0	0
SANJN2n	09346000	Navajo River at Edith, Colorado	0	0	9,179	31.83	112,802	2,234	8
SANJN4i	09355000	Spring Creek at La Boca, Colorado	0	0	6,935	16.93	37,489	10,589	97
SANJN5n	09361500	Animas River at Durango, Colorado	23,254	0	10,174	32.03	448,791	5,553	1
UCDEV4n	09337000	Pine Creek near Escalante, Utah	0	0	9,379	21.00	43,403	0	0
UCDOL1n	9165000	Dolores River below Rico, Colorado	21,711	0	10,629	33.27	67,463	0	0
UCDOL2n	09166500	Dolores River at Dolores, Colorado	0	0	9,444	28.12	255,583	2,114	5
UPGRN2n	09217000	Green River near Green River, Wyoming	0	392,500	6,878	8.48	2,818,091	8,450	8
UPGRN3i	09222000	Blacks Fork near Lyman, Wyoming	46,470	0	8,298	18.25	520,400	79,736	81
UPGRN5n	9235600	Pot Creek above Diversions near Vernal, Utah	0	0	8,141	20.64	15,837	0	0
WHTYA2n	09303000	North Fork White River at Buford, Colorado	0	0	9,545	34.34	165,844	830	0
WHTYA3n	09304200	White River above Coal Creek near Meeker, Colorado	7,658	0	8,257	24.21	133,023	1,839	6

Appendix 1. Catchment characteristics and annual load statistics for catchments examined in the Upper Colorado River Basin.—Continued

[Shading denotes irrigated agricultural catchments]

Catchment designation	Catchment outlet monitoring station number	Catchment outlet monitoring station name	Annual dissolved-solids load statistics							
			Maximum annual dissolved-solids load, in tons	Minimum annual dissolved-solids load, in tons	Range of annual dissolved-solids loads, in tons	Mean annual dissolved-solids load, in tons	Median annual dissolved-solids load, in tons	Standard deviation of annual dissolved-solids loads, in tons	Skewness of annual dissolved-solids loads, unitless	Kurtosis of annual dissolved-solids loads, unitless
COHED1n	09034250	Colorado River at Windy Gap near Granby, Colorado	32,455	5,937	26,518	12,795	11,087	6,746	1.54	2.57
COHED2n	09070000	Eagle River below Gypsum, Colorado	134,419	99,573	34,846	117,964	117,629	11,746	–0.05	–1.45
COHED4i	09153290	Reed Wash near Mack, Colorado	54,182	42,849	11,333	49,901	51,109	3,408	–0.88	–0.06
COHED5i	09153300	Reed Wash near Loma, Colorado	142,172	112,036	30,136	133,271	135,369	8,849	–1.68	3.34
COHED6i	09163500	Colorado River near Colorado-Utah state line	892,418	552,040	340,377	691,422	653,828	106,751	0.58	–0.45
GUNNI1n	09110000	Taylor River at Almont, Colorado	20,780	6,461	14,319	12,279	10,750	4,005	0.63	–0.59
GUNNI2n	09132500	North Fork Gunnison River near Somerset, Colorado	65,269	13,091	52,178	39,467	37,384	15,684	0.18	–1.21
