USGS
science for a changing world

Estimated Decreases in Dissolved-Solids Loads in Four Tributaries to the Colorado River in the Grand Valley, Colorado, 1973-96

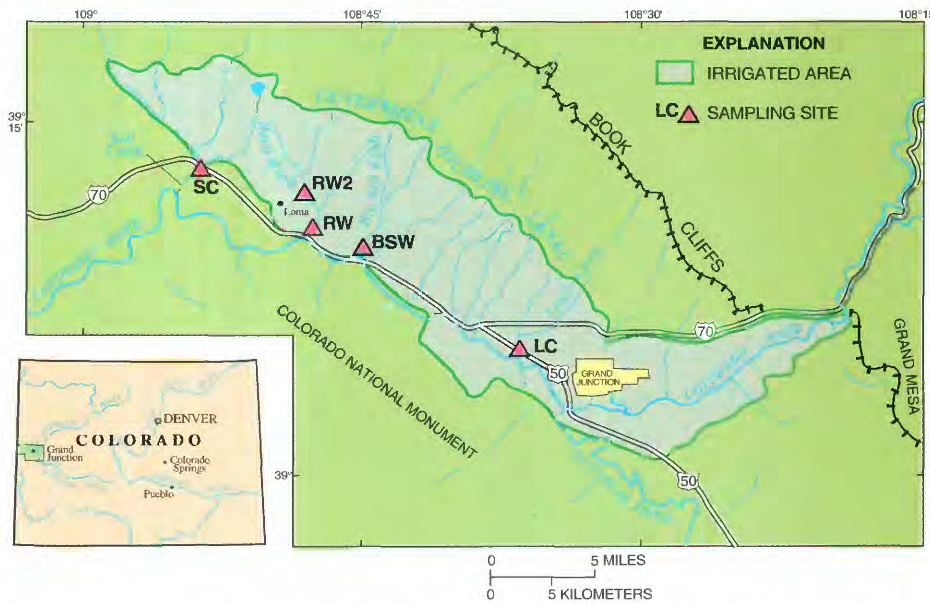

***Figure 1.** Location of the Grand Valley, extent of irrigated area, and locations of study sites.*

The Colorado River is used extensively for municipal, agricultural, and industrial purposes in seven Western States. Since water development began in the 1870's, the average dissolved-solids concentrations in the lower Colorado River has more than doubled when compared to pre-development concentrations (U.S. Department of the Interior, 1995). The dissolved-solids concentration, commonly referred to as salinity, is a measure of salts, such as sodium chloride, calcium bicarbonate, and calcium sulfate, that are dissolved in water. Dissolved solids can have adverse effects on agricultural, municipal, and industrial uses, especially in the lower part of the basin. The Colorado River Basin Salinity Control Act, passed by the U.S. Congress in 1974, authorized the Bureau of Reclamation (BOR) and the U.S. Department of Agriculture (USDA) to plan and construct salinity-control projects to decrease dissolved-solids loading to the Colorado River. One of the authorized projects was a salinity-control project to address dissolved-solids loading from irrigated agricultural lands in the Grand Valley (fig. 1). Because ground water that was recharged primarily from irrigation practices was the major source of dissolved-solids loading from the Grand Valley (Bureau of Reclamation, 1978), the salinity-control project was designed to decrease the recharge to this ground water from canal, lateral, and ditch leakage and from deep percolation in irrigated fields. The salinity-control project in the Grand Valley consisted of two parts: (1) The BOR lined parts of the Government Highline Canal (fig. 1) and placed some laterals in pipe to decrease distribution-system losses, and (2) the USDA (through the Natural Resources Conservation Service) was responsible for on-farm improvements to decrease water losses from on-farm ditches and to decrease deep percolation from fields.

In 1994, the BOR requested the U.S. Geological Survey (USGS) to examine trends in dissolved-solids data for the Colorado and Gunnison Rivers to examine the effectiveness of the salinity-control projects in the Grand Valley (U.S. Department of the Interior, 1995). Significant downward trends in dissolved-solids concentrations and loads in the Colorado River downstream from the Grand Valley were reported by Butler (1996). However, dissolved-solids concentrations and loads also had significant downward trends in the Colorado River upstream from the Grand Valley, which introduced some uncertainty in determining the effect of the Grand Valley salinity-control projects on the dissolved-solids trends in the Colorado River.

