Prepared in cooperation with Mesa County and the City of Grand Junction

Concentrations and Loads of Selenium in Selected Tributaries to the Colorado River in the Grand Valley, Western Colorado, 2004–2006

Scientific Investigations Report 2008–5036

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

Photo on the left:
Mancos Shale hills in Persigo Wash subbasin. Photograph was taken facing northeast from the intersection of 24 Road and K Road (see fig. 5). Photo taken by Ken Leib, U.S. Geological Survey, 2004.

Photo on the right:
Furrow irrigation in Persigo Wash subbasin. Photograph was taken facing southwest from the intersection of 24 Road and K Road (see fig. 5). Photo taken by Ken Leib, U.S. Geological Survey, 2005.

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Conversion Factors, Datums, and Abbreviations

Multiply	By	To obtain
	Length	
Inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
pound per day	0.4536	kilogram per day
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per day per square mile [(ton/d)/mi^2]	0.3503	megagram per day per square kilometer [(Mg/d)/km^2]
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year

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

$$°F=(1.8×°C)+32$$

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

$$°C=(°F-32)/1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).Elevation, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).Concentrations of chemical constituents in water are given in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Water year is defined in this report as the 12-month period October 1 through September 30, designated by the calendar year in which it ends.

Abbreviations

GVSTF	Grand Valley Selenium Task Force
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
NaBr	sodium bromide
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
WWTP	wastewater treatment plant

Concentrations and Loads of Selenium in Selected Tributaries to the Colorado River in the Grand Valley, Western Colorado, 2004–2006

By Kenneth J. Leib

Abstract

The reach of the Colorado River from the Gunnison River confluence to the Utah Border, and tributaries in the Grand Valley, are on the State of Colorado 303(d) list of impaired water bodies because the concentrations of dissolved selenium in these streams exceed the State of Colorado chronic standard of 4.6 micrograms per liter at the 85th percentile level. In response to concerns raised by a local watershed initiative about the issue of selenium in the Grand Valley, the U.S. Geological Survey, in cooperation with Mesa County and the City of Grand Junction, developed a study to characterize and determine the sources of selenium and how these sources are related to changes in land use.

This report describes the methods and results of a study of concentrations and loads of selenium in three tributaries to the Colorado River in the Grand Valley. The study area consists of three subbasins, Persigo Wash, Adobe Creek, and Lewis Wash, each representing transitional agricultural to residential, agricultural, and residential land-use types, respectively. These subbasins represent different land-use types and the tributaries that drain each subbasin contribute moderate to high concentrations and loads of selenium to the Colorado River. Two synoptic-sampling events were conducted in each tributary to characterize variations in water quality during the nonirrigation season. Water samples were collected for analysis of dissolved selenium, total nitrogen, and total dissolved solids (salinity). Streamflow was measured by either the tracer-dilution or standard current-meter method.

In Persigo Wash selenium concentrations generally decreased or remained constant in a downstream direction whereas selenium loads increased. Effluent from the Persigo Wash wastewater treatment plant diluted selenium concentrations in Persigo Wash and increased the selenium load. The concentrations and loads of salinity and total nitrogen generally increased downstream in Persigo Wash. Concentrations and loads of selenium correlated well with concentrations and loads of total nitrogen ($R^2 = 0.80$ and 0.83, respectively). Concentrations and loads of total nitrogen also correlated well with streamflow ($R^2 = 0.89$ and 0.99, respectively).

In Adobe Creek concentrations and loads of selenium generally increased downstream. The largest selenium loads in Adobe Creek were observed between a 1.6-mile-long reach extending approximately from the Grand Valley Canal to the Main Line Grand Valley Canal, where selenium load increased 0.72 pounds per day. This reach accounted for about 81 percent of the total selenium load at the mouth of Adobe Creek (site AC1). Results from the synoptic sampling in Adobe Creek indicated that there was very little seasonal variation in selenium concentration during the nonirrigation season. Salinity concentrations were more variable than selenium concentrations during the nonirrigation season. The concentrations and loads of salinity and total nitrogen generally increased downstream. Concentrations and loads of selenium correlated well with concentrations and loads of total nitrogen ($R^2 = 0.89$ and 0.98, respectively). Streamflow also was related to concentrations and loads of total nitrogen; results indicated a fair correlation for concentration ($R^2 = 0.51$) and a good correlation for load ($R^2 = 0.95$).

In Lewis Wash concentrations and loads of selenium generally increased downstream. Selenium concentrations measured in Lewis Wash were lower than those measured in Persigo Wash or Adobe Creek. Salinity concentrations were similar to those measured in Persigo Wash and Adobe Creek. Salinity concentrations were similar among sites during each synoptic-sampling event. Salinity loads in Lewis Wash were highest during the beginning of the nonirrigation season. Concentrations and loads of total nitrogen generally increased downstream. There was a fair correlation for selenium and total nitrogen concentration ($R^2 = 0.71$).

Step-trend analysis was used to determine if a significant difference ($p < 0.05$) existed between early (4–23–1977 to 3–19–1979) and later (4–23–2002 to 3–19–2004) periods of historical streamflow and salinity concentration and load data at the U.S. Geological Survey streamflow gaging station near the mouth of Lewis Wash (site LW1). Two types of statistical tests, the t-test and the Wilcoxon Signed Rank Test (sign test), were used to determine if step trends were present in the dataset. The t-test results indicate that there was no significant decrease in the annual or seasonal (irrigation and nonirrigation season) streamflow rate at site LW1, with the exception of the

irrigation season for the 1977 compared to 2002 water years. The t-tests for concentrations and loads of salinity indicate that both annual and seasonal salinity concentrations and loads were lower during the later period of data collection for all water years and seasons tested, with the exception of salinity concentration during water year 1978. The sign tests, unlike the t-tests, indicated that there was a significant decrease in streamflow during the later period nonirrigation seasons that were tested. Sign-test results for concentrations and loads of salinity were generally the same as those for the t-test analysis.

An estimate of the decrease in annual salinity loading at site LW1 was calculated using data for water years 1978 and 2003. The data indicated a reduction in annual salinity load of approximately 2,450 tons. The reduction in annual salinity load may have occurred as a result of salinity control work done by the Natural Resources Conservation Service and the Bureau of Reclamation or as a result of changes in land use, particularly the conversion of agricultural land to residential development.

Introduction

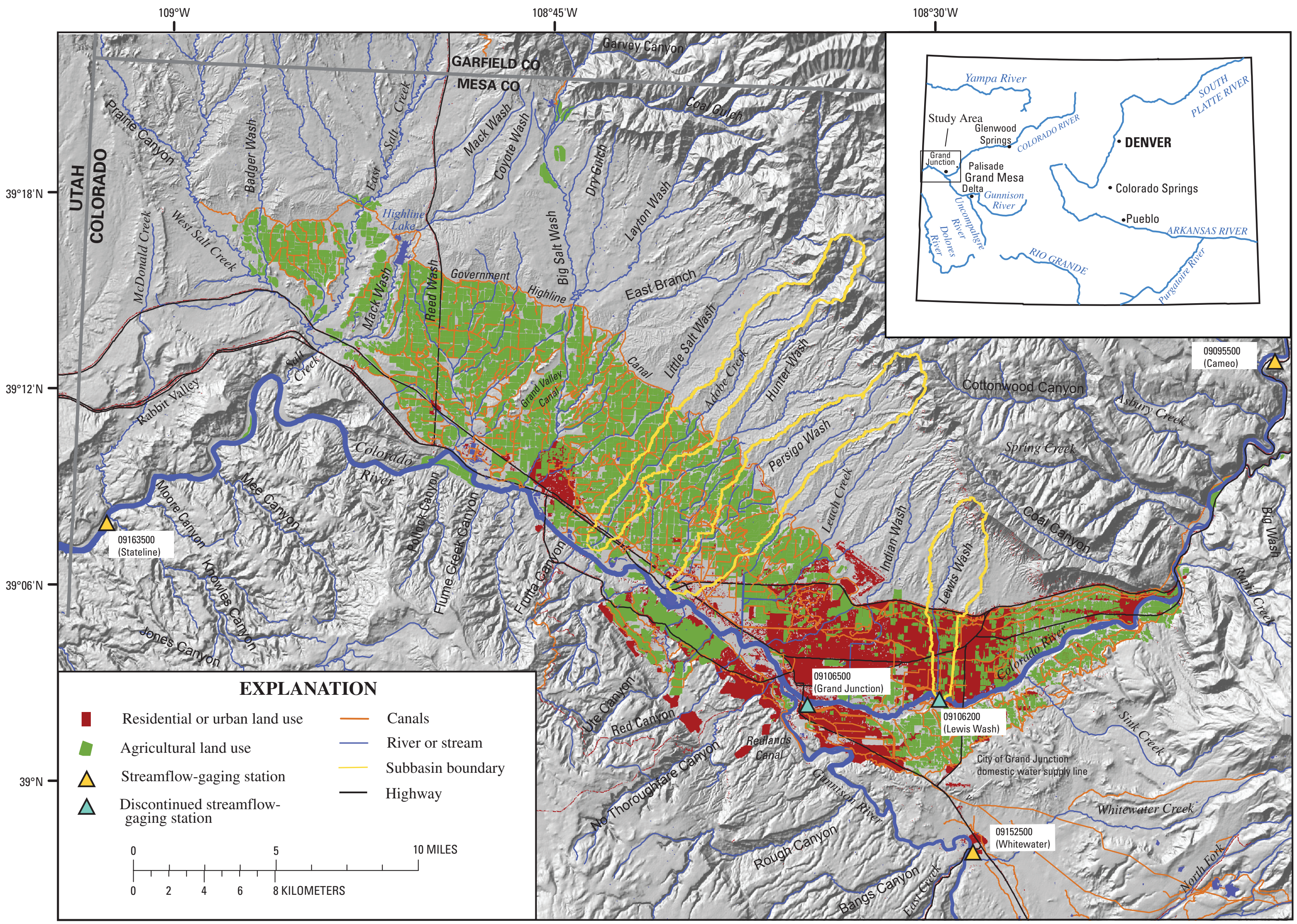
Elevated concentrations of dissolved selenium in tributaries and main-stem reaches of the Colorado River in the Grand Valley region of western Colorado are an ongoing concern to local, State, and Federal agencies, local water providers, and landowners. This concern stems from a need to address regulatory water-quality issues and impairment of native fish habitat. The Colorado River (from the Gunnison River confluence to the Utah border) and tributaries to the Colorado River in the Grand Valley are on the State of Colorado 303(d) list of impaired water bodies (Colorado Department of Public Health and Environment, 2006). These tributaries and segments of the Colorado River are listed as impaired because dissolved selenium values at these locations exceed the State of Colorado chronic selenium standard of 4.6 micrograms per liter (µg/L) at the 85th percentile level. Selenium is a trace element that bioaccumulates in aquatic food chains and has been shown to cause reproductive failure, deformities, and other adverse impacts in fish, including some threatened and endangered fish species (Hamilton, 1998; Lemly, 2002). The Colorado River, and parts of the river's tributaries in the Grand Valley that are within the 100-year flood plain of the river, are designated critical habitat for four fish species (Colorado Pikeminnow, Razorback Sucker, Bonytail, and Humpback Chub) that are listed under the Endangered Species Act.

Selenium exists naturally in the Mancos Shale and in Mancos Shale-derived soils common to the Grand Valley. Studies in the Grand and Gunnison Valley regions of western Colorado (Butler, 2001; Butler and Leib, 2002) indicate that selenium mobilization occurs primarily in shallow aquifers and results from deep percolation from irrigation and seepage of irrigation water from unlined canals. Water in shallow aquifers is a diffuse nonpoint source of return flow to tributaries and the Colorado River, thus making it difficult to determine source locations of selenium loading. Irrigation is common in the Grand Valley in agricultural and urban settings. With the exception of the Gunnison River, the majority of selenium load to the Colorado River in the Grand Valley comes from tributaries on the north side of the valley (fig. 1), particularly those from Persigo Wash downstream to Badger Wash that are underlain by Mancos Shale. Most of the historical water-quality data for these tributaries has been collected at the outflow or mouth of each tributary; therefore, little is known about specific selenium-loading source locations within the individual tributary subbasins. The steady transition from agricultural land use to residential and urban land use (fig. 1) is expected to continue in the Grand Valley. How this transition will affect selenium levels in rivers and streams of the Grand Valley is uncertain.

A local watershed initiative to address the selenium issue in the Grand Valley was established in 2002 through the formation of the Grand Valley Selenium Task Force (GVSTF). This group, consisting of local, State, and Federal interests, examines potential remediation scenarios and best-management practices designed to help address the selenium issue in the Grand Valley. The GVSTF has identified a need to characterize selenium sources in tributaries that have large loads and high concentrations of selenium. The GVSTF also identified a need to investigate how land-use change, particularly the conversion from agricultural to urban uses, will affect selenium loads and concentrations. In response to the needs identified by the GVSTF, the U.S. Geological Survey (USGS), in cooperation with Mesa County and the City of Grand Junction, developed a study to characterize selenium-loading sources in three tributaries to the Colorado River in order to identify selenium sources and how these sources may relate to land-use changes in the Grand Valley.

Purpose and Scope

The purpose of this report is to describe the study methods and results of a characterization study of concentrations and loads of selenium in three tributaries to the Colorado River in the Grand Valley. The study area consists of three subbasins—Persigo Wash, Adobe Creek, and Lewis Wash—each representing transitional agricultural to urban, agricultural, and urban land-use types, respectively. These subbasins were selected because they represent different land-use types and because the tributaries that drain each subbasin contribute moderate to high concentrations and loads of selenium to the Colorado River. Six sampling trips were conducted from December 2004 through March 2006 to collect information needed to characterize selenium sources within each tributary subbasin. Of the six trips, two were conducted on each tributary, one in early winter and one in early spring. Water samples were collected for analysis of dissolved selenium, total nitrogen, and total dissolved solids (hereinafter referred to as "salinity"). Concentrations of total nitrogen and salinity



Base from U.S. Geological Survey 1:24,000 digital data,
National Elevation Data, National Hydrography Data,
National Land Use CoverData, date 2001, 1983 North
American Datum, Universal Transverse Mercator projection,
Zone 13

Figure 1. Subbasin locations and major land-use types in the Grand Valley, western Colorado.

can covary with selenium concentration and load (Butler and others, 1996) and thus were deemed important constituents to analyze for this study. Streamflow was measured by using the tracer-dilution and standard current-meter methods. Where practical to use, the tracer-dilution method (Zellweger and others, 1989; Kimball, 1996) was considered to be the most accurate way to measure streamflow given stream channel conditions (silts and clays) and the small streamflow rates typical of each tributary. The sample data were analyzed and high loading areas in each tributary subbasin are discussed and reported. An historical account of land-use change and salinity control in the study area also is provided.