GUNNI3i	09135900	Leroux Creek at Hotchkiss, Colorado	17,050	4,276	12,775	9,927	8,556	4,878	0.36	–1.63
GUNNI4i	09144250	Gunnison River at Delta, Colorado	968,330	329,928	638,402	562,967	533,170	189,824	1.16	1.01
GUNNI7i	09149500	Uncompahgre River at Delta, Colorado	323,726	162,057	161,670	227,168	226,909	44,760	0.39	–0.51
GUNNI8i	09152500	Gunnison River near Grand Junction, Colorado	428,708	109,361	319,347	352,202	387,911	86,946	–1.90	2.83
LOGRN1n	09266500	Ashley Creek near Vernal, Utah	10,341	3,064	7,277	6,267	5,946	2,024	0.37	–0.47
LOGRN2i	09271500	Ashley Creek near Jensen, Utah	100,757	13,695	87,062	36,537	34,507	24,765	2.19	5.83
LOGRN3n	09279100	Rock Creek near Talmage, Utah	8,193	4,016	4,177	6,228	6,303	1,402	–0.13	–1.37
LOGRN6i	09302000	Duchesne River near Randlett, Utah	236,299	42,047	194,252	119,809	122,521	51,480	0.59	–0.11
LOGRN7i	09314280	Desert Seep Wash near Wellington, Utah	121,018	34,827	86,191	86,003	83,515	27,124	–0.58	–0.40
LOGRN9n	09326500	Ferron Creek (Upper Station) near Ferron, Utah	43,994	7,338	36,655	22,776	20,110	10,270	0.72	–0.04
SANJN10i	09371010	San Juan River at Four Corners, Colorado	117,639	8,381	109,258	57,886	62,745	28,797	0.10	–0.54
SANJN11i	09371500	McElmo Creek near Cortez, Colorado	134,879	66,701	68,178	102,400	107,294	22,572	–0.20	–1.08
SANJN12n	09378630	Recapture Creek near Blanding, Utah	561	3	558	178	130	168	0.96	0.00
SANJN2n	09346000	Navajo River at Edith, Colorado	21,548	7,564	13,984	14,006	13,130	4,401	0.34	–1.00
SANJN4i	09355000	Spring Creek at La Boca, Colorado	11,406	2,739	8,667	7,879	8,277	2,222	–0.80	0.60
SANJN5n	09361500	Animas River at Durango, Colorado	206,039	86,448	119,591	159,507	154,514	33,170	–0.29	–0.50
UCDEV4n	09337000	Pine Creek near Escalante, Utah	2,468	158	2,310	1,163	1,215	598	0.24	–0.21
UCDOL1n	9165000	Dolores River below Rico, Colorado	19,930	10,870	9,060	15,709	14,418	3,274	0.00	–1.76
UCDOL2n	09166500	Dolores River at Dolores, Colorado	59,236	19,135	40,101	40,438	34,616	14,222	0.06	–1.47
UPGRN2n	09217000	Green River near Green River, Wyoming	128,958	47,274	81,684	83,332	80,083	22,677	0.37	–0.32
UPGRN3i	09222000	Blacks Fork near Lyman, Wyoming	294,192	29,608	264,584	113,573	96,877	73,231	1.78	4.27
UPGRN5n	9235600	Pot Creek above Diversions near Vernal, Utah	1,235	48	1,187	399	363	315	1.37	1.81
WHTYA2n	09303000	North Fork White River at Buford, Colorado	70,199	34,031	36,167	52,510	52,031	8,676	0.16	–0.03
WHTYA3n	09304200	White River above Coal Creek near Meeker, Colorado	40,371	612	39,759	19,570	20,325	10,823	0.20	–0.71