Examining dissolved-solids loads in tributary streams and washes that dissect the Grand Valley (fig. 1) could be a more direct measure of effects of salinity-control projects than are dissolved-solids loads in the Colorado River. These streams and washes carry much of the irrigation-induced dissolved-solids load resulting from subsurface irrigation return flow to the Colorado River. If salinity-control projects in these relatively small watersheds were effective, there could be measurable decreases in dissolved-solids loads in the streams in these areas.

During 1973–83, the USGS, in cooperation with the BOR, operated several gaging stations on selected streams in the Grand Valley. Daily streamflow and specific conductance were recorded, and water-quality samples were collected at some of the stations. All the gaging stations operated by the USGS, where water-quality data had been collected, were discontinued by October 1983. In 1991, the National Irrigation Water Quality Program (NIWQP) of the U.S. Department of the Interior began a study in the Grand Valley. The focus of the NIWQP study was on selenium sources and pathways and effects of selenium on fish and birds (Butler and others, 1996). Although no gaging stations were reactivated in support of the NIWQP study, water samples for chemical analyses that included dissolved solids were collected at several sites where the gaging stations had been located in 1973–83. Data collected for NIWQP were to be used to estimate selenium and dissolved-solids loads at outflow sites on the major streams and washes draining irrigated areas in the Grand Valley. By 1996, sufficient streamflow and chemical data had been collected to estimate dissolved-solids loads for four of the sites (fig. 1) at former gaging stations: Leach Creek (site LC), Big Salt Wash (site BSW), Reed Wash (site RW), and Salt Creek (site SC). Dissolved-solids loads during 1973–83 then could be compared to dissolved-solids loads for 1991–96 for the four sites to determine the effects of salinity-control projects in the Grand Valley.

This fact sheet describes changes in dissolved-solids loads in four streams in the Grand Valley between 1973–83 and 1991–96 and the relation between changes in loads and implementation of salinity-control projects. The fact sheet also describes the methods used to compute dissolved-solids loads and the rationale for making the load comparisons between 1973–83 and 1991–96.

Methods Used To Estimate Dissolved-Solids Loads

Daily streamflow, daily specific conductance, and periodic water-quality data that were collected at the four sites are summarized in table 1. It is more appropriate to compare dissolved-solids loads between time periods if loads were calculated using the same method. Because only periodic water-quality and streamflow data were collected during 1991–96 (table 1) at the four sites, only periodic data were available for computing dissolved-solids loads for 1991–96. Therefore, to compare the loads for 1973–83 to loads for 1991–96, the loads for 1973–83 also needed to be computed using only periodic data.

The method for estimating loads using only periodic water-quality and streamflow data is referred to as the periodic method. In this method, loads are computed for individual samples by using the dissolved-solids concentration from the chemical analysis of water samples and the streamflow measured when the sample was collected. The individual dissolved-solids loads then are separated into irrigation-season and nonirrigation-season samples, and means are computed for each set of seasonal data. A mean annual load is determined by computing a weighted mean of the two seasonal mean loads. The weighting factors are based on the fraction of the year each season encompasses (the

Table 1. Sampling sites and summary of daily and periodic data collected in 1973–83 and 1991–96

[POR, period of record; N, number of samples]