Acknowledgments

The author of this report acknowledges with appreciation the following individuals involved in this study. Thanks to Craig Muelot, Travis Brophy, and Blair Rollins from Mesa State College who volunteered their time assisting with sample collection and laboratory work; to Eileen List (City of Grand Junction) and Mike Baker (U.S. Bureau of Reclamation) for providing review comments; and to the Grand Valley Selenium Task Force for providing insight during the development, implementation, and interpretive stages of the study. Special thanks are extended to Rick Krueger (U.S. Fish and Wildlife Service) and David Butler (USGS, retired) for providing technical reviews.

The Grand Valley Region

The Grand Valley region is situated along the Colorado River in western Colorado in Mesa County (fig. 1). The Grand Valley region is informally defined in this report as the area shown in figure 1, and is referred to as “the Grand Valley” for the remainder of the report. The elevation near the confluence of the Colorado and Gunnison Rivers is approximately 4,550 ft. The population of the Grand Valley was about 127,000 people in 2004 (Colorado Department of Local Affairs, 2006). This estimate includes the City of Grand Junction, which had a population of about 44,780 and is the largest city in Colorado west of the Continental Divide (Mesa County, 2006). The population of the Grand Valley is forecast to nearly double in size by 2025 (Mesa County, 2006). Various uses of Colorado River water (agricultural, domestic, industrial, and recreational) by this increasing population in the Grand Valley have altered the historical patterns of streamflow, water quality, and wildlife habitat. Ground water is a little-used resource in the Grand Valley because it is either unavailable or its quality is poor to the degree that costly treatment would be needed for most uses.

Hydrologic conditions in the Grand Valley are complicated by an extensive system of Federal and private canal systems (fig. 1, shown in orange) that divert water from the Colorado and Gunnison Rivers and various small tributary streams. The Colorado River supplies the vast majority of irrigation source water in the Grand Valley. Domestic water in the Grand Valley is used for potable applications and as a supplemental irrigation supply for some residential users. Domestic water is supplied predominately from the Grand Mesa to the southeast (fig. 1) and the Colorado River. Industry and recreation use consume relatively small amounts of water compared to agriculture and domestic use. Three streamflow-gaging stations operated by the USGS: (1) station 09095500 Colorado River near Cameo, Colo. (hereinafter the “Cameo” station); (2) station 09152500 Gunnison River near Grand Junction, Colo. (hereinafter the “Whitewater” station); and (3) station 09163500 Colorado River near Colorado-Utah State line (hereinafter the “State-line” station), monitor the amount of water that enters and exits the Grand Valley in the Colorado and Gunnison Rivers (fig. 1, table 1). Information for selected discontinued stations also is included in table 1. Data from the discontinued stations as well as from the three currently (2007) active stations are used in this report.

Climate and Hydrology

Climate in the Grand Valley is semiarid. Average precipitation is about 8 in/yr (Doesken and others, 2006), with the majority occurring as monsoonal moisture from late summer through fall. Vegetation consists of native grasses and shrubs that are tolerant of the dry environment. Irrigated areas and riparian zones near perennial streams are home to native vegetation such as willows and cottonwood trees and nonnative vegetation like tamarisk.

Snowmelt runoff during late spring and early summer is the main source of streamflow to the Grand Valley. Precipitation during winter months in Colorado is stored as snowpack at high elevations and is a reliable source of water for residents of the Grand Valley and many other areas in the Western United States. Streamflow rates during the peak of the snowmelt runoff season (May-June) are typically much greater than streamflow rates during the rest of the year. Peak streamflow in the Colorado and Gunnison Rivers is attenuated somewhat as a result of reservoir storage and management; however, annual streamflows generally are unaffected. Transmountain diversions from the western to the eastern slope of the Continental Divide exceed 500,000 acre-ft/yr (Driver, 1994), which is approximately 11 percent of the annual total runoff volume at the State-line station.

During water years 2004-2006, annual streamflows at the Cameo and Whitewater stations contributed approximately 67 and 40 percent, respectively, of the annual streamflow at the State-line station, (U.S. Geological Survey, 2004-06). Combined percentages for the Cameo and Whitewater stations are greater than 100 percent of the volume of the State-line station total because of loss from consumptive water use within the Grand Valley and measurement error. The Bureau of Reclamation (USBR) estimates consumptive use in the Grand Valley to be approximately 5.5 percent of the total inflow into the Grand

Table 1. U.S. Geological Survey streamflow-gaging stations at selected sites in the Grand Valley, western Colorado.

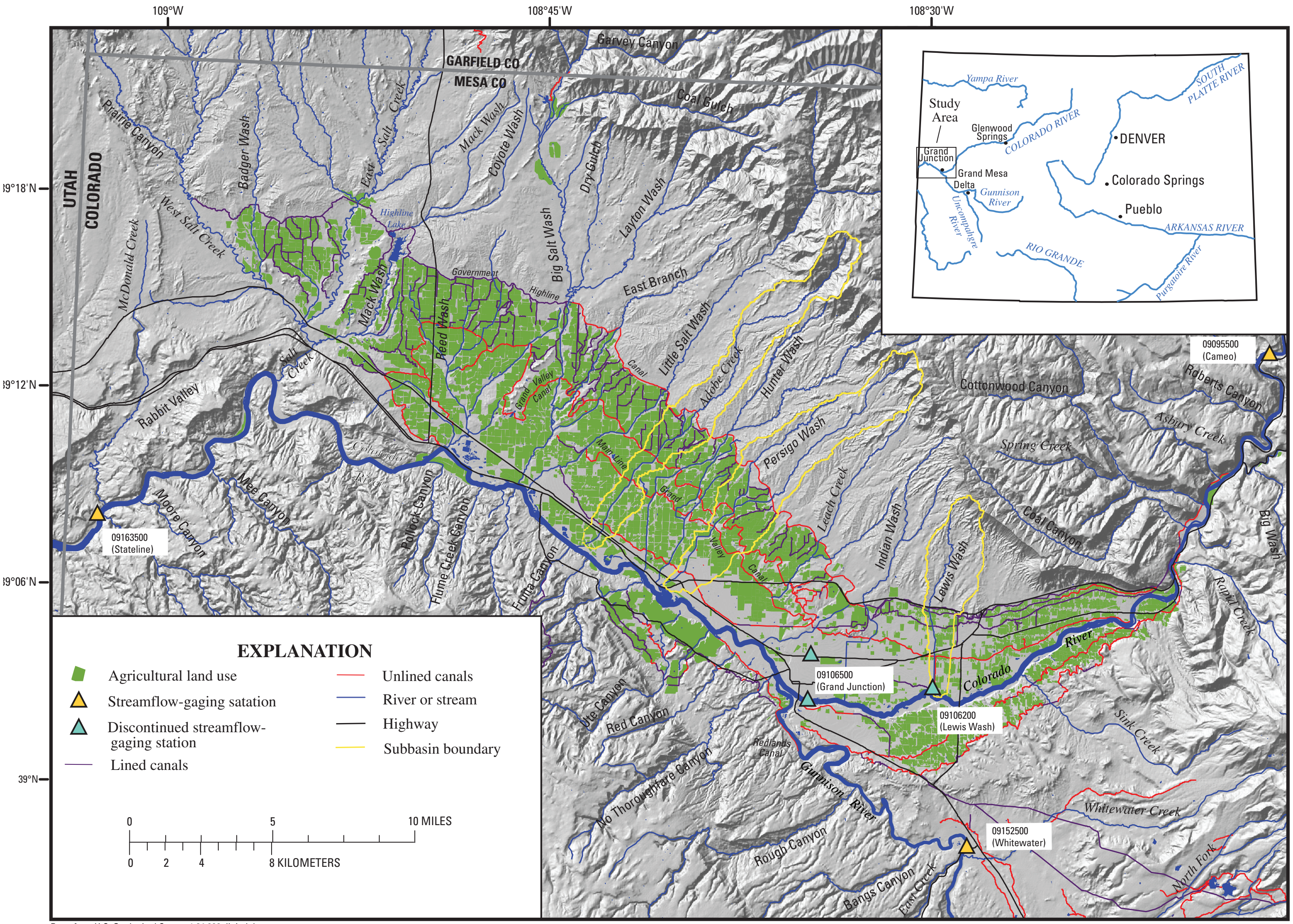
Station name	Station number	Station short name	Status
Colorado River near Cameo, Colo.	09095500	Cameo	Active
Lewis Wash at Grand Junction, Colo.	09106200	Lewis Wash	Discontinued
Colorado River at Grand Junction, Colo.	09106500	Grand Junction	Discontinued
Gunnison River near Grand Junction, Colo.	09152500	Whitewater	Active
Colorado River near Colorado-Utah State line	09163500	State line	Active

Valley (U.S. Bureau of Reclamation, 1986). On the basis of these estimates, it is reasonable to assume that the contribution to the streamflow of the Colorado River from within the Grand Valley is relatively small. This small contribution is due to the semiarid climate in the Grand Valley. Without a steady source of irrigation water from the Colorado and Gunnison Rivers, the Grand Valley would not be able to support the large agricultural community that currently exists. However, despite the small contribution of water from the Grand Valley itself, tributary streams downgradient from irrigated areas are perennial (flow year-round). This water is mostly sourced from the irrigation system and, if not totally consumed, returns to the Colorado River as ground or surface water. The ground water can seep directly from irrigation canals (seepage) or infiltrate below the plant root zone after being applied to crops (deep percolation). Water that returns to the Colorado River as surface water is typically irrigation return flow or administrative spill (where return flow is water that runs off of fields, and administrative spill is water that is delivered to other parts of a subbasin or excess water from the canal system). Therefore, without irrigation, it is likely that most of the tributary streams in the Grand Valley would be ephemeral and would flow only during periods of moderate to intense rainfall or snowmelt.

Irrigation

Three major canal systems, the Government Highline, Grand Valley, and Redlands Canals, are used to carry irrigation water to various locations in the Grand Valley (fig. 1). These three canals have a maximum combined capacity of approximately 3,230 ft^3/s. Also shown on figure 1 are GIS data layers that depict the spatial extent of agricultural land use (green) and residential land use (red) as of calendar year 2001 (Techni Graphic Systems, 2003). It is likely that the spatial extent of agricultural and residential land use has changed since 2001; however, the general extent of each type of use for the period of study (2004–2006) is represented by the 2001 data layers. The Government Highline and Grand Valley Canals supply Colorado River irrigation water to roughly 58,900 acres of agricultural land (Techni Graphic Systems, 2003), which is approximately 94 percent of the total amount of agricultural land in the Grand Valley. The Government Highline Canal, as the name indicates, services the highest elevations in the northern part of the Grand Valley, and the Grand Valley Canal supplies irrigation water to areas between the Government Highline service area and the Colorado River. Orchard Mesa, in the southeastern part of the Grand Valley, also is supplied by the Government Highline Canal through a diversion pipe that crosses the Colorado River just east of Palisade, Colo. The Redlands Canal supplies Gunnison River water to approximately 3,600 acres of agricultural land on the southwest side of the Colorado River (Techni Graphic Systems, 2003). The total amount of agricultural land serviced by these canals is nearly 62,500 acres. The Redland and Grand Valley Canals, and also the canal system for Orchard Mesa, are privately owned and managed by local companies. The Government Highline Canal is federally owned and is operated by the Grand Valley Water Users Association.

The Government Highline and the Grand Valley Canals flow through each of the three study area subbasins in the northern part of the Grand Valley (fig. 1). In Lewis Wash subbasin, the Government Highline Canal is lined with an impermeable membrane to prevent canal-water seepage. Other reaches of the Government Highline Canal also are lined but not in Adobe Creek or Persigo Wash subbasins (fig. 2). Additionally, most of the laterals that deliver irrigation water from the Government Highline Canal are carried in buried pipe in all three subbasins. This lining and piping work was done in the 1980’s and 1990’s by the USBR as part of the Colorado River Basin Salinity Control Program (U.S. Bureau of Reclamation, 1978; Butler, 1995). Other lining projects (predominately concrete) exist in the Grand Valley Canal system and in irrigation districts servicing areas south of the Colorado River (fig. 2). These projects were built by various ditch companies to prevent property or canal damage from excessive seepage and to conserve water in the canal system; however, the majority of the large non-Federal canal systems remain unlined in the Grand Valley. Note that various other smaller canal systems that branch from private canal systems in the Grand Valley exist but were not included in figure 2



Base from U.S. Geological Survey 1:24,000 digital data, National Elevation Data, National Hydrography Data, National Land Use CoverData, date 2001, 1983 North American Datum, Universal Transverse Mercator projection, Zone 13

Figure 2. Subbasin locations and canal lining in the Grand Valley, western Colorado.

because data were not available to determine if these smaller canals and laterals were lined or unlined.

Irrigation diversions from the Colorado River to each of the study area subbasins (and the Grand Valley in general) typically remain constant from year to year (fig. 3*A*). Annual return flows from irrigated lands also are fairly constant but can fluctuate with climatic conditions. Typically, if climatic conditions are wetter than normal, temperatures will be cooler and consumptive use will be lower (more return flow), whereas if climatic conditions are dryer than normal, temperatures will be hotter and consumptive use will be greater (less return flow). An example of this fluctuation in streamflow is shown for the Lewis Wash streamflow-gaging station in figure 3*B*. Streamflow at the Lewis Wash station for water years 1977 and 2002 was below average (2,940 and 3,260 acre-ft, respectively) during the irrigation season (April–October). These volumes equate to about 56 to 62 percent of the irrigation season average (5,230 acre-ft) at the Lewis Wash gage. The percentage of streamflow in the Colorado River at the State-line station for the same period of record during the irrigation season was approximately 33 percent of average for water year 2002 and 31 percent of average for water year 1977. There was a larger percentage of average streamflow in Lewis Wash (56–62 percent) compared to the Colorado River (31–33 percent) during drought conditions. The difference exists because under Colorado law, senior water rights in the Grand Valley mandate that streamflow from the Colorado River be diverted for irrigation purposes in the Grand Valley. Also shown in figure 3*B*, is the fluctuation of seasonal streamflow at the Lewis Wash station. During the irrigation season in the Grand Valley, streamflow in tributaries to the Colorado River increases substantially as a result of the delivered irrigation water. During the nonirrigation season (November–March), streamflow decreases rapidly to pre-irrigation levels and continues to steadily decrease as the soils in the irrigated areas drain out. Ground-water levels in shallow Mancos Shale aquifers tend to decrease gradually as does the rate of ground-water return flow during the nonirrigation season (Butler and others, 1996).