[1]From 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, 50 p., available online at http://pubs.usgs.gov/sir/2009/5007

Appendix 2.

Appendix 2. Annual dissolved-solids loads for catchments examined in the Upper Colorado River Basin.

[Shading denotes irrigated agricultural catchments. **Abbreviations:** —, not available]

Catchment designation	Catchment outlet monitoring station number	Upstream monitoring station number with dissolved-solids loads that were subtracted from dissolved-solids loads of catchment outlet monitoring site	Annual dissolved-solids load for catchment, in tons[1]												
			1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
COHED1n	09034250	09010500, 9025000, 09032000, 09032100, 09024000	—	—	—	—	—	—	—	—	—	—	32,455	14,680	18,665
COHED2n	09070000	09067005	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED4i	09153290	None	—	—	—	—	—	—	—	—	—	—	46,864	48,720	54,182
COHED5i	09153300	None	129,440	132,359	135,077	139,817	142,172	138,912	135,661	139,750	127,490	112,036	—	—	—
COHED6i	09163500	09152500, 09106150	—	—	—	—	—	—	—	—	—	—	—	—	—
GUNNI1n	09110000	09109000	—	—	—	—	—	—	—	—	—	—	20,780	18,541	16,334
GUNNI2n	09132500	None	—	—	—	—	35,717	45,442	50,294	19,974	43,449	58,801	61,860	62,744	65,269
GUNNI3i	09135900	None	—	—	—	—	—	—	—	—	—	—	17,050	16,962	15,700
GUNNI4i	09144250	09132500, 09134000, 09135900 09143500, 09128000	—	—	—	—	—	—	—	—	—	—	—	—	968,330
GUNNI7i	09149500	09147500	—	—	—	—	—	—	—	—	—	—	323,726	269,357	251,098
GUNNI8i	09152500	09147500, 09144250	—	—	—	—	—	—	—	—	—	—	109,361	166,044	225,945
LOGRN1n	09266500	None	5,004	7,272	5,392	3,064	4,816	4,692	6,655	4,952	6,554	10,341	8,509	8,159	9,405
LOGRN2i	09271500	09266500, 09270500	37,000	44,124	39,403	16,539	13,695	22,832	33,905	22,009	35,109	100,757	—	—	—
LOGRN3n	09279100	09279000	4,990	5,706	5,816	4,790	6,343	6,264	7,408	7,499	7,779	7,650	8,147	7,222	8,193
LOGRN6i	09302000	09299500, 09295000	147,289	149,032	124,771	71,485	96,294	128,572	122,521	106,229	141,419	236,299	208,962	145,991	158,882
LOGRN7i	09314280	None	68,506	101,531	76,509	34,827	42,307	76,878	102,333	77,381	83,515	121,018	115,764	115,340	102,128
LOGRN9n	9326500	None	—	18,808	28,451	13,355	7,338	21,411	26,014	32,390	14,669	28,460	43,015	43,994	27,417
SANJN10i	09371010	09368000, 09371000	—	—	—	—	—	—	—	—	—	—	80,956	89,780	68,448
SANJN11i	09371500	None	—	—	—	—	—	—	—	—	66,701	131,529	90,084	104,703	110,340
SANJN12n	09378630	None	22	147	64	3	241	420	444	30	95	561	114	346	227
SANJN2n	09346000	None	—	—	—	—	—	—	—	—	—	—	13,385	21,548	18,481
SANJN4i	09355000	None	—	—	—	—	—	—	—	—	—	—	8,623	10,125	9,144
SANJN5n	09361500	None	—	—	—	—	—	—	—	—	—	—	194,361	206,039	203,153
UCDEV4n	09337000	None	904	795	770	158	672	1,576	1,211	1,330	1,633	2,468	1,685	1,867	1,219
UCDOL1n	9165000	None	—	—	—	—	—	—	—	—	—	—	19,559	19,112	19,930
UCDOL2n	09166500	09165000	—	—	—	—	—	—	—	—	—	—	56,286	58,675	56,566
UPGRN2n	09217000	09211200, 09215550	—	—	—	—	—	—	—	—	116,025	128,958	116,808	72,721	59,582
UPGRN3i	09222000	None	138,408	150,514	93,532	29,608	95,822	53,110	97,932	68,931	113,680	294,192	—	—	—
UPGRN5n	9235600	None	414	753	367	48	180	319	593	223	359	1,235	943	366	441
WHTYA2n	09303000	None	—	—	—	34,031	52,031	52,123	50,521	41,540	54,168	61,235	68,417	70,199	62,429
WHTYA3n	09304200	09304000, 09303000	—	—	—	—	12,279	21,500	15,250	8,330	21,545	24,145	40,371	25,851	37,265

Appendix 2. Annual dissolved-solids loads for catchments examined in the Upper Colorado River Basin.—Continued

[Shading denotes irrigated agricultural catchments. **Abbreviations:** –, not available]