Sampling site (fig. 1)	USGS station number	Stream name	Period of record, daily streamflow and conductance		Periodic water-quality sampling			
			1973–83	1991–96	1973–83		1991–96	
					POR	N	POR	N
LC	09152650	Leach Creek	04/73–09/77	None	08/73–07/77	28	03/91–12/96	32
BSW	09153270	Big Salt Wash	03/73–09/77	None	08/73–07/77	29	03/91–12/96	20
RW	09153300	Reed Wash	04/73–09/83	None	08/73–10/82	48	03/91–12/96	39
SC	09163490	Salt Creek	04/73–09/83	None	08/73–09/83	53	03/91–11/96	30

irrigation season encompasses about 59 percent of the year, the nonirrigation season about 41 percent of the year). The reason for using a seasonally weighted mean is because of the large differences in streamflow and dissolved-solids loads between the irrigation and nonirrigation seasons in many Grand Valley streams and washes. If the periodic sampling was biased to one of the seasons (for example, if most of the samples were collected in the irrigation season), then an arithmetic mean on all the samples might result in an unrealistic mean dissolved-solids load, if that mean is assumed to represent the daily load throughout the year. Using a seasonally weighted mean removes seasonal sampling bias. Once the seasonally weighted mean is calculated, the resultant mean load is assumed to represent the mean annual dissolved-solids load and is multiplied by 365.25 to estimate the total annual dissolved-solids load for a multi-year period in which the sampling was done.

To determine if annual dissolved-solids loads computed using only periodic data are representative of actual loads, the loads for 1973–83 also were computed using another method called SLOAD. A computer program named SLOAD (Salt LOAD) was developed by Liebermann and others (1987) for estimating dissolved-solids loads in streams and rivers. In the SLOAD method, daily streamflow, daily specific-conductance, and periodic dissolved-solids data are used to estimate loads. Two equations are computed using the periodic data. One equation relates dissolved-solids load to streamflow, and the second equation relates dissolved-solids load to streamflow and specific conductance. The equations then are used to compute daily loads for the time period of interest using the daily streamflow record and, if available, daily specific conductance. The daily loads are summed to give monthly and annual dissolved-solids loads. Dissolved-solids loads computed using the SLOAD method should be a more accurate estimate of dissolved-solids loads when compared to the periodic method because much more detailed data (daily streamflow and specific conductance) are used instead of only periodic dissolved-solids data. A comparison of the two methods is provided in the next section of this fact sheet.

Comparison of Methods

Annual dissolved-solids loads calculated by the two methods are compared in table 2. The loads are applicable to the periods when the gaging stations were operated at the four sites during 1973–83 (table 1). The differences in annual loads ranged from about 4 to 8 percent (table 2). Using the periodic method, the annual dissolved-solids loads for Leach Creek and Big Salt Wash were less than the annual loads computed using the SLOAD method; the opposite was true for Reed Wash and Salt Creek (table 2). For the four stations, the annual loads based only on periodic data are not substantially different than the annual loads computed using SLOAD. The implication is that the periodic dissolved-solids-load data were collected over the general range of streamflow and dissolved-solids concentrations for several years at these four sites and that fairly reliable estimates of annual dissolved-solids loads can be obtained without having daily streamflow data. A disadvantage of using only periodic samples is that runoff from large storms may be missed. In the Grand Valley, such storms are relatively infrequent and often of short duration. At least for the periods when the four gaging stations were operated, results indicated that using only periodic data for computing dissolved-solids loads provides reasonable estimates of the annual loads.

Table 2. Comparison of annual dissolved-solids loads computed using two methods

[Periodic method, only periodic water-quality and streamflow data are used to estimate loads; SLOAD method, daily streamflow and specific conductance are used to estimate loads; loads for Leach Creek and Big Salt Wash are based on data collected during 1973–77, and loads for Reed Wash and Salt Creek are based on data collected during 1973–83; loads are in tons per year]

Stream	Annual dissolved-solids load		Difference in loads, periodic minus SLOAD	
	Periodic	SLOAD	Load	Percent
Leach Creek	41,400	44,900	–3,500	–7.8
Big Salt Wash	83,200	88,200	–5,000	–5.7
Reed Wash	139,600	130,000	9,600	7.4
Salt Creek	131,300	125,500	5,800	4.6

Comparison of Dissolved-Solids Loads for Two Study Periods

Estimated dissolved-solids loads in Leach Creek, Big Salt Wash, Reed Wash, and Salt Creek were lower in 1991–96 than in the earlier period (table 3; fig. 2). Only the dissolved-solids loads computed using the periodic method are compared for the earlier period and 1991–96. Decreases in the annual dissolved-solids loads ranged from about 13.3 to 20.6 percent in the four streams. The largest decreases in annual dissolved-solids loads were in Reed Wash (27,600 tons) and Salt Creek (27,000 tons).