Water Quality

The most prevalent water-quality concerns in the Grand Valley are related to elevated concentrations of salinity and selenium in the Colorado River and tributaries to the Colorado. Elevated levels of these two constituents are directly attributable to the location and amount of irrigation in the Grand Valley. As mentioned previously, the concerns about selenium are driven by regulatory and aquatic health issues, whereas concerns regarding salinity are driven by regulatory provisions (Salinity Control Act, 1974, Public Law 93-320) and concerns of downstream users about the costs incurred from decreased crop production and treatment of river water with elevated salinity. Although the primary focus of this report is to characterize the sources of selenium, some discussion of salinity is included because efforts to control salinity mobilization also can help control selenium mobilization (Butler, 2001).

Chemical constituent data are presented in this report as concentration or load or both. Concentrations and loads of dissolved selenium are given in units of micrograms per liter (μg/L) and pounds per day (lb/d) respectively. Concentrations and loads of total nitrogen are given in milligrams per liter (mg/L) and pounds per day, whereas concentrations and loads of salinity are given in units of milligrams per liter and tons per day (ton/d) respectively. These units are the most commonly used units of measure for these constituents in the Grand Valley region. Concentration values are important for tracking standard exceedances and also for assessing levels of stream toxicity for aquatic biota. Load values are used to determine the relative amounts of each constituent contributed by different source areas and often are represented as relative percentages of a total end-point load. Load is calculated by using the following equation:

$$L = (C)(Q)(\text{unit conversion constant}), \qquad (1)$$

where

L is constituent load in pounds per day or tons per day depending on constituent type,

C is constituent concentration in micrograms per liter for selenium or milligrams per liter for salinity,

Q is streamflow in cubic feet per second, and the constant is 0.0054 for pounds per day units and 0.0027 for tons per day units.

Tributary streams to the Colorado River in the Grand Valley that have the highest selenium and salinity concentrations tend to be those in subbasins that have large tracts of agricultural or residential development and extensive outcrops of, and soils derived from, the Mancos Shale. Volcanic ash layers that occur as interbeds throughout the Mancos Shale could be the source of selenium and other trace constituents in the Grand Valley (Butler and others, 1996). Sources of salinity in the Mancos Shale most likely originated from evapoconcentration associated with the recession of the brackish waters of the Western Interior Seaway. The salinity and selenium stored in the Mancos Shale, however, are not harmful to the aquatic environment while in situ. Water is needed to mobilize the salinity and selenium stored in the Mancos Shale. Water comes in the form of precipitation or it is diverted and delivered from the Colorado and Gunnison Rivers for irrigation of residential and agricultural areas. During the process of delivering and applying irrigation water, some of the water remains on the land surface and becomes “tail water,” and some is lost to the ground-water system as seepage (from the delivery system) or deep percolation (irrigation water that percolates below the crop root zone and is not consumed). As the unused irrigation water moves over the land surface or through the subsurface as ground water, it mobilizes salinity and selenium by mechanical or chemical means. Without irrigation water, the rate of mobilization and loading of salinity and selenium from the Mancos Shale would be greatly reduced because

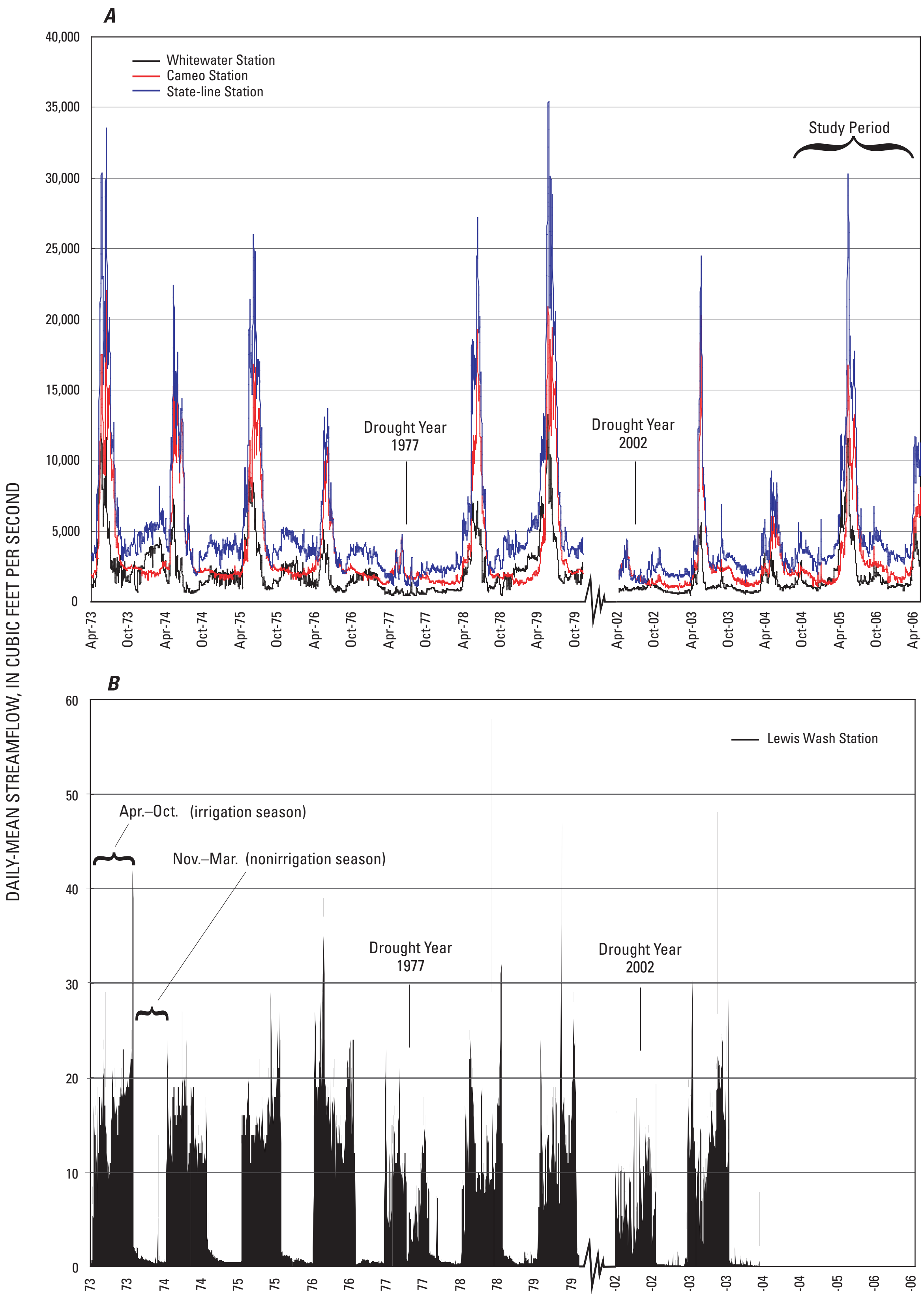


Figure 3. (*A*) Daily-mean streamflow at selected streamflow-gaging station, 1973–1979, and 2002–2006; and (*B*) daily-mean streamflow at Lewis Wash streamflow-gaging station, 1973–1979 and 2002–2004, Grand Valley, western Colorado.

only water that originated as precipitation would be available. Approximately 8 inches of precipitation falls in the Grand Valley annually, whereas the applied irrigation water averages about 54 inches annually (U.S. Bureau of Reclamation, 1978).

Concentrations and loads of salinity and selenium vary spatially and seasonally in the Colorado and Gunnison Rivers in Grand Valley (fig. 4). Spatially, concentrations and loads of selenium tend to be higher in the Colorado River downstream from the confluence of the Colorado and Gunnison Rivers. In large part this is due to the chemical composition of water in the Gunnison River (based on data collected at the Whitewater station). Concentrations and loads of selenium measured at the Whitewater station are considerably higher than the concentrations and loads measured in the Colorado River upstream from the Gunnison River at the Cameo and Grand Junction stations (fig. 4*A*). There are several thousand acres of irrigated land between the Cameo and Grand Junction stations that could potentially be a source of selenium to the Colorado River; however, data for water years 1994–1995 (period of record at the Grand Junction station) indicate there is not a substantial increase in selenium levels between the stations. Selenium loads are highest at the State-line station; however, concentrations are typically less than those observed at the Whitewater station. For water years 1994–1995 (fig. 4), approximately 38 percent of the median selenium load at the State-line station originated from within the Grand Valley, 55 percent originated from the Gunnison River basin, and 7 percent originated from areas upstream from the Grand Valley. For water years 2005-2006, approximately 47 percent of the median selenium load at the State-line station originated from within the Grand Valley, 46 percent originated from the Gunnison River basin, and 7 percent originated from areas upstream from the Grand Valley. The most recent 10 years of selenium record at the time this report was written (water years 1997–2006, not shown in fig. 4) indicates that approximately 41 percent of the median selenium load at the State-line station originated from within the Grand Valley, 52 percent originated from the Gunnison River basin, and 7 percent originated from areas upstream from the Grand Valley. Note that selenium samples were collected at different intervals during the historical period of record. As a result, the variability in the relative percentages of selenium load reported from each source area may be higher than if all the data were collected during the same period.

Concentrations and loads of salinity, unlike selenium, are similar at the Cameo and Whitewater stations (fig. 4*B*). The Cameo station has salinity levels comparable to those at the Whitewater station partly because of a large natural source of salinity around the Glenwood Springs region. Many saline springs in this region drain a geologic formation known as the Eagle Valley Evaporite. The salinity load from the Eagle Valley Evaporite accounts for approximately 60 percent of the salinity load at the Cameo station (Chafin, 2002). Salinity levels at the Whitewater station are not affected by the Eagle Valley Evaporite; however, salinity loads are comparable to those observed at the Cameo station because of the large area of irrigated land upstream from the Whitewater station (primarily marine shales of Cretaceous age including, the Mancos Shale). For water years 1994–1995 (fig. 4), approximately 9 percent of the median salinity load at the State-line station originated from within the Grand Valley, 45 percent originated from the Gunnison River basin, and 46 percent originated from areas upstream from the Grand Valley. For water years 2005–2006 (fig, 4*B*), approximately 29 percent of the median salinity load at the State-line station originated from within the Grand Valley, 32 percent originated from the Gunnison River basin, and 39 percent originated from areas upstream from the Grand Valley. The most recent 10 years of salinity record at the time this report was written (water years 1997–2006, not shown in fig. 4) indicates that approximately 21 percent of the median salinity load at the State-line station originated from within the Grand Valley, 34 percent originated from the Gunnison River basin, and 45 percent originated from areas upstream from the Grand Valley. Note that the relative proportions of salinity load to and from the Grand Valley region are highly variable among the different periods. The low percentage of salinity load contributed by the Grand Valley from 1994–1995 likely was due to the large annual snowpack and subsequent spring runoff that water year; therefore, it is likely that the overall contribution of salinity load from the Grand Valley did not decrease, but the relative contributions from areas upstream did. As with selenium, different sampling intervals may result in an increase in the variability in the relative percentages of salinity load reported from each source area.

Characterization of Selenium Concentrations and Loads

Three subbasin tributaries to the Colorado River within the Grand Valley—Persigo Wash, Adobe Creek, and Lewis Wash—were selected for study on the basis of different land-use characteristics and the moderate to high levels of selenium each tributary contributes to the Colorado. The USGS and the State of Colorado Water Quality Control Division have collected historical data at the mouths of these tributaries in the past, and much is known about the relative contributions of selenium from each stream to the Colorado River. Little was known, however, about specific sources of selenium within each subbasin. To better define the source areas of selenium within each subbasin, the USGS conducted six sampling trips to the subbasins from 2004–2006.

Study Methods

Water samples and field measurements were collected in a synoptic approach during each sampling trip to the subbasin tributaries. The water-quality data were collected at multiple points along a stream within a short period, typically 4–8 hours, to provide a “snapshot” of conditions over a long

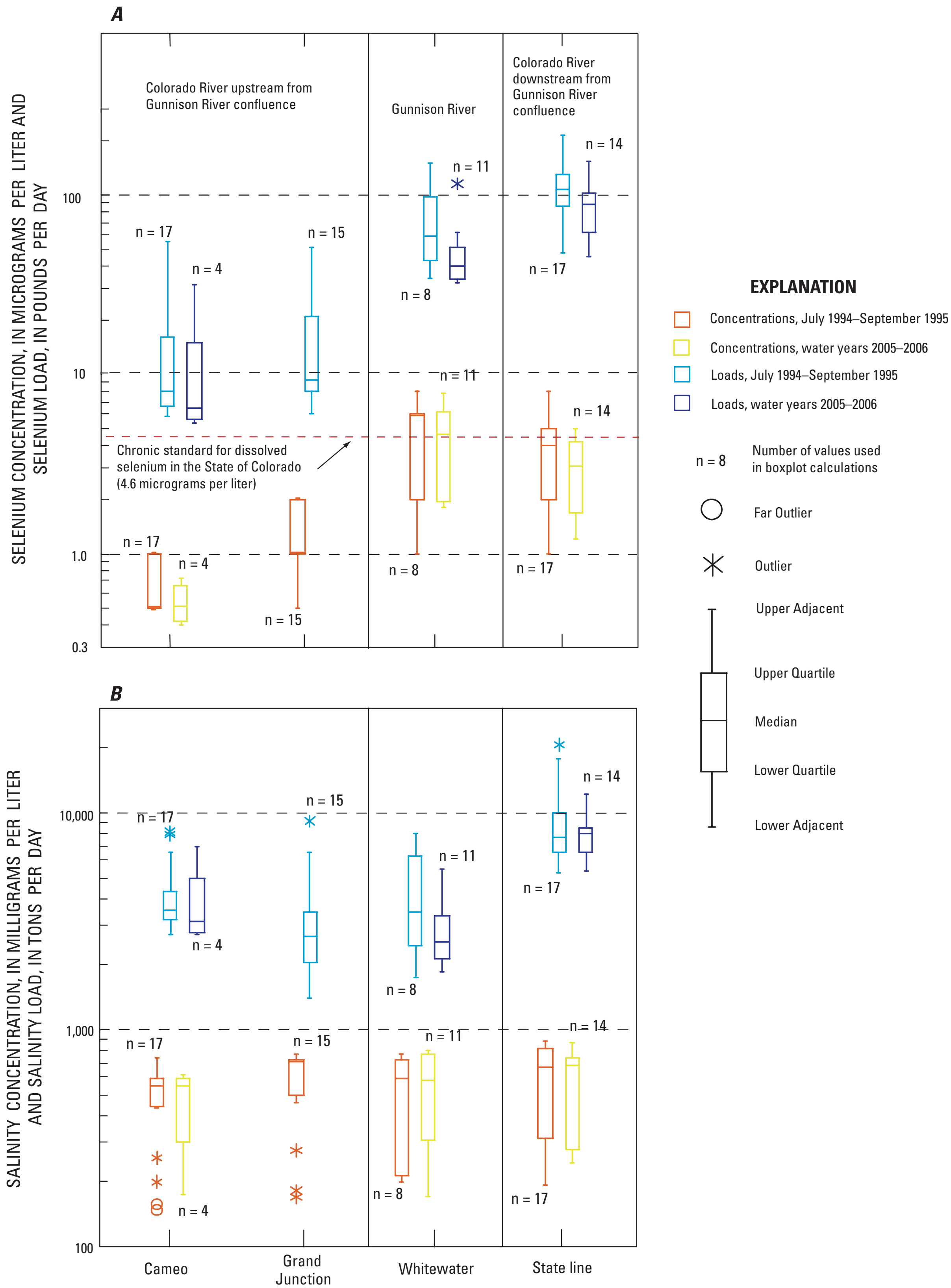


Figure 4. Distribution of (*A*) selenium concentrations and loads, and (*B*) salinity concentrations and loads, in mainstem rivers of the Grand Valley, western Colorado.