Catchment designation	Annual dissolved-solids load for catchment, in tons[1]—Continued																
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
COHED1n	9,438	9,411	7,779	7,560	8,910	7,658	12,872	9,361	14,145	21,702	22,817	12,735	13,980	12,950	6,196	5,937	6,640
COHED2n	—	—	110,333	99,573	110,149	109,190	117,629	105,358	124,889	124,979	134,419	129,570	131,513	—	—	—	—
COHED4i	51,109	51,929	52,710	53,086	51,140	48,824	53,197	53,014	51,494	51,033	47,024	47,872	43,265	42,849	—	—	—
COHED5i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED6i	—	—	—	—	892,418	860,015	752,374	762,284	744,257	700,810	646,501	653,828	652,342	552,040	612,820	561,377	597,426
GUNNI1n	14,251	9,506	9,599	8,558	10,986	9,267	13,814	10,515	17,757	13,928	16,563	10,267	11,972	10,266	8,424	6,461	7,799
GUNNI2n	45,267	26,443	29,663	17,682	31,942	29,100	58,338	31,556	60,848	39,051	52,325	45,004	28,619	25,970	21,608	13,091	26,084
GUNNI3i	14,516	5,290	5,163	4,276	5,055	6,142	11,062	7,056	12,222	8,556	—	—	—	—	—	—	—
GUNNI4i	832,528	533,170	383,402	329,928	455,918	492,035	584,750	446,252	630,634	535,689	—	—	—	—	—	—	—
GUNNI7i	271,589	192,942	176,966	187,393	179,478	227,422	250,789	219,562	246,708	226,395	265,361	232,454	296,232	191,633	205,311	166,891	162,057
GUNNI8i	300,118	378,065	386,143	392,518	389,679	409,610	408,080	428,708	380,686	401,977	399,335	384,273	415,667	389,931	391,252	360,015	326,628
LOGRN1n	7,910	5,405	3,227	4,959	6,488	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN2i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN3n	6,456	5,233	4,327	4,271	4,016	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN6i	188,114	99,792	54,462	42,047	73,871	73,177	77,683	69,092	—	—	—	—	—	—	—	—	—
LOGRN7i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN9n	28,519	17,008	15,662	13,037	13,287	17,122	—	—	—	—	—	—	—	—	—	—	—
SANJN10i	74,415	27,392	23,721	19,894	32,244	8,381	72,045	32,823	53,349	50,331	46,904	66,373	81,308	91,086	117,639	62,745	—
SANJN11i	120,173	109,885	92,034	71,342	79,414	117,712	134,879	—	—	—	—	—	—	—	—	—	—
SANJN12n	210	200	47	5	37	—	—	—	—	—	—	—	—	—	—	—	—
SANJN2n	16,065	9,963	10,027	7,564	10,265	11,870	16,300	12,874	19,729	—	—	—	—	—	—	—	—
SANJN4i	11,406	8,712	8,365	6,541	8,311	9,856	10,506	7,960	9,979	8,011	8,243	6,210	6,807	5,731	6,894	2,739	3,413
SANJN5n	203,740	152,510	148,493	131,142	159,617	154,528	178,466	140,196	188,566	125,458	193,830	154,501	178,644	125,725	146,613	86,448	118,115
UCDEV4n	1,589	1,461	817	346	443	—	—	—	—	—	—	—	—	—	—	—	—
UCDOL1n	19,012	14,040	13,374	10,870	13,914	14,418	17,348	12,168	18,493	11,972	—	—	—	—	—	—	—
UCDOL2n	59,236	33,137	32,711	19,135	32,827	34,616	47,568	28,130	45,030	21,782	—	—	—	—	—	—	—
UPGRN2n	92,301	77,191	78,511	100,626	99,560	81,655	84,785	74,908	57,639	83,397	51,601	76,437	47,274	—	—	—	—
UPGRN3i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
UPGRN5n	458	172	91	113	111	—	—	—	—	—	—	—	—	—	—	—	—
WHTYA2n	51,935	49,959	47,230	42,287	47,117	43,930	53,316	42,165	54,887	56,463	61,110	63,452	54,387	50,183	47,634	—	—
WHTYA3n	19,149	14,637	8,884	612	11,133	9,229	26,228	6,166	32,218	29,022	27,583	—	—	—	—	—	—

[1]From Anning, D.W., Bauch, N.J., Gerner, S.J., Flynn, M.E., Hamlin, S.N., Moore, S.J., Schaefer, D.H., Anderholm, S.K., and Spangler L.E., 2007, Dissolved solids in basin-fill aquifers and major river systems in the southwestern United States: U.S. Geological Survey Scientific Investigations Report 2006–5315, 168 p.

Appendix 3.

Appendix 3. Annual precipitation for years of dissolved-solids loads for catchments examined in the Upper Colorado River Basin.