The changes in loads for the four streams are of sufficient magnitude to indicate that dissolved-solids loading from the Grand Valley has decreased over the last 23 years. The largest single known effect on dissolved-solids loads in the Grand Valley was the implementation of salinity-control projects. In the Grand Valley, the BOR salinity-control projects began in late 1980 with the Stage I project in the Reed Wash Basin. The Stage I project was completed in 1983. Because BOR salinity-control work was occurring in Reed Wash during 1981–83, the dissolved-solids load for the earlier period was determined for 1973–80 (table 3; fig. 2) instead of 1973–83. In the Salt Creek Basin, the BOR did salinity-control work from 1986 to 1991. Decreases in dissolved solids resulting from BOR work in the Reed Wash and Salt Creek Basins would have occurred before the 1991–96 sampling period. In Big Salt Wash Basin, the BOR salinity-control work was started in 1991 and was completed by early 1993. Because of the overlap of the salinity-control work with the 1991–96 sampling period in Big Salt Wash, the loads for 1991–96 might not completely reflect effects of salinity control. In the Leach Creek Basin, the BOR salinity work did not start until 1995.

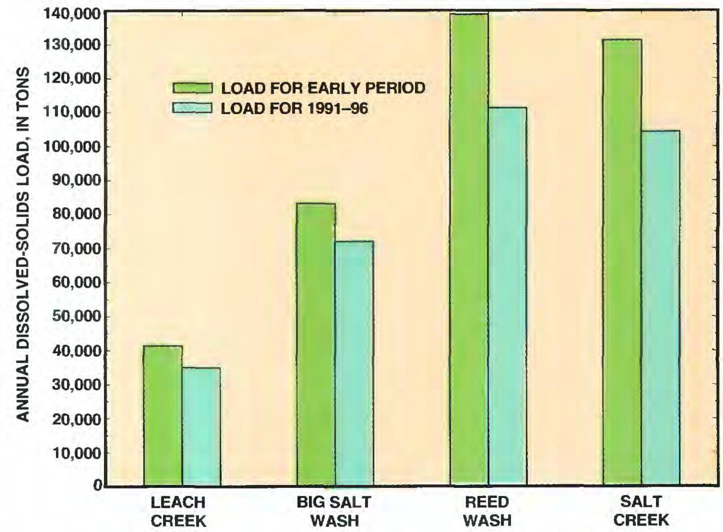

Figure 2. Annual dissolved-solids loads in four streams in the Grand Valley for two study periods. Early periods are prior to Bureau of Reclamation salinity-control projects and are 1973–77 for Leach Creek and Big Salt Wash; 1973–80 for Reed Wash; and 1973–83 for Salt Creek.

Table 3. Comparison of annual dissolved-solids loads for the 1973–83 and 1991–96 study periods

[Annual dissolved-solids loads for earlier periods are prior to Bureau of Reclamation salinity-control projects in the basin. earlier periods are: 1973–77 for Leach Creek and Big Salt Wash; 1973–80 for Reed Wash; and 1973–83 for Salt Creek; loads for both study periods were computed using periodic method; loads, in tons per year]

Stream	Annual load, earlier period	Annual load for 1991–96	Change in load, 1991–96 to the early period, in tons and percent
Leach Creek	41,400	35,000	–6,400 (–15.5%)
Big Salt Wash	83,200	72,100	–11,100 (–13.3%)
Reed Wash	138,900	111,300	–27,600 (–19.9%)
Salt Creek	131,300	104,300	–27,000 (–20.6%)
Total	394,800	322,700	–72,100 (–18.3%)

The second part of the Grand Valley salinity-control project is the on-farm work done by the USDA. The USDA implemented the on-farm program in 1979, and work has been done at various farms throughout the Grand Valley since 1979. Because of the variable nature of the on-farm program, the effects of that salinity-control work are cumulative since 1979. To document the full extent of the effects of the salinity-control projects on dissolved-solids loads in the four study basins, additional sampling would be needed after all salinity-control projects in the study basins are completed.