reach of the stream. Because multiple synoptics can provide information on temporal variations in stream-water quality, the tributary streams were sampled at both early and later parts of the nonirrigation season, which typically extends from the beginning of November through the end of March of the following calendar year. A sampling program that is designed to identify diffuse ground-water inflow to a stream or nonpoint sources of a given chemical constituent is generally conducted during the nonirrigation season in order to avoid having to adjust streamflow measurements and analytical results (chemical concentrations) for the effects of diversions from the canal system. Canal water that is routed through multiple diversion points to a given sampling reach can result in an erroneous interpretation of observed increases or decreases in concentrations and loads. Also, all canal diversions that affect the sampling reach during the irrigation season must be considered and accounted for, which can greatly increase the number of required sampling points for a given synoptic sampling event. The 2004 and 2005 sampling events were the most comprehensive and are described in detail in the following sections. Follow-up sampling was done in 2006 to confirm findings of the first three synoptics and to provide additional data to characterize conditions during the nonirrigation season. The water-quality and streamflow data collected during the synoptic sampling are stored in the USGS National Water Quality Information system (NWIS) database and can be retrieved from the World Wide Web at URL: *http://waterdata.usgs.gov/nwis*

Each synoptic included the collection of water samples and field measurements at all sites (appendix) along the entire flowing reach of each subbasin tributary and also any surface water inflows such as tributaries, seeps, and piped inlets that were observed. The synoptic included field measurements of streamflow, temperature, dissolved oxygen, and specific conductance, as well as collection of water samples for analysis of dissolved selenium, major ions (used for the calculation of salinity concentration), and total nitrogen. Dissolved selenium samples were collected at all sites, and salinity and nutrient samples were collected at sites where inflows were present or a change in land use was apparent. Field measurements were made using methods described by Wilde and others (2003). Laboratory analysis of dissolved selenium, major ions, and total nitrogen were done by the USGS National Water-Quality Laboratory in Denver, Colorado, using procedures described by Garbarino and others (2006) for dissolved selenium and by Fishman and Friedman (1989) for other inorganic constituents.

Streamflow measurements were made using the tracer-dilution method (Zellweger and others, 1989; Kimball, 1996), standard current-meter methods (Rantz and others, 1982), or volumetrically (Rantz and others, 1982) depending on logistics and the data resolution required for each synoptic. Sodium bromide (NaBr) was chosen as the tracer injectate because of the low background levels of bromide (Br) in each of the subbasin tributaries. In the final analysis, the concentration of Br was used to calculate streamflow. The tracer dilution method was preferred for the 2004 to 2005 synoptics because the method allows for high precision and a large number of samples to be collected in a relatively short period. The short sampling period is desirable because synoptic studies are designed to take a snapshot of stream conditions so that variations in the rate of streamflow are minimized. Thus, the shorter the sampling period, the higher the likelihood for steady-state conditions, particularly if the synoptic study is conducted during the nonirrigation season (as was the case for this study). The current-meter method was used for the 2006 synoptics when the requirement for steady-state streamflow conditions was less likely to be compromised because fewer samples were collected in each subbasin tributary. The volumetric method of streamflow measurement was used when streamflows were too small to be measured with a current meter and the flow being measured emanated from a pipe or a culvert.

All data are presented with error estimates (concentration) or compounded-error estimates (streamflow and load). Estimates of streamflow error for the tracer-dilution method were calculated using error propagation techniques described in Williams and Leib (2005). Error is introduced into the tracer-dilution method when the injection rates of NaBr fluctuate and when laboratory analysis of bromide concentration varies in quality-assurance replicates. Errors for current-meter measurements were estimated using guidelines described by Rantz and others (1982). Error estimates for current meter measurements are less quantitative than those used for the tracer-dilution method in that they are based primarily on considerations of channel type (rock, cobble, sand, mud), uniformity of streamflow and velocity in a given measurement section, presence of ice, and bank conditions (such as undercut banks and weeds). Based on the presence or absence of each of the aforementioned conditions during a current-meter measurement, an estimate of error (typically from 8 to 15 percent) is made by the individual making the measurement. The error associated with concentration of a constituent of interest in a water sample is not a compounded value, but rather a direct measurement of the precision associated with multiple analytical results from one sample location (replication). Replication in this instance is the process of collecting a stream water sample and providing two separate aliquots for laboratory analysis. Two replicate pairs were collected in each subbasin. Salinity replicates differed from 17 to less than 0.01 mg/L, and selenium replicates differed from 8.1 to less than 0.01 µg/L. The standard deviation of major ions used in the salinity-replicate analysis ranged from 5.7 to 0.02 mg/L, and the standard deviation for selenium was 2.1 µg/L. This process tests the precision associated with the instrumentation used for the analysis. These results then are used to calculate standard deviations for use in propagating the error associated with the load calculations. For load calculations, the error associated with the streamflow measurement (by either the tracer-dilution or current-meter method) is compounded with the error associated with the laboratory analysis for the constituent concentration of interest. The calculation of compounded error for load estimates is based on the following equation from Taylor (1997):

$$Le = \left(\sqrt{\left(\frac{Qe}{Q}\right) + \left(\frac{Ce}{C}\right)^2}\right) CL, \qquad (2)$$

where

- Le is the compounded error for constituent load,
- Qe is the error of the streamflow measurement,
- Q is the measured streamflow,
- Ce is the error of the concentration value,
- C is the measured constituent concentration, and
- CL is the measured load.

Error estimates are used as an indicator of the accuracy of the measured streamflow, constituent concentration, or loading value. The error estimates provided in this report give a range of values that are most likely to contain the true value for the sample or measurement of interest and are depicted by using error bars in the graphs presented in the following sections. The smaller the range of error, the more accurate will be the streamflow, concentration, or loading values.

Persigo Wash

Streamflow and water-quality data were collected at selected sites along the entire flowing part of Persigo Wash on November 21, 2004, and March 7, 2006 (fig. 5). The tracer-dilution method was used to measure streamflows in November. A total of 23 samples were collected for the analysis of selenium, 17 for determination of streamflow, and 6 for the analysis of salinity and total nitrogen. Five tributaries to Persigo Wash were sampled and 17 sites were sampled on the main stem. The current-meter method was used to measure streamflow in March 2006; no tributary samples were collected, and six main-stem sites were sampled for analysis of selenium and total nitrogen. Salinity concentrations were calculated for the March 2006 synoptic. A relation between specific conductance and salinity (sampled in November 2004) was established using simple linear regression. Specific-conductance values from the March 2006 synoptic were used as explanatory variables in the simple linear regression equation to estimate salinity (Helsel and Hirsch, 2002).

Streamflow, as well as selenium, salinity, and nutrient concentrations and loads at each main stem and tributary site (where applicable), are shown in figure 6. The appendix lists the full USGS station name and number for each site shown in figure 6.

During the November 2004 synoptic, concentrations of selenium in Persigo Wash generally decreased in a downstream direction whereas loads increased (fig. 6, *A* and *B*). The highest concentrations of selenium in Persigo Wash were sampled from the inflow of two unnamed tributaries (PT80 and PT75) in the upper part of the subbasin, near J Road. The concentrations measured at PT80 (95.5 µg/L) and PT75 (127 µg/L) were approximately seven to nine times greater than concentrations measured at the mouth of Persigo Wash (P1, 14.2 µg/L). Selenium concentration measured at site P73 (78.4 µg/L), the main-stem site on Persigo Wash just downstream from tributaries PT80 and PT75, also was elevated relative to other reaches in Persigo Wash. Concentrations in main-stem samples downstream from the two tributaries decreased steadily between sites P73 and P50, at which point selenium concentrations generally remained stable between sites P50 and P20 at about 35 to 46 µg/L. The pattern in the concentration data indicates that selenium concentrations upstream from site P73 and the Grand Valley and Main Line Grand Valley Canals (collectively referred to as "the Grand Valley Canal System") may be higher because the geology and soils in this area are higher in selenium. The increase in streamflow in Persigo Wash downstream from site P73 has a dilution effect on the higher selenium concentrations observed upstream from site P73. Seepage and deep percolation to Persigo Wash from canals and irrigated lands are a likely source of the increased streamflow.

Effluent from the Persigo Wash Wastewater Treatment Plant (WWTP) flows into Persigo Wash near its mouth, at sample site PT15 (fig. 5). Site P20 is approximately 15 ft upstream from the WWTP outfall, and site P1 is approximately 300 ft downstream near the mouth of Persigo Wash. Analysis of samples from November 2004 indicate that inflow of the WWTP effluent caused a decrease in (dilutes) the concentration of selenium in Persigo Wash from 46.2 µg/L at site P20 to 14.2 µg/L at site P1, but contributed to an increase in the selenium load of approximately 0.19 lb/d. The decrease in selenium concentration in Persigo Wash is a result of the much lower concentration in the effluent, which is generally in the range of 2 to 3 µg/L (Joe Holcomb, City of Grand Junction, written commun., 2007). Thus, the selenium load (to Persigo Wash) from the WWTP effluent is governed primarily by the rate of effluent discharge rather than variations in selenium concentration. Rates of effluent discharge vary throughout the day, but are generally greatest in late morning and late evening (Eileen List, City of Grand Junction, oral commun., 2007).

Selenium loads in Persigo Wash generally increased downstream and were highest near the mouth. Two reaches of Persigo Wash, between sites P80 and P73 and sites between P65 and P45, showed the largest increases. The P80 to P73 reach is downgradient from the Government Highline Canal, which is unlined in the Persigo Wash subbasin (fig. 2). The P80 to P73 reach is approximately 1,300 ft in length and has two tributaries that drain to it. In November 2004, selenium load from tributaries and ground water in this reach increased the selenium load in Persigo Wash from 0.125 lb/d at site P80 to 0.67 lb/d at site P73 (fig. 6*B*). The load at site P73 accounted for about 48 percent of the total load at the mouth of Persigo Wash (site P1). The gain in streamflow in the P80 to P73 reach was 0.65 ft^3/s, or about 3.6 percent of the total flow at site P1 near the mouth of Persigo Wash. The surface- and ground-water sources are predominantly from diffuse ground-water inflow from canal seepage and deep percolation from irrigated lands. The majority of the selenium load

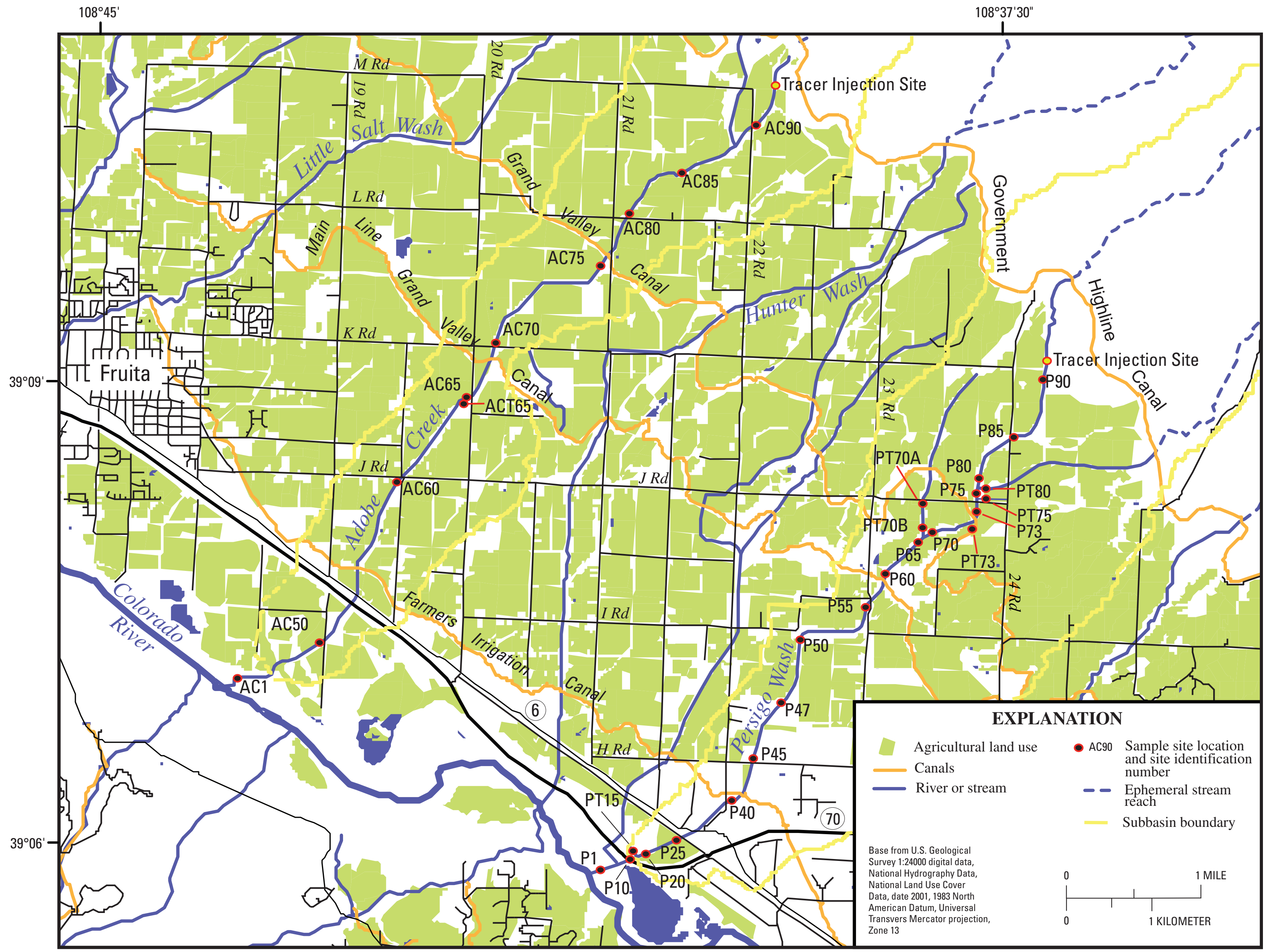


Figure 5. Location of synoptic sampling sites on Persigo Wash and Adobe Creek, Grand Valley, western Colorado.