[Shading denotes irrigated agricultural catchments. **Abbreviations:** —, not applicable]

Catchment designation	Annual precipitation for years of dissolved-solids loads, in inches[1]														
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
COHED1n	—	—	—	—	—	—	—	—	—	—	32.82	23.96	29.32	19.60	23.33
COHED2n	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED4i	—	—	—	—	—	—	—	—	—	—	12.91	10.42	11.58	12.53	9.81
COHED5i	7.68	9.91	8.20	5.10	8.65	9.75	10.98	7.79	10.22	10.18	—	—	—	—	—
COHED6i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GUNNI1n	—	—	—	—	—	—	—	—	—	—	26.73	23.14	25.88	19.85	17.71
GUNNI2n	—	—	—	—	33.34	32.09	31.38	27.16	33.92	32.30	39.31	37.26	40.68	24.69	26.50
GUNNI3i	—	—	—	—	—	—	—	—	—	—	35.76	36.95	42.52	26.73	30.45
GUNNI4i	—	—	—	—	—	—	—	—	—	—	—	—	26.21	19.10	20.52
GUNNI7i	—	—	—	—	—	—	—	—	—	—	15.11	16.56	15.34	14.27	14.04
GUNNI8i	—	—	—	—	—	—	—	—	—	—	20.34	22.58	21.98	18.50	18.18
LOGRN1n	15.20	28.64	24.20	17.65	27.77	22.91	29.74	22.43	32.74	36.30	31.27	27.49	33.71	26.34	21.07
LOGRN2i	4.78	9.76	7.26	6.74	9.20	8.41	9.66	7.89	13.02	12.59	—	—	—	—	—
LOGRN3n	10.75	20.15	14.91	13.39	21.73	16.02	25.16	17.47	28.66	25.69	23.41	22.62	26.88	24.41	16.38
LOGRN6i	7.80	17.05	12.97	10.91	16.40	14.33	18.47	13.43	20.48	21.02	17.71	15.51	19.84	17.27	13.07
LOGRN7i	4.32	8.33	6.56	6.03	7.57	9.59	11.91	9.13	11.27	10.78	9.95	11.26	9.40	—	—
LOGRN9n	—	23.03	16.44	13.17	28.32	25.54	29.34	21.17	34.11	33.51	36.56	26.72	29.80	22.00	23.33
SANJN10i	—	—	—	—	—	—	—	—	—	—	8.59	12.09	12.63	9.96	12.40
SANJN11i	—	—	—	—	—	—	—	—	15.46	17.64	14.45	20.27	21.03	15.38	17.11
SANJN12n	18.59	27.48	20.20	13.59	26.14	41.31	34.34	25.43	27.17	36.65	21.59	35.43	30.38	23.63	28.21
SANJN2n	—	—	—	—	—	—	—	—	—	—	35.15	42.99	42.73	29.49	32.87
SANJN4i	—	—	—	—	—	—	—	—	—	—	16.19	19.21	21.89	18.89	18.23
SANJN5n	—	—	—	—	—	—	—	—	—	—	40.36	40.34	41.97	32.52	32.09
UCDEV4n	12.40	25.98	21.55	12.20	19.34	25.63	23.71	20.41	23.63	24.01	20.17	23.65	20.48	26.69	23.06
UCDOL1n	—	—	—	—	—	—	—	—	—	—	43.96	41.92	44.95	36.57	36.05
UCDOL2n	—	—	—	—	—	—	—	—	—	—	33.74	35.19	37.27	30.60	31.02
UPGRN2n	—	—	—	—	—	—	—	—	11.87	12.82	9.67	5.78	10.92	8.79	5.52
UPGRN3i	10.32	18.03	16.33	13.28	20.32	14.16	19.28	16.01	21.98	23.60	—	—	—	—	—
UPGRN5n	14.11	22.96	19.48	14.25	21.95	16.10	22.62	18.64	27.26	27.77	25.29	19.79	24.96	18.81	16.24
WHTYA2n	—	—	—	17.82	37.83	40.28	37.40	31.44	41.18	43.03	47.94	38.57	45.52	29.54	33.20
WHTYA3n	—	—	—	—	24.56	25.54	25.79	23.00	28.42	28.05	33.42	26.48	31.96	22.15	22.95

Appendix 3. Annual precipitation for years of dissolved-solids loads for catchments examined in the Upper Colorado River Basin.—Continued

[Shading denotes irrigated agricultural catchments. **Abbreviations:** —, not applicable]