Other factors, in addition to salinity-control projects, could affect dissolved-solids loads. Changes in dissolved-solids loads in parts of the four study basins that are upstream from the irrigated areas (north of the Government Highline Canal in fig. 1) could affect loads measured at outflow stations. However, on a long-term basis, annual dissolved-solids loads in the four study basins from areas upstream from irrigated land in the Grand Valley might not be a major component of the loads measured at the outflow sites. Of the four study basins, the Salt Creek Basin has by far the largest drainage-basin area outside of the irrigated area. Data collected by the USGS on tributaries of Salt Creek during the 1970's and early 1980's (U.S. Geological Survey, 1974–83) indicated that the annual dissolved-solids loads discharging into Salt Creek from the drainage basin upstream from the Government Highline Canal are relatively small when compared to the load computed for the outflow site near I-70 (site SC in fig. 1).

Another potential effect on dissolved-solids loads in streams and washes draining the Grand Valley is conversion of agricultural land to residential and commercial development. Conversion of irrigated land to other uses could affect dissolved-solids loading in the Grand Valley. However, the effect of land-use changes on dissolved-solids loads has not been documented for the Grand Valley. Conversion of agricultural land has not been extensive in the Reed Wash and Salt Creek Basins during 1973–96. Some of the area around Fruita in the lower Big Salt Wash Basin has been affected by urbanization, especially in the 1990's, and some agricultural land in the Leach Creek Basin was converted to other uses during the study period.

Relation of Salinity-Control Projects to Dissolved-Solids Loads

The previously discussed analysis of dissolved-solids data collected by the USGS since 1973 indicated that annual dissolved-solids loads have decreased in four streams that drain irrigated areas in the western Grand Valley. In the Big Salt Wash, Reed Wash, and Salt Creek Basins, implementation of salinity-control projects by the BOR and the USDA was the most significant known change in these basins that could cause decreases in dissolved-solids loads. In those three drainage basins, the projected decrease in dissolved-solids loads from the BOR part (canal lining and piping of laterals) of the salinity-control project was about 53,000 tons per year (U.S. Department of the Interior, 1995; Bureau of Reclamation, written commun., 1997). The total projected decrease in dissolved-solids loads for the three basins would be greater than 53,000 tons per year if the salinity decreases from the USDA on-farm salinity-control projects were included; however, these decreases have not been determined for specific drainage basins.

Additional analysis of other water-quality and streamflow data tends to substantiate the dissolved-solids-load decreases reported in this fact sheet. For example, review of the annual streamflow data for the USGS gaging station on Reed Wash at site RW2 (fig. 1) indicates a decrease in annual mean streamflow after 1982 (fig. 3). The Stage I salinity-control project lined 6.8 miles of the Government Highline Canal and placed 34.2 miles of open laterals in pipe in the upper Reed Wash Basin from 1981 to early 1983 (Bureau of Reclamation, 1985). Some of the ground-water recharge from canal and lateral leakage in upper Reed Wash was eliminated, and the Stage I work should have decreased ground-water discharge