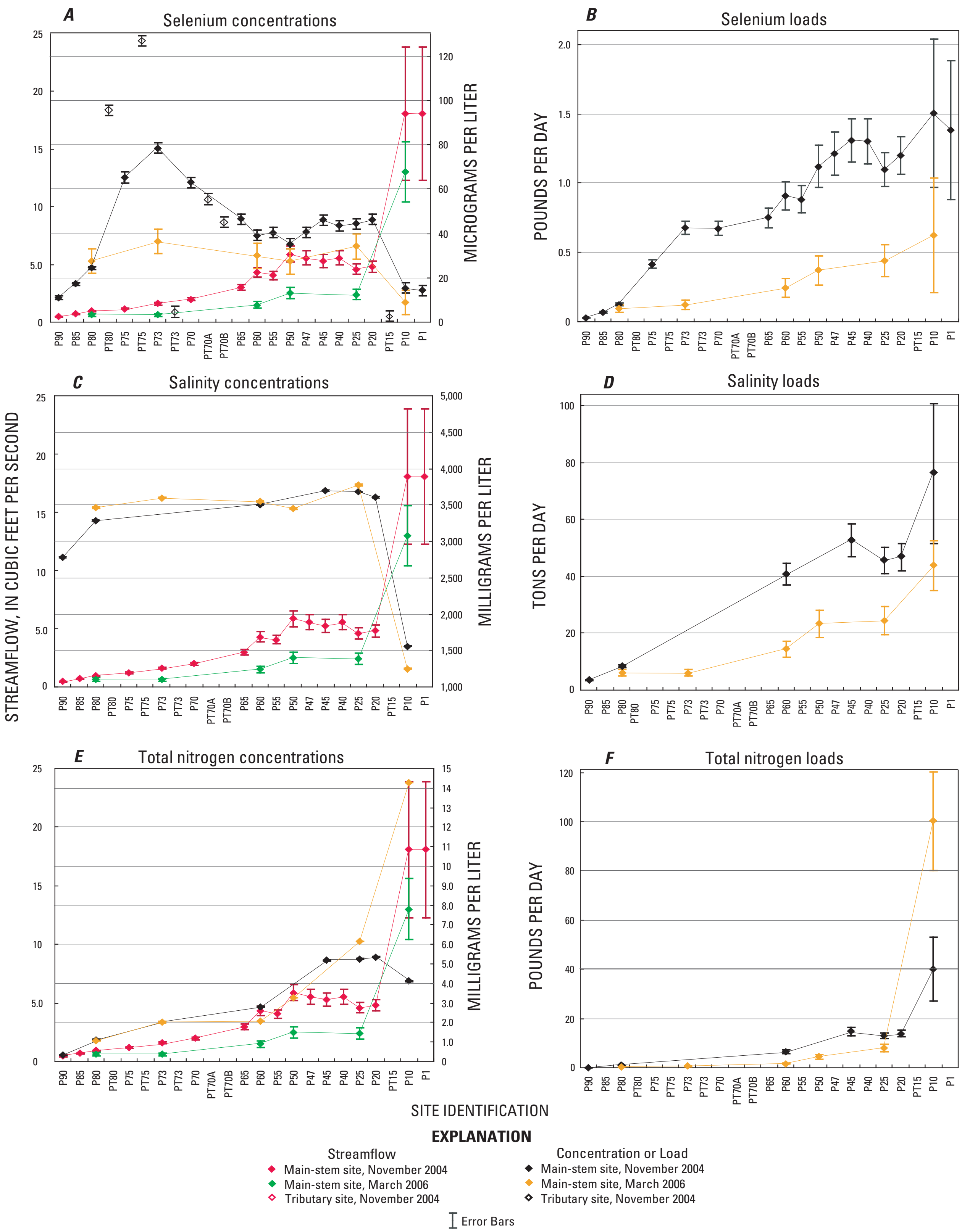


Figure 6. Results for the November 2004 and March 2006 synoptic-sampling in Persigo Wash, Grand Valley, western Colorado, for (*A*) streamflow and selenium concentrations, (*B*) selenium loads, (*C*) streamflow and salinity concentrations, (*D*) salinity loads, (*E*) streamflow and total nitrogen concentrations, and (*F*) total nitrogen loads.

increase between sites P80 and P73 is likely from the east side of Persigo Wash basin. This assumption is supported by the amount of drainage area to the east of the P80 to P73 reach and the presence of the two east-side tributaries. No inflow from the west side of Persigo Wash was identified in the P80 to P73 reach.

The increase in selenium load in the P65 to P45 (approximately 7,900 ft in length) reach during the November 2004 synoptic was similar to that of the P80 to P73 reach. However, there were no identifiable tributaries in the P65 to P45 reach. Selenium loads in this reach increased steadily from 0.75 lb/d at site P65 to 1.30 lb/d at site P45 (fig. 6*B)*. The increase in selenium load most likely can be attributed to canal seepage and deep percolation. Seepage and deep percolation occur during the irrigation season (April through October), but the water that is recharged to the ground-water system (via seepage and deep percolation) continues to drain out during the nonirrigation season, mobilizing selenium and salinity in the process. Rainfall during the night prior to the November 21 sampling synoptic may have increased streamflows and selenium loads in the P65 to P45 reach relative to downstream sampling sites. The assertion that Persigo Wash streamflows and selenium loads may have been affected by the rain is based on field observations that indicated a decrease in the stream clarity of Persigo Wash. The decrease in stream clarity could likely be attributed to an increase in sediment to Persigo Wash from rainfall runoff. The rainfall runoff, in and of itself, should not increase the selenium load in Persigo Wash; however, rainfall runoff may have mobilized selenium contained in shallow soils or evaporative salt crusts. If runoff from the rain moved as a wave down Persigo Wash, and was encountered during sampling primarily in the P65 to P45 reach, then streamflows and selenium loads measured from P65 to P45 could have been uncharacteristically higher than at some of the downstream sampling sites.

The largest source of selenium load downstream from the P65 to P45 reach during the November 2004 synoptic was the WWTP. The WWTP contributed approximately 13.6 percent (0.19 lb/d) of the selenium load and 73 percent of the streamflow (13.3 ft^3/s) at site P1 near the mouth of Persigo Wash. Selenium loads from diffuse ground-water sources downstream from site P45 do not appear to be contributing an appreciable selenium load to Persigo Wash.

Selenium samples were collected at six sites during the March 2006 synoptic. Sites were selected based on areas of interest identified from the November 2004 synoptic. The sites were P80, P73, P60, P50, P25, and P10 (fig. 5). The P80 to P73 reach was selected so as to bracket the reach of Persigo Wash that contained the PT80 and PT75 tributaries, both of which had very high concentrations of selenium during the November 2004 synoptic. The P73 to P60 reach (approximately 2,640 ft in length) was selected because it brackets the Grand Valley Canals, and site P50 was selected because the largest increases in streamflow (with the exception of the WWTP inflow) in Persigo Wash occurred in the P73 to P50 reach during the November 2004 synoptic. Sites P25 and P10 were chosen to bracket the WWTP. Sites P25 and P10 also were selected because there were historical data available for comparison for each site.

Concentrations and loads of selenium observed during the March 2006 synoptic differed from those measured during the November 2004 synoptic (fig. 6*A* and *B*). Selenium concentrations did not vary much during the March 2006 synoptic among the six sites that were sampled. Generally, concentrations were about 30 μg/L, with the exception of site P10, where it was 8.9 μg/L (dilution effect from the WWTP discharge). Concentrations and loads of selenium were most dissimilar between the two synoptics at site P73, which is directly downstream from where tributaries PT80 and PT75 drain into Persigo Wash. Selenium concentrations measured during the November 2004 synoptic were in excess of 90 μg/L in both tributaries and caused a substantial increase in selenium concentration and load in the P80 to P73 reach. Concentrations and loads of selenium increased substantially less in this reach during the March 2006 synoptic. Site PT80 was dry during the March 2006 synoptic and site PT75 was flowing but was not measured because of debris in the channel. Streamflow was not directly measured at site PT80 during the November 2004 synoptic (main-stem sites were subtracted to estimate inflow in the reaches bracketing tributaries), but flowing water was observed. A smaller increase in selenium concentrations and loads during the March sampling (as compared to November) may indicate that areas highly concentrated in water soluble selenium have drained out by March, which is about 5 months after the end of the irrigation season. Further sampling in the PT80 and PT73 tributaries would help better identify areas where salinity/selenium control work could be most effective at reducing concentrations and loads of these constituents.

Streamflow measurements for the March 2006 synoptic confirmed the November 2004 finding that the P73 to P50 reach was still the reach of Persigo Wash where the majority of the increase in streamflow occurs, aside from the flow that discharges to Persigo Wash from the WWTP (fig. 6, *A*,*C* and *E*). No increase in streamflow was measured between sites P80 and P73 (0.64 and 0.62 ft^3/s, respectively) or between sites P50 and P25 (2.5 and 2.4 ft^3/s, respectively). The majority of selenium loading during the March 2006 synoptic occurred in the P73 to P50 reach (0.25 lb/d), with approximately 52 percent of that load occurring in the relatively short P60 to P50 reach (0.13 lb/d) (fig. 6*B*) By contrast, the increase in selenium load in the P80 to P73 reach was 0.03 lb/d and in the P50 to P25 reach was 0.07 lb/d. The results of the March 2006 synoptic are consistent with the previous assertion that seepage and deep percolation from canals and irrigated lands are likely increasing streamflow rates and lowering selenium concentrations in Persigo Wash downstream from site P73. The seepage and deep percolation may dilute the selenium concentrations seasonally in various reaches of Persigo Wash; however, the effect to the system is that selenium load increases.

Salinity samples were collected at seven sites during the November 2004 synoptic, and salinity concentration was calculated for six sites by using a regression equation (Helsel and Hirsch, 2002) of specific conductance on salinity for the March 2006 synoptic. Two of the sites sampled in November 2004 were dropped for the March 2006 synoptic and replaced with two other sites based on selenium sample results from the November 2004 synoptic (fig. 6*C*). In March 2006, site P90 was replaced with site P73 to better bracket the P80 to P73 reach where the high selenium tributaries drain into Persigo Wash. Site P45 was replaced by site P50 because streamflow gains were highest in the P73 to P50 reach during the November 2004 synoptic. Site P50 also was used to determine which part of the salinity load was entering Persigo Wash near the Main Line Grand Valley Canal in the P65 to P45 reach.

Salinity concentrations generally increased downstream and were nearly the same at all sites during both synoptics despite a decrease in streamflows during the March 2006 sampling (fig. 6*C*). The March 2006 data indicated that there was little increase in salinity concentration or load in the P80 to P73 reach (fig. 6*D*). During the November 2004 synoptic the salinity load at site P45 was higher than that at P25, which may have been due to additional load contributed by rainfall runoff. If it is assumed that salinity loads from the P45 and P25 sites are probably more similar than the November 2004 sample data indicated, then, based on the March 2006 synoptic, the majority of salinity loading in the P65 to P45 reach seems to occur between sites P60 and P50. A large increase in salinity load, for both synoptics occurred between sites P25 and P10, as a consequence of the WWTP discharge. However, the large increase in salinity load corresponds to a large decrease in salinity concentration because of the low salinity concentration in the treated effluent from the WWTP.

A ratio of selenium load to salinity load was developed for both synoptics. The selenium to salinity ratio is an estimate of the amount of selenium load reduction (in pounds) that might occur if salinity load were reduced by 1 ton. Therefore, the higher the ratio, the greater the potential for reducing selenium load coincident with salinity control efforts. The ratio of selenium load to salinity load for the November 2004 synoptic was 0.020 and the ratio for the March 2006 synoptic was 0.017 (table 2). A previous study in Montrose Arroyo in the Gunnison River Basin determined that the ratio of selenium to salinity was 0.040 (Butler, 2001). A salinity control project in Montrose Arroyo determined that the amount of selenium reduced by salinity control work was nearly twice what that ratio indicated. Therefore, it is suggested that the ratios presented in this study be considered only as a general indication of how selenium loads may respond to salinity control work.

Samples for analysis of total nitrogen were collected at seven sites during the November 2004 synoptic and at six sites during the March 2006 synoptic. Concentrations and loads of total nitrogen increased downstream (fig. 6, *E* and *F*). Concentrations and loads of selenium were related to concentrations and loads of total nitrogen for both synoptics by using simple linear regression (Helsel and Hirsch, 2002). The WWTP loads were excluded from the regression analysis because of the artificial nature of the selenium to total nitrogen correlation after treatment. Results indicated a good correlation for both concentrations and loads (R^2 = 0.80 and 0.83, respectively). Concentrations and loads of total nitrogen also correlated well with streamflow (R^2 = 0.89 and 0.99, respectively).