Catchment designation	Annual precipitation for years of dissolved-solids loads, in inches[1]—Continued														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
COHED1n	21.35	23.11	24.82	22.01	27.01	20.85	29.72	26.76	30.35	23.52	26.82	24.79	21.32	16.90	29.04
COHED2n	16.37	15.47	19.41	16.15	21.15	14.73	24.52	20.10	22.90	17.88	20.59	—	—	—	—
COHED4i	6.12	6.56	9.31	11.18	14.50	8.02	12.52	10.13	13.94	8.77	10.83	6.58	—	—	—
COHED5i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED6i	—	—	11.98	13.11	16.70	10.62	16.21	11.58	18.11	13.03	14.99	10.07	12.07	8.91	10.90
GUNNI1n	18.87	19.66	20.28	20.74	22.70	18.34	30.34	20.64	25.27	17.47	25.39	19.65	18.14	14.18	19.76
GUNNI2n	25.99	23.09	28.78	27.32	36.16	25.54	43.47	32.74	37.47	26.71	29.97	23.27	23.60	19.43	25.55
GUNNI3i	23.28	22.92	28.27	26.72	36.93	25.85	40.40	26.69	—	—	—	—	—	—	—
GUNNI4i	15.97	15.33	18.23	20.16	24.34	17.96	27.48	17.78	—	—	—	—	—	—	—
GUNNI7i	10.09	11.04	12.11	15.69	14.31	12.04	18.03	10.57	19.65	12.81	19.96	10.72	13.39	10.32	12.75
GUNNI8i	13.15	13.24	16.47	19.31	22.79	15.39	23.75	17.68	25.12	18.37	21.26	14.36	16.66	12.01	16.39
LOGRN1n	20.84	24.93	31.69	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN2i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN3n	16.93	19.63	21.21	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN6i	12.44	13.68	15.71	13.27	17.95	13.02	—	—	—	—	—	—	—	—	—
LOGRN7i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN9n	20.73	19.52	24.24	20.79	—	—	—	—	—	—	—	—	—	—	—
SANJN10i	6.61	8.67	7.68	13.60	11.71	8.63	11.97	5.42	14.29	8.34	12.54	5.65	9.71	5.21	—
SANJN11i	9.70	13.16	12.64	17.41	16.54	—	—	—	—	—	—	—	—	—	—
SANJN12n	17.94	17.71	23.64	—	—	—	—	—	—	—	—	—	—	—	—
SANJN2n	25.26	30.94	35.77	35.81	40.10	35.80	42.51	—	—	—	—	—	—	—	—
SANJN4i	10.44	16.94	16.07	17.91	18.89	15.39	19.58	10.78	24.69	14.66	24.31	11.31	17.39	8.80	14.81
SANJN5n	26.00	31.20	31.77	31.64	35.26	28.59	38.56	23.36	42.89	29.91	44.04	24.14	32.90	19.66	28.93
UCDEV4n	14.57	16.54	20.78	—	—	—	—	—	—	—	—	—	—	—	—
UCDOL1n	28.26	29.83	35.57	32.66	36.54	27.20	39.45	18.21	—	—	—	—	—	—	—
UCDOL2n	24.11	24.32	28.10	28.40	30.55	23.15	31.98	15.78	—	—	—	—	—	—	—
UPGRN2n	7.50	7.03	9.60	7.76	10.73	5.98	13.34	7.49	11.46	10.81	10.95	—	—	—	—
UPGRN3i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
UPGRN5n	16.96	19.39	23.16	—	—	—	—	—	—	—	—	—	—	—	—
WHTYA2n	29.24	26.31	36.20	29.90	34.33	24.78	42.31	33.24	47.29	34.86	34.63	32.27	28.72	—	—
WHTYA3n	19.51	17.77	24.64	21.84	23.84	18.49	30.48	23.53	36.14	—	—	—	—	—	—

[1]Computed from PRISM Group, 2007, Digital climate data: Oregon State University, accessed August 2009 at http://www.ocs.oregonstate.edu/prism/index.phtml

Appendix 4.

Appendix 4. Annual monthly average (April through October) maximum temperature for years of dissolved-solids loads for catchments examined in the Upper Colorado River Basin.