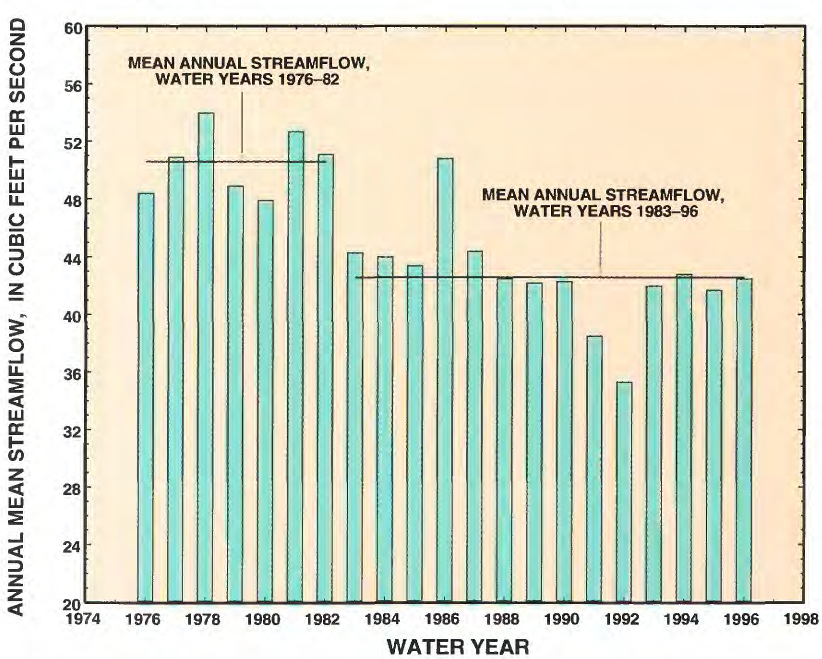

Figure 3. Annual mean streamflow for USGS gaging station on upper Reed Wash (site RW2 in fig. 1), water year 1976–96.

into Reed Wash throughout the year. Subsequently, annual streamflow and dissolved-solids loads have decreased in Reed Wash.

The dissolved-solids loads presented in this fact sheet are considered estimates. Assuming the errors in streamflow measurements and water-quality data and errors in the computation method are relatively consistent for the study period, then the load differences between the 1973–83 and 1991–96 study periods should be reasonable approximations of changes in dissolved-solids loads. Also, the decreases in dissolved-solids loads reported for the four streams cannot be interpreted as a direct measure of the actual salinity (dissolved-solids) decreases attained by Federal salinity-control projects in those four basins. There could have been some long-term changes in crops, water use, and irrigated acreage in these areas that were not related to the salinity-control program. However, results of this study indicate that, since the implementation of salinity-control projects, dissolved-solids loads have decreased in four streams that drain irrigated agricultural areas in the Grand Valley.

References Clted

Bureau of Reclamation, 1978, Stage One development, Grand Valley Unit, definite plan report—Appendix B, hydrosalinity, land resource, economics: Salt Lake City, five numbered sections plus attachments.

____1985, Grand Valley Unit, Stage Two development, final environmental impact statement: Bureau of Reclamation Report INT FES86–10, 217 p.

Butler, D.L., 1996, Trend analysis of selected water-quality data associated with salinity-control projects in the Grand Valley, in the lower Gunnison River Basin, and at Meeker Dome, western Colorado: U.S. Geological Survey Water-Resources Investigations Report 95–4272, 38 p.

Butler, D.L., Wright, W.G., Stewart, K.C., Osmundson, B.C., Krueger, R.P., and Crabtree, D.W., 1996, Detailed study of selenium and other constituents in water, bottom sediment, soil, alfalfa, and biota associated with irrigation drainage in the Uncompahgre Project area and in the Grand Valley, west-central Colorado, 1991–93: U.S. Geological Survey Water-Resources Investigations Report 96–4138, 136 p.

Liebermann, T.D., Middelburg, R.F., and Irvine, S.A., 1987, User's manual for estimation of dissolved-solids concentrations and loads in surface water: U.S. Geological Survey Water-Resources Investigations Report 86–4124, 51 p.

U.S. Department of the Interior, 1995, Quality of water—Colorado River Basin: Salt Lake City, Bureau of Reclamation, Upper Colorado Region, Progress Report 17, 96 p., plus appendix.

U.S. Geological Survey, 1974–83, Water resources data, Colorado, water years 1974–83, v. 2, Colorado River Basin above Dolores River: U.S. Geological Survey Water-Data Reports CO–74–2 through CO–83–2.

—David L. Butler

Water Resources Division,
Grand Junction, Colorado

For more information about this study, write to:
Subdistrict Chief
U.S. Geological Survey
764 Horizon Drive, Room 125
Grand Junction, CO 81506
email:dlbutler@usgs.gov