There are several possible reasons for the good correlations between selenium and total nitrogen. Selenium and nitrogen species may simply respond in a similar way chemically or mechanically where environmental controls such as redox potential, adsorption, bacterial process, and (or) ion exchange are concerned. However, evidence exists that indicates a direct link between nitrogen species and selenium. Weres and others (1989) showed that nitrate induces mildly oxidizing conditions and can inhibit microbial fixation of selenium. Nitrogen species such as nitrate and nitrite may inhibit the reduction of selenium as a result of preferential selection by bacteria, thus selenium levels may be elevated when nitrogen species are elevated (Oremland and others, 1989). Wright and Butler (1993) suggested that nitrate and nitrite species of nitrogen in ground water can act as mobilizing agents (oxidants) for selenium in the absence of oxygen. Although further investigation is needed, controlling the various sources of nitrogen in ground water may help reduce selenium in anaerobic conditions and control selenium mobilization to surface-water systems.

The increase in total nitrogen concentrations and loads in the P60 to P25 reach (fig. 6, *E* and *F*) could be a result of several factors including livestock, fertilizer application, and septic systems. Septic-system density in the lower part of Persigo Wash subbasin may be higher than in other areas of the subbasin because of residential development (fig. 1), thus causing an increase in total nitrogen in Persigo Wash. For both synoptics, the largest source of total nitrogen to Persigo Wash was from the WWTP (PT15), which increased the total nitrogen load from 13.8 to 40.2 lb/d for the November 2004 synoptic and from 8.0 to 100 lb/d during the March 2006 synoptic. Total nitrogen concentrations in the effluent from the WWTP were low enough to decrease the total nitrogen concentration in Persigo Wash (site P10) during the November 2004 synoptic from 5.3 to 4.1 mg/L. Total nitrogen concentrations were much higher in the WWTP effluent during the March 2006 synoptic and actually caused an increase in total nitrogen concentrations at site P10 from 6.2 to 14.3 mg/L.

Adobe Creek

Streamflow and water-quality data were collected at selected points along the entire flowing part of Adobe Creek on January 29, 2005, and March 8, 2006 (fig. 5). The tracer-dilution method was used to measure streamflows in January. A total of 10 samples were collected for the analysis of selenium, 10 for determination of streamflow, and 9 for the analysis of salinity and total nitrogen. One small tributary to Adobe Creek was sampled, and nine sites were sampled on the main stem of Adobe Creek. The current-meter method was used to measure streamflow in March 2006; six main-stem sites were sampled for selenium and total nitrogen, and no tributary samples were collected. Salinity concentrations were calculated for the March 2006 synoptic. A relation between specific conductance and salinity (sampled in January 2005) was established using simple linear regression (Helsel and Hirsch, 2002).

Streamflow, as well as selenium, salinity, and nutrient concentrations and loads at each main stem and tributary site (where applicable) are shown in figure 7. The appendix lists the full USGS station name and number for each site shown in figure 7. During the January 2005 synoptic, the tributary site (ACT65) was measured volumetrically. Therefore, streamflows, concentrations, and loads (fig. 7*A*, *B*, and *C*) are shown for the ACT65 tributary site, unlike other tributary sites where the tracer-dilution method was used to indirectly measure streamflow. Salinity concentrations were calculated for the March 2006 synoptic by using the same simple linear regression techniques as were used for Persigo Wash.

In general, concentrations and loads of selenium in Adobe Creek increased in a downstream direction (fig. 7, *A* and *B*), during the January 2005 synoptic. The highest concentration of selenium in Adobe Creek was sampled from the inflow of an unnamed tributary (ACT65) in the middle part of the subbasin near 20 Road (fig. 5). The concentration measured at ACT65 (120 µg/L) was about three times greater than concentrations measured near the mouth of Adobe Creek at site AC1 (38.5 µg/L). Selenium concentration measured at site AC60 (48.6 µg/L), a main-stem site downstream from the ACT65 inflow, had the highest selenium concentration of any main-stem site on Adobe Creek, although sites downstream from AC75 generally had similar concentrations to that of AC60 ranging from 35.8 to 45.9 µg/L. Selenium concentration and streamflow increased substantially in the AC75 (16.8 µg/L) to AC65 (45.9 µg/L) reach, relative to other parts of Adobe Creek. No flowing tributaries were observed in this section, so the source of the inflow most likely is diffuse ground-water inflow from canal seepage and deep percolation from irrigated lands. The AC75 to AC65 reach is loosely defined by the locations of the Grand Valley and Main Line Grand Valley Canals, which are both unlined in Adobe Creek subbasin. In Persigo Wash, selenium concentrations tended to decrease near the Grand Valley Canals during both synoptics; however, during the January 2005 synoptic in Adobe Creek, concentrations near the canals increased substantially as did streamflows.

Samples for the analysis of selenium were collected at six sites during the March 2006 synoptic. Sites were selected based on areas of interest identified from the January 2005 synoptic using the same criteria as was used for Persigo Wash where areas of elevated selenium load or increased streamflow were given priority. The sites were AC85, AC75, AC70, AC65, AC60, and AC1.

Selenium concentrations observed during the March 2006 synoptic were very similar to those observed during the January 2005. Streamflow, however, had a somewhat different pattern. In general during March 2006 synoptic, streamflow did not increase as much in the AC75 to AC65 reach (0.46 ft^3/s) compared to January 2005 (2.2 ft^3/s). During the March 2006 synoptic, in the AC70 to AC65 reach, selenium concentration increased but streamflow was about the same. This condition indicates that a chemical rather than a physical control may exist for selenium in this reach of Adobe Creek, or that there is a small but highly concentrated inflow that was not identified during the Adobe Creek reconnaissance prior to each synoptic.

Selenium loads in Adobe Creek generally increased downstream and were highest near the mouth during the January 2005 synoptic. The reach of Adobe Creek between sites AC75 and AC65 accounted for the largest loading increases. Selenium load in the AC75 to AC65 reach increased 0.72 lb/d. The AC75 to AC65 reach is approximately 8,600 ft (1.6 mi) in length and had no identifiable surface inflows during the January 2005 synoptic. The selenium-load increase between sites AC75 and AC65 accounted for about 81 percent of the total load at the mouth of Adobe Creek (site AC1). The gain in streamflow in the AC75 to AC65 reach was 2.19 ft^3/s, or about 52 percent of the total flow at site AC1 near the mouth of Adobe Creek. The disproportionate increase in selenium load compared to streamflow increase indicates that chemical and not just physical controls are governing the mobilization of selenium load in the AC75 to AC65 reach.

During the March 2006 synoptic, selenium loads increased downstream in similar manner as the January 2005 loads, but the increases were not as large in the AC75 to AC65 reach. Selenium loading in the AC75 to AC65 reach increased the selenium load in Adobe Creek from 0.08 lb/d at site AC75 to 0.32 lb/d at site AC65. The increase in selenium load between sites AC75 and AC65 accounted for about 47 percent of the total load at the mouth of Adobe Creek (site AC1). The gain in streamflow in the AC75 to AC65 reach was 0.46 ft^3/s, or about 19 percent of the total flow at site AC1. Also, during the March 2006 synoptic, selenium loads increased disproportionately to streamflow between sites AC70 and AC65, and indicates that chemical and physical controls may exist for selenium in this reach of Adobe Creek. Another loading source may be unidentified surface inflows that are highly concentrated with selenium. In general, selenium load increases calculated for both synoptics were greatest in the AC75 to AC60 reach (fig. 7*B*), with a relatively small amount of selenium loading occurring in the AC90 to AC75 and AC60 to AC1 (March 2006 only) reaches.

The large increases in streamflow in the AC75 to AC65 reach during the January 2005 synoptic most likely occurred as a result of canal seepage and deep percolation from irrigated land. The effects of seepage and deep percolation appear to be most prominent in the early part of the nonirrigation season judging from the relatively small increases in streamflow that occurred in the AC75 to A65 reach in March 2006. These results indicate that the seepage and deep percolation rates may be higher in Adobe Creek subbasin than in Persigo Wash subbasin. With high rates of seepage and deep percolation, irrigation water readily infiltrates from canals and irrigated lands to the ground-water system and ultimately the stream as diffuse ground-water inflow. High rates of seepage and

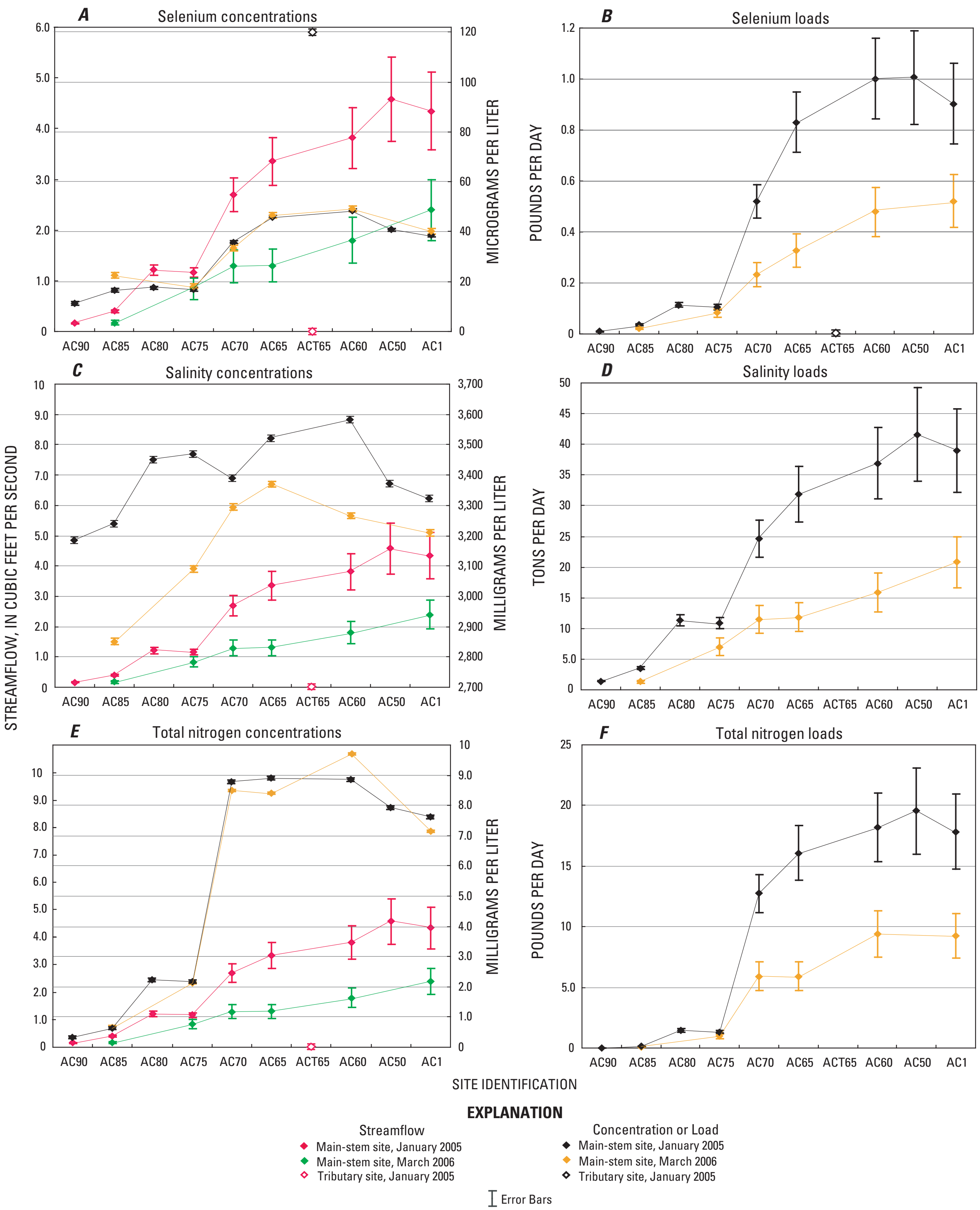


Figure 7. Results for the January 2006 and March 2006 synoptic-sampling in Adobe Creek, Grand Valley, western Colorado, for (*A*) streamflow and selenium concentrations, (*B*) selenium loads, (*C*) streamflow and salinity concentrations, (*D*) salinity loads, (*E*) streamflow and total nitrogen concentrations, and (*F*) total nitrogen loads.

deep percolation create the potential to mobilize selenium and salinity at an accelerated rate relative to other areas with lower seepage rates. Note that the length of canals and the amount of irrigated land, where canal length is used as a surrogate for seepage and irrigated land is used as a surrogate for deep percolation, in a given subbasin also may affect ground-water recharge (and ultimately streamflow). Although the amount of irrigated land in Persigo Wash and Adobe Creek upstream from the Main Line Grand Valley Canal is approximately the same, a longer segment of the Grand Valley and Main Line Grand Valley Canals are contained in Persigo Wash subbasin (fig. 2). The Grand Valley Canal system spans approximately 5.1 mi in Persigo Wash subbasin and 2.0 mi in Adobe Creek subbasin. Nevertheless, Persigo Wash and Adobe Creek have similar selenium and salinity loading rates in the area where each intersects the Grand Valley Canal system. Despite the similar loading rates, salinity-control efforts may be most cost effective in Adobe Creek because it is likely there would be a greater load reduction per unit area of treatment because of the suspected higher seepage and deep percolation rates. Further investigation is needed, however, to verify relatively higher seepage and deep percolation rates in Adobe Creek.

Salinity samples were collected at nine sites during the January 2005 synoptic. For the March 2006 synoptic, salinity values were estimated by using a regression equation (using the same approach that was used for Persigo Wash). Sites that bracketed reaches having the most selenium and salinity loading during the January 2005 synoptic were selected to be sampled again in March 2006. Salinity concentrations, unlike selenium concentrations, were quite different for each synoptic (fig. 7). Salinity concentrations were higher during the January 2005 synoptic. The lowest salinity concentrations reported for either synoptic were at upper-reach sites AC85 and AC75 during March 2006. Salinity loads calculated for the March 2006 synoptic were about one-half those of the January 2005 synoptic. The much lower salinity load during the March 2006 synoptic was attributable to the lower streamflow and concentration condition.

During the January 2005 synoptic, large increases in salinity load (26.0 ton/d) occurred in the A75 to A60 reach, which is also where the large selenium-loading increase occurred (fig. 7*B* and *D*). Salinity loads increased considerably downstream from AC75 during the January 2005 synoptic; however, this was not the case during the March 2006 synoptic. During the March 2006 synoptic, salinity loads increased gradually, and the large increase downstream from site AC75 was not as pronounced.

A ratio of selenium load to salinity load that could be used to estimate potential reductions in selenium based on estimated reductions in salinity from salinity control projects was developed using data from both synoptics. The ratios of selenium to salinity for both synoptics were similar with the results indicating a ratio of 0.018 in January 2005 and 0.022 in March 2006 (table 2). The ratio indicates pounds of selenium per ton of salinity.