[Shading denotes irrigated agricultural catchments. **Abbreviations:** —, not applicable]

Catchment designation	Annual monthly average (April through October) maximum temperature for years of dissolved-solids loads, in degrees Celsius[1]														
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
COHED1n	—	—	—	—	—	—	—	—	—	—	13.62	14.94	14.12	15.75	16.00
COHED2n	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED4i	—	—	—	—	—	—	—	—	—	—	25.28	26.65	26.09	27.08	27.91
COHED5i	27.13	25.24	26.57	27.57	26.85	27.03	26.62	26.96	25.57	25.67	—	—	—	—	—
COHED6i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
GUNNI1n	—	—	—	—	—	—	—	—	—	—	12.87	14.21	13.25	14.81	15.07
GUNNI2n	—	—	—	—	18.02	18.27	17.76	17.84	16.49	17.02	16.25	17.73	16.82	18.17	18.41
GUNNI3i	—	—	—	—	—	—	—	—	—	—	17.79	18.94	17.85	18.94	19.43
GUNNI4i	—	—	—	—	—	—	—	—	—	—	—	—	21.74	22.95	23.26
GUNNI7i	—	—	—	—	—	—	—	—	—	—	22.10	23.34	22.27	23.70	24.14
GUNNI8i	—	—	—	—	—	—	—	—	—	—	21.17	22.78	21.67	23.00	23.37
LOGRN1n	16.36	13.85	15.35	15.47	15.71	16.48	15.58	16.18	14.46	15.47	14.83	15.72	14.26	14.86	15.53
LOGRN2i	24.24	21.66	23.16	24.35	23.44	24.03	23.14	23.67	21.91	22.33	—	—	—	—	—
LOGRN3n	18.32	15.74	17.45	18.30	17.95	18.64	17.52	17.86	16.15	16.10	15.83	17.09	16.83	17.46	18.20
LOGRN6i	21.23	18.73	20.38	21.27	20.62	21.21	20.23	20.72	19.15	19.34	19.36	20.55	19.59	20.55	21.49
LOGRN7i	24.92	22.84	24.60	25.72	24.73	25.38	24.40	24.60	22.56	22.86	23.18	24.72	23.44	—	—
LOGRN9n	—	14.33	15.97	16.96	16.36	16.94	15.75	16.33	14.52	14.76	14.93	16.60	15.69	16.79	17.19
SANJN10i	—	—	—	—	—	—	—	—	—	—	25.57	26.15	24.97	26.25	26.54
SANJN11i	—	—	—	—	—	—	—	—	22.91	22.72	23.04	23.86	22.68	24.20	24.43
SANJN12n	18.22	16.41	17.09	18.12	17.97	17.85	17.43	17.52	16.48	16.53	16.78	17.20	16.30	17.48	17.94
SANJN2n	—	—	—	—	—	—	—	—	—	—	15.90	16.65	15.77	17.39	17.44
SANJN4i	—	—	—	—	—	—	—	—	—	—	22.19	23.91	22.69	24.36	24.75
SANJN5n	—	—	—	—	—	—	—	—	—	—	14.46	14.93	13.82	15.33	15.45
UCDEV4n	18.20	15.84	16.86	17.82	17.48	17.93	16.96	17.57	16.08	16.26	17.03	17.53	16.35	17.78	18.17
UCDOL1n	—	—	—	—	—	—	—	—	—	—	13.07	13.45	12.47	13.86	13.85
UCDOL2n	—	—	—	—	—	—	—	—	—	—	15.97	16.53	15.49	16.90	17.05
UPGRN2n	—	—	—	—	—	—	—	—	18.58	18.67	18.64	20.63	19.38	21.27	22.32
UPGRN3i	18.06	15.59	17.70	18.35	17.75	18.62	17.65	18.00	16.15	16.04	—	—	—	—	—
UPGRN5n	18.73	16.26	17.85	18.36	17.93	18.67	17.71	18.39	16.51	17.09	16.86	17.99	16.49	17.76	18.95
WHTYA2n	—	—	—	16.92	16.43	16.08	15.79	16.12	14.30	14.62	14.08	15.49	15.20	16.08	16.52
WHTYA3n	—	—	—	—	19.66	19.45	19.03	19.33	17.49	17.85	17.27	18.91	19.11	18.82	19.69

Appendix 4. Annual monthly average (April through October) maximum temperature for years of dissolved-solids loads for catchments examined in the Upper Colorado River Basin.—Continued