Samples for the analysis of total nitrogen samples were collected at nine sites during the January 2005 synoptic and six sites during the March 2006 synoptic. The sites selected for the March 2006 synoptic were based on those chosen for selenium. All sites that were sampled were on the main stem of Adobe Creek.

During the January 2005 synoptic, total nitrogen concentrations increased between sites AC90 (0.32 mg/L) and AC75 (2.1 mg/L), and a larger increase in total nitrogen was observed between sites AC75 (2.1 mg/L) and AC70 (8.7 mg/L) (fig. 7*E*). Total nitrogen concentration remained near 8 mg/L between sites AC70 and AC1 near the mouth of Adobe Creek. The same pattern of total nitrogen concentration increases from upstream to downstream during the January 2005 synoptic also was observed during the March 2006 synoptic. The increase in total nitrogen concentration in the AC75 to AC70 reach brackets a poultry farm. Study results indicate the poultry farm area is a likely source of nitrogen, possibly from chicken manure if the manure is disposed of onsite or amended to soils to fertilize crops in the AC75 to AC70 reach.

Total nitrogen loads during the 2005 synoptic, like concentrations, increased substantially in the AC75 (1.3 lb/d) to AC70 (12.7 lb/d) reach (fig. 7*F*). This increase (11.4 lb/d) accounted for approximately 67 percent of the total load near the mouth of Adobe Creek at site AC1. Similar increases in total nitrogen load were observed during the January 2005 and March 2006 synoptics, with the exception of site AC65 which did not have an increased total nitrogen load relative to site AC70 in March 2006.

By using simple linear regression (Helsel and Hirsch, 2002), it appears that selenium loads and concentrations are related to total nitrogen loads and concentrations for both synoptics. The results indicated a good correlation for both concentration ($R^2 = 0.89$) and load ($R^2 = 0.98$). Streamflow also was related to total nitrogen loads and concentrations using simple linear regression. The results indicated a fair correlation for concentration ($R^2 = 0.51$) and a good correlation for load ($R^2 = 0.95$). This analysis indicates that total nitrogen concentration explains more of the variation in selenium concentration than streamflow does, and that the variation in selenium load is explained proportionally by total nitrogen load and streamflow.

Lewis Wash

Streamflow and water-quality data were collected at selected sites along the entire flowing part of Lewis Wash on December 11, 2004, and March 6, 2006 (fig. 8). The tracer-dilution method was used to measure streamflows in December. A total of 16 samples were collected for the analysis of selenium, 12 for determination of streamflow, and 6 for the analysis of salinity and total nitrogen. Four tributaries to Lewis Wash were sampled, and 12 sites were sampled

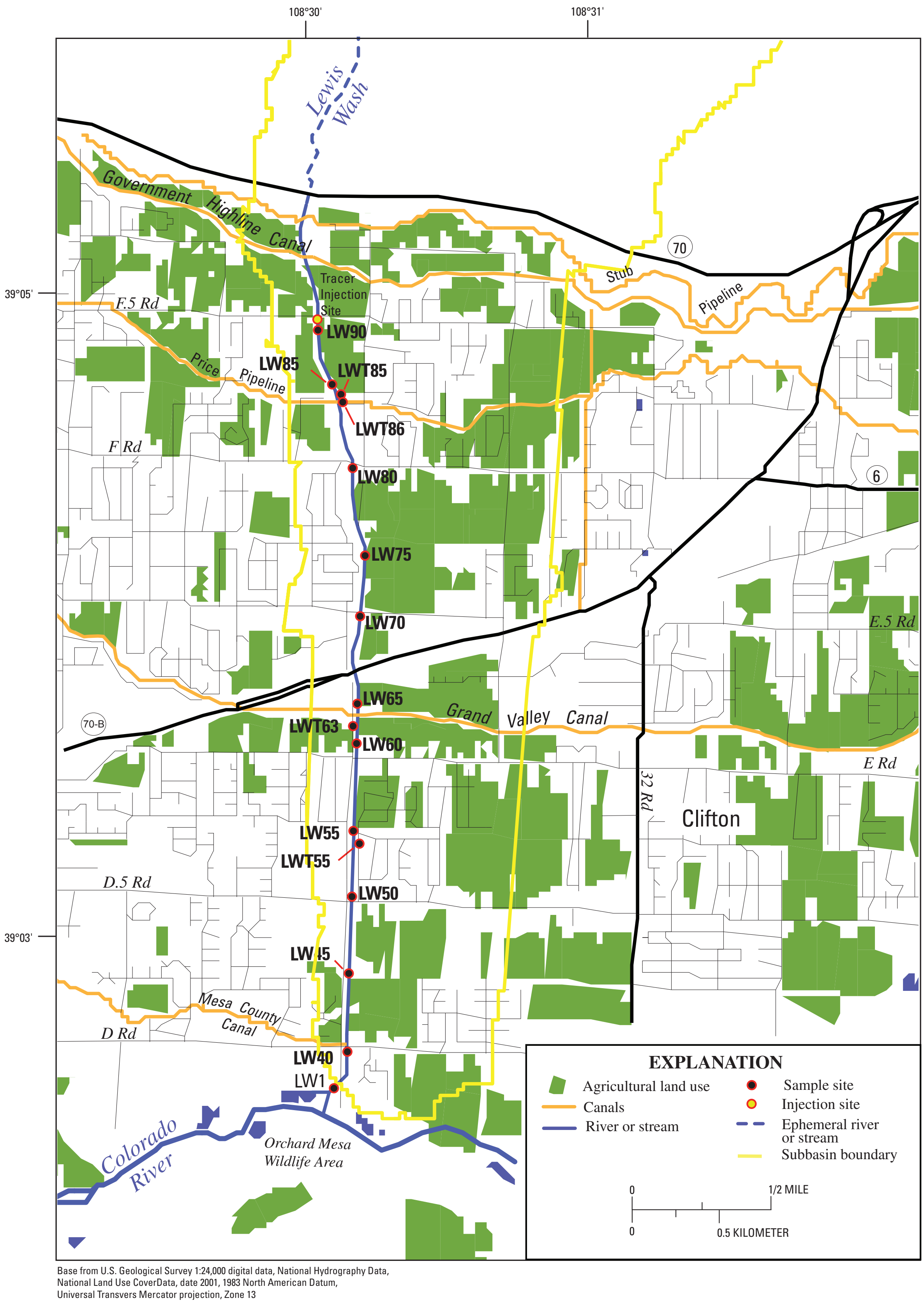


Figure 8. Location of synoptic-sampling sites on Lewis Wash, Grand Valley, western Colorado.

on the main stem. The current-meter method was used to measure streamflow in March 2006; six main-stem sites were sampled for analysis of selenium and total nitrogen, and no tributary samples were collected. Salinity concentrations were calculated for the March 2006 synoptic. A relation between specific conductance and salinity (sampled in December 2004) was established using simple linear regression (Helsel and Hirsch, 2002).

Streamflow, as well as selenium, salinity, and nutrient concentrations and loads at each main-stem and tributary site (where applicable), are shown in figure 9. The appendix lists the full USGS station name and number for each site shown in figure 9. Inflow rate for tributary sites LWT63 and LWT55 was directly measured volumetrically during the December 2004 synoptic. Therefore, streamflows, concentrations, and loads (fig. 9*A*, *B*, and *C*) are shown for these tributary sites, unlike other tributary sites where the tracer-dilution method was used to indirectly measure gains in streamflow.

In general, selenium concentrations in Lewis Wash increased downstream (fig. 9*A*) during the December 2004 synoptic. The highest concentration of selenium in Lewis Wash was sampled from the inflow of an unnamed tributary (LWT55) in the lower part of the subbasin near D.5 Road. The concentration measured at LWT55 (26.9 µg/L) was marginally higher than concentration measured near the mouth of Lewis Wash at site LW1 (19.1 µg/L). Concentrations measured in Lewis Wash were lower than those observed in Persigo Wash or Adobe Creek. The range of selenium concentrations for the December 2004 synoptic for main-stem samples was 3.0 to 19.1 µg/L, whereas in Persigo Wash (November 2004) and Adobe Creek (January 2005), the ranges of selenium concentrations were 11.0 to 78.4 µg/L and 11.3 to 48.6 µg/L respectively. Ranges for selenium concentrations in Lewis Wash during the March 2006 synoptic were consistent with the December 2004 synoptic and were similarly lower than for the March 2006 synoptics in Persigo Wash and Adobe Creek. Selenium concentrations in March 2006 in the LW85 to LW70 reach (4.9 to 3.0 µg/L) were the lowest observed at any main-stem sites for this study. The lowest main-stem concentration observed in Persigo Wash was 11.0 µg/L, which was observed at site P90 during the November 2004 synoptic, and the lowest concentration in Adobe Creek was 11.3 µg/L at site AC90 during the January 2005 synoptic. Selenium concentrations in the LW85 to LW70 reach were also the only main-stem sites measured for this study that had selenium concentrations below the State of Colorado acute water-quality aquatic-life standard for selenium of 4.6 µg/L.

Streamflow-measurement data were limited for the December 2004 synoptic because the tracer injectate used for the tracer-dilution method was not recovered at the majority of sites in Lewis Wash. Failure to recover the tracer injectate in Lewis Wash may have resulted from problems with the injection pump apparatus or a loss of streamflow to ground water (no irrigation diversions operate during the nonirrigation season; therefore, it was assumed any loss would be to the ground-water system). Tracer injectate was not recovered downstream from site LW85 (near the Price Pipeline). Initially it was thought that the main and secondary pumps may have failed (there is a backup pump that activates if the main pump fails) or the tubing that routes the tracer injectate to the stream became frozen. The pump apparatus is equipped with a data logger that records pump revolutions in the form of a voltage signal. Each voltage signal indicates one revolution of the pump and also indicates pump operation. The voltage signals downloaded from the data logger for the Lewis Wash injection indicated that the main pump operated at an acceptable rate (pump revolutions were constant) and that there was no period in which the voltage signals were missing (no main pump failure). To test if the tubing was frozen or if the injectate was being lost to the ground-water system, two slug injections were done in January and February of 2006. A slug of NaBr (January 2006) or Rhodamine-WT (February 2006) was added to Lewis Wash at site LW90 where the pump apparatus originally was located for the December 2004 synoptic, and a continuously recording water-quality monitor equipped with a specific- conductance meter and fluorometer was placed at site LW80. The water-quality monitor was left at site LW80 for 1 week after each slug test. The results from the water-quality monitor showed that neither the NaBr nor Rhodamine-WT passed the LW80 site within 1 week after the slugs were added to Lewis Wash. These results indicated that the pump apparatus was not what caused the injectate recovery problems, but rather a loss of streamflow to the ground-water system.

The LW90 to LW85 reach of Lewis Wash was identified as the general location for the loss of streamflow (and tracer injectate) to the ground-water system. Field reconnaissance done in February 2006 showed that Lewis Wash was nearly dry at site LW85 and that streamflow increased substantially just north of where F Road crosses the wash. Streamflow measurements from the March 2006 synoptic confirmed this observation where streamflow was 0.001 ft^3/s at site LW85 and 0.06 ft^3/s at site LW80. All major canals and laterals upstream from site LW80 are lined or piped, so increases in streamflow at LW80 because of canal seepage are not likely to be the source of the observed ground-water inflow in this area. However, certain geologic features in the Grand Valley region may be controlling surface- and ground-water interactions in the Lewis Wash subbasin. The LW90 to LW80 reach brackets a geologic contact between the Mancos Shale and the Pinedale and Bull Lake age Quaternary alluvium (Tweto, 1976). Also, the USBR found evidence of a “cobble aquifer” beneath parts of the Grand Valley including Lewis Wash subbasin (U.S. Bureau of Reclamation, 1986). Core samples from wells drilled in the area show evidence that the Colorado River likely flowed further to the north of the current river location. During the period when the Colorado River was further north, gravels and cobbles aggraded and formed deposits ranging from 10 to 65 ft thick. Eolian deposits, locally sourced colluviums, and the Quaternary alluvium cap the cobble aquifer, making it difficult to distinguish at the ground surface without the use of core testing. Streamflow in the LW90 to LW85 reach may be affected by these geologic features. One

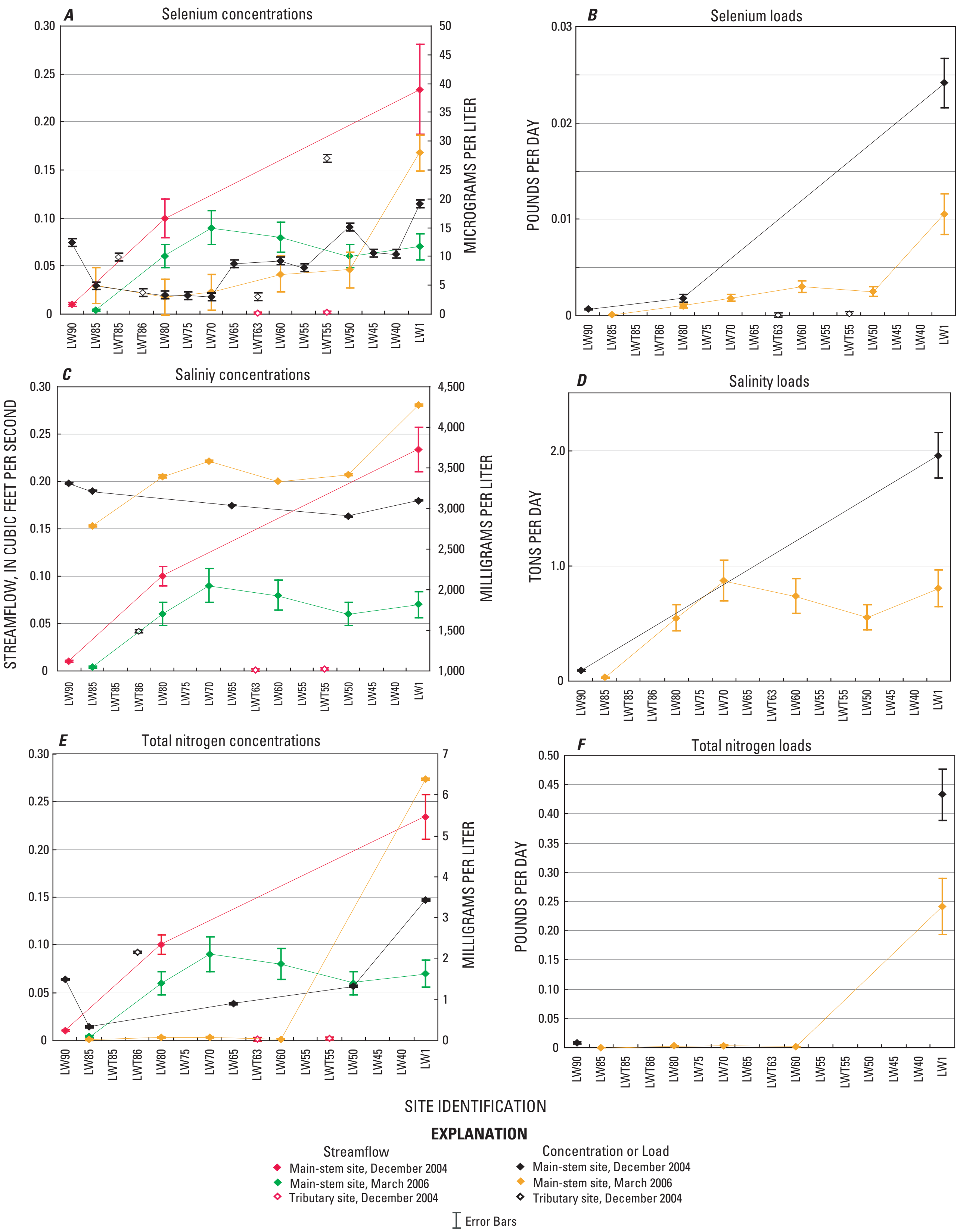


Figure 9. Results for the December 2004 and March 2006 synoptic sampling in Lewis Wash, Grand Valley, western Colorado, for (*A*) streamflow and selenium concentrations, (*B*) selenium loads, (*C*) streamflow and salinity concentrations, (*D*) salinity loads (*E*) streamflow and total nitrogen concentrations, and (*F*) total nitrogen loads.