[Shading denotes irrigated agricultural catchments. **Abbreviations:** —, not applicable]

Catchment designation	Annual monthly average (April through October) maximum temperature for years of dissolved-solids loads, in degrees Celsius[1]—Continued														
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
COHED1n	15.39	15.52	15.00	15.13	13.66	16.05	13.91	15.16	15.26	16.05	15.18	17.39	17.31	17.74	17.43
COHED2n	18.55	18.89	18.32	18.73	17.29	19.37	17.33	18.67	18.96	19.32	18.32	—	—	—	—
COHED4i	27.72	27.51	26.59	27.69	25.98	27.73	25.27	27.11	25.91	26.71	26.09	28.75	—	—	—
COHED5i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
COHED6i	—	—	24.31	25.34	23.56	25.57	23.24	24.84	23.37	24.24	23.50	26.16	26.00	26.00	26.13
GUNNI1n	15.05	15.06	14.57	14.61	12.85	13.80	12.13	14.72	15.83	16.51	15.36	17.77	17.41	18.01	18.03
GUNNI2n	18.12	18.04	16.46	17.98	16.17	18.87	16.85	18.51	16.56	17.34	16.40	18.77	18.40	18.75	18.98
GUNNI3i	19.32	19.29	18.57	19.43	17.54	19.93	18.04	19.16	—	—	—	—	—	—	—
GUNNI4i	23.28	23.15	22.36	23.20	21.41	23.56	21.53	23.04	—	—	—	—	—	—	—
GUNNI7i	24.22	23.79	23.03	23.83	22.37	24.09	22.18	23.78	22.15	22.53	21.86	24.20	23.90	24.29	24.57
GUNNI8i	23.07	23.08	22.09	22.93	20.91	23.22	21.42	22.83	21.29	21.70	20.94	23.44	23.17	23.36	23.58
LOGRN1n	14.54	14.68	13.51	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN2i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN3n	17.02	17.31	16.28	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN6i	20.75	20.99	19.80	21.13	18.95	21.61	—	—	—	—	—	—	—	—	—
LOGRN7i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
LOGRN9n	16.54	16.75	15.47	16.92	—	—	—	—	—	—	—	—	—	—	—
SANJN10i	27.34	26.62	26.04	26.19	25.72	26.89	25.82	26.99	25.91	26.04	25.18	27.80	27.66	27.63	—
SANJN11i	25.11	24.53	24.13	24.34	23.69	—	—	—	—	—	—	—	—	—	—
SANJN12n	16.65	17.73	16.60	—	—	—	—	—	—	—	—	—	—	—	—
SANJN2n	18.08	16.93	16.75	17.10	16.46	17.50	16.25	—	—	—	—	—	—	—	—
SANJN4i	25.10	22.54	22.20	22.67	22.36	23.88	22.99	24.33	22.66	23.41	22.57	25.11	24.80	25.24	25.38
SANJN5n	15.81	15.19	14.54	15.31	14.77	15.80	14.45	15.60	15.95	16.10	15.23	17.94	18.00	18.20	18.29
UCDEV4n	18.55	17.86	16.86	—	—	—	—	—	—	—	—	—	—	—	—
UCDOL1n	14.25	13.47	12.37	14.13	13.49	14.61	13.11	14.27	—	—	—	—	—	—	—
UCDOL2n	17.44	16.63	15.98	17.02	16.35	17.58	16.02	17.34	—	—	—	—	—	—	—
UPGRN2n	20.76	20.78	19.64	20.84	17.70	21.20	18.28	19.68	18.86	19.08	18.99	—	—	—	—
UPGRN3i	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
UPGRN5n	18.04	18.10	16.81	—	—	—	—	—	—	—	—	—	—	—	—
WHTYA2n	15.77	16.23	15.27	15.73	14.31	15.50	14.27	15.48	15.22	15.51	14.63	17.35	16.93	—	—
WHTYA3n	19.09	19.37	18.34	19.19	17.71	19.64	17.33	18.91	17.86	—	—	—	—	—	—

[1]Computed from PRISM Group, 2007, Digital climate data: Oregon State University, accessed August 2009 at http://www.ocs.oregonstate.edu/prism/index.phtml

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