scenario is that surface water in Lewis Wash near site LW90 is lost to the alluvium or cobble aquifer (hence the loss of tracer injectate) and subsequently resurfaces downstream in Lewis Wash or remains in the ground-water system. This scenario is supported by the low selenium concentrations at the LW85 to LW70 sites and the salinity values that were in the range of those observed in Persigo Wash and Adobe Creek. This indicates that oxidized selenium encounters a reducing environment rendering selenium immobile. This reducing environment may be the cobble aquifer acting as a sink for selenium during the nonirrigation season. Whether selenium is or is not remobilized during different parts of the year is not known. Another possible scenario is that the cobble aquifer in the LW85 to LW70 reach contains alluvial sediments that are high in salinity but low in selenium.

Because of the loss of injectate and the inability to compare streamflow among sites, selenium load calculations were limited for the December 2004 synoptic. Streamflow was measured at three main-stem sites (LW90, LW80, and LW1) and two tributary sites (LWT63 and LWT55) using the current-meter method, thus selenium loads were calculated at five sites for the December 2004 synoptic. During the March 2006 synoptic, six current-meter streamflow measurements were made at main-stem sites, which allowed for six selenium-load calculations.

Selenium loads calculated for the December 2004 synoptic (fig. 9*B*) indicated that selenium loads were highest at the mouth of Lewis Wash (site LW1, 0.024 lb/d) and that a small fraction (0.001 lb/d) of that load occurred between sites LW90 and LW80). Results from the March 2006 synoptic indicated that the majority of selenium loading in Lewis Wash occurred downstream from site LW50 and very little selenium loading occurred between sites LW85 and LW50, despite an increase in streamflow. Streamflow in the LW50 to LW1 reach did not increase much during the March 2006 synoptic. The two tributaries that had streamflow were directly measured (volumetrically) during the December 2004 synoptic and accounted for only a very small part of the total selenium load at site LW1 (fig. 9*B*).

Samples for the analysis of salinity were collected at six sites during the December 2004 synoptic and salinity was calculated by using a regression equation for the March 2006 synoptic (using the same approach that was used for Persigo Wash). Salinity concentrations, unlike selenium concentrations, were somewhat different for each synoptic. In general, salinity concentrations were higher during the March 2006 synoptic, with the exception of site LW85, which was higher in December 2004 (fig. 9*C*). The lowest concentration (2,900 mg/L) observed during the December synoptic was at site LW50; however, salinity concentrations were similar among all sites in Lewis Wash. During the March 2006 synoptic, salinity concentrations were more variable among sites. The lowest salinity concentrations occurred at site LW85 (2,780 mg/L). Salinity concentrations generally increased and ranged from 2,780 to 4,270 mg/L between sites LW85 and LW1 during the March 2006 synoptic, whereas, salinity concentration decreased slightly in this reach in December 2004. Salinity concentrations observed in Lewis Wash in December 2004 and March 2006 were similar to those observed in Persigo Wash and Adobe Creek.

Salinity-load data in Lewis Wash were limited by the lack of streamflow data for the December 2004 synoptic. Salinity loads were calculated for two sites where the current-meter method was used to measure streamflow (fig. 9*D*). The only site where salinity-load data were available for the December 2004 and March 2006 synoptics was LW1. The data indicate that the salinity load in December 2004 was more than double that of March 2006 (1.96 and 0.81 ton/d, respectively). The same pattern was observed in Persigo Wash and Adobe Creek, where salinity loads during the December 2004 synoptic were about double what was observed in March 2006. The lower observed salinity loads in March 2006 may have resulted from lower streamflow during the latter part of the nonirrigation season in all three subbasin tributaries. During the March 2006 synoptic, salinity loads did not follow the same pattern as selenium loads; salinity loads were highest at site LW70 and selenium loads were highest at site LW1. The deviation in the pattern of salinity load among sites from that of selenium load was unique to Lewis Wash. In Persigo Wash and Adobe Creek, salinity and selenium load was always highest at the same site and salinity load generally followed a similar pattern to that of selenium load. Results from the March 2006 synoptic indicated that all salinity loading in Lewis Wash occurred between sites LW85 and LW70. The increase in salinity load in this reach probably is associated with the increase in streamflow just north of F Road. Factors governing the rather abrupt increase in streamflow in this area are not fully understood but may be related to the geology of the area.

A ratio of selenium load to salinity load that could be used to estimate reductions in selenium based on estimated reductions in salinity from salinity control projects was developed using available data from the March 2006 Lewis Wash synoptic. The selenium to salinity load ratio for the March 2006 synoptic was 0.005 pounds of selenium per ton of salinity. No ratio was calculated for the December 2004 synoptic because the load data that were available represented only a small percentage of the study reach. The selenium/salinity ratio for Lewis Wash was substantially smaller than those calculated for Persigo Wash and Adobe Creek (0.017, and 0.022, respectively in March 2006). This indicates that less selenium would be removed per unit of salinity reduction by salinity control work in Lewis Wash compared to the other two subbasin tributaries. The ratio of selenium to salinity in Lewis Wash may be influenced by the geology of the subbasin, historical salinity control work on the Government Highline Canal system, and possibly residential development.

Total nitrogen samples were collected at six sites during the December 2004 and March 2006 synoptics. The sites selected for total nitrogen sampling during the March 2006 synoptic were the same as those chosen for selenium sampling. During the December 2004 synoptic, five main-stem sites and one tributary site (LWT86) were sampled. During the March 2006 synoptic, six main-stem sites were sampled, of which one sample (site LW50) was destroyed during shipment.

During the December 2004 synoptic, total nitrogen concentration decreased between sites LW90 (1.5 mg/L) and LW85 (0.33 mg/L) and increased downstream to site LW1 at the mouth (3.43 mg/L) (fig. 9*E*). The highest concentrations for both synoptics were observed at site LW1. Concentrations increased substantially between sites LW60 and LW1 from less than 0.1 to 6.4 mg/L during the March 2006 synoptic. Selenium and salinity concentrations also increased in this reach, but streamflow remained fairly constant.

Total nitrogen-load data in Lewis Wash were limited for the December 2004 synoptic because of the lack of associated streamflow data. Total nitrogen loads were calculated at two sites where the current-meter method was used to measure streamflow. The only site where total-nitrogen load data were available for the December 2004 and the March 2006 synoptics was LW1. The data indicate larger total nitrogen loads (0.43 lb/d) in December 2004 relative to March 2006 (0.24 lb/d) (fig. 9*F*); however, the total nitrogen loads in Lewis Wash were generally 30 to 40 times less than those observed in Persigo Wash (not including the total nitrogen load from the WWTP) and Adobe Creek. Total nitrogen loads were calculated at five main-stem sites during the March 2006 synoptic. The data indicated that very little nitrogen loading (< 0.01 lb/d) occurred between sites LW85 and LW60 (fig. 9*F*). The vast majority of total nitrogen loading (0.24 lb/d) occurred between sites LW60 and LW1. Selenium loads increased in this reach as well; however, salinity loads were relatively unchanged.

By using simple linear regression (Helsel and Hirsch, 2002), selenium concentrations were related to total nitrogen concentrations for each synoptic. Selenium loads and streamflow were not tested for a relation to total nitrogen loads because load and streamflow data were limited. The results indicated a fair correlation for selenium and total nitrogen concentration ($R^2 = 0.71$). Total nitrogen and selenium concentrations in Lewis Wash did not have as good of a correlation as for Persigo Wash and Adobe Creek (0.80 and 0.89, respectively).

Ratios of Selenium to Salinity in Persigo Wash, Adobe Creek, and Lewis Wash

The GVSTF, through the use of this and other studies, seeks to identify areas in the Grand Valley where efforts to control selenium loading would be most cost effective. This typically is done by identifying areas that have the largest selenium loads in a given subbasin. Salinity loads also need to be considered, however, because reductions in selenium load can occur simultaneously with salinity control work (Butler, 2001). Therefore, for purposes of targeting areas for salinity and selenium control, selenium to salinity ratios were calculated at all sites where the data were available to make the calculation (table 2). Recall that selenium to salinity ratio is an estimate of the amount of selenium load reduction (in pounds) that might occur if salinity load were reduced by 1 ton. Therefore, the higher the ratio in table 2, the greater the potential for reducing selenium load coincident with salinity control efforts.

The selenium to salinity ratios for Persigo Wash, Adobe Creek, and Lewis Wash that were described previously in this report represent the average condition for each subbasin tributary during the nonirrigation season. The ratios indicate that salinity control projects in Persigo Wash and Adobe Creek subbasins would reduce selenium load by about the same amount, whereas salinity control projects in Lewis Wash subbasin would reduce only about 25 percent as much of the selenium load per ton of salinity reduction.

Selenium to salinity loading ratios calculated at individual sampling sites for the nonirrigation season were used to indicate which reaches within each subbasin have the most potential for selenium reductions. In Persigo Wash, the reach between sites P60 and P20 had the highest selenium to salinity ratios, and the highest ratios occurred during the early part of the nonirrigation season. In Adobe Creek, the area downstream from site AC70 had the highest selenium to salinity ratios, and the highest ratios occurred during the late part of the nonirrigation season. In Lewis Wash, the area near site LW1 had the highest selenium to salinity ratios.

Land-Use Change in the Grand Valley Study Area

The GVSTF has identified a need to investigate how land-use change will affect selenium loads and concentrations in the Grand Valley. The two types of land-use change that are expected to have the largest effect on salinity and selenium loads in the Grand Valley are residential development on previously unirrigated Mancos Shale outcrops/Mancos Shale derived soils, and residential development on previously irrigated Mancos Shale outcrops/Mancos Shale derived soils. In the Grand Valley, urban development has taken place primarily on agricultural land. Areas shown in red in figure 1 illustrate the extent of residential development in the Grand Valley as of 2001, where urban development includes moderate to intense residential development, businesses, and industrial applications.

The previously unirrigated areas that potentially could be developed are mostly to the north of the Government Highline Canal and are not served irrigation water by the existing system (fig. 1). This area is underlain primarily by Mancos Shale and Mancos Shale-derived soils that are high in selenium and salinity and is of particular concern to the GVSTF because studies have shown that naturally weathered selenate is transported in ground water to depths at which it is reduced and stored as selenite or elemental selenium (Butler and others, 1996). The reduced forms of selenium are abundant in the Mancos Shale-derived soils and are easily remobilized by

Table 2. Selenium to salinity ratios for Persigo Wash, Adobe Creek, and Lewis Wash, Grand Valley, western Colorado.

[AC, Adobe Creek subbasin site; LW, Lewis Wash subbasin site; P, Persigo Wash subbasin site; units, ratios are given in pounds of selenium per ton of salinity; --, insufficient data for representative calculated value]

Persigo Wash			Adobe Creek			Lewis Wash		
Site identification	November 2004	March 2006	Site identification	January 2005	March 2006	Site identification	December 2005	March 2006
P90	0.008		AC90	0.007		LW90	0.007	
P80	0.015	0.016	AC85	0.01	0.016	LW85		0.004
P73		0.020	AC80	0.01		LW80		0.002
P60	0.022	0.017	AC75	0.01	0.012	LW70		0.002
P50		0.016	AC70	0.021	0.020	LW60		0.004
P45	0.025		AC65	0.026	0.028	LW50		0.005
P25	0.024	0.018	AC60	0.027	0.030	LW1	0.012	0.013
P20	0.026		AC55	0.025				
P10	0.020	0.014	AC50	0.024				
			AC1	0.023	0.025			
Average	**0.020**	**0.017**		**0.018**	**0.022**		**--**	**0.005**

oxygen-rich irrigation water. Irrigation of residential lands on these soils would likely provide an oxygen-rich water source that would remobilize and flush the stored selenium from the soils to streams as diffuse ground-water inflows.

Unlike the adverse selenium mobilization effects of residential development of previously unirrigated areas, the effect of residential development of agricultural land (areas shown in green in fig. 1) is harder to predict. Irrigation of agricultural land in the Grand Valley since the early 1900s has leached shallow soils of much of the available selenium and salinity. Although selenium and salt can still be leached from parent material and deeper soils zones beneath the irrigated areas, there is less potential for irrigation of new residential development to flush selenium and salinity from the soil in large quantities. Most likely, there still would be some degree of mobilization of selenium and salinity from areas of new residential development; however, the amount of mobilization relative to that which is caused by agriculture is uncertain. There is probably a range of mobilization/loading that will occur depending on local characteristics. For example, there would likely be less mobilization/loading from new subdivisions that have a high density of impervious area (less irrigated turf grass) and have piped irrigation laterals, infrastructures, and sprinkler systems. Optimizing the rate and total volume of irrigation water applied to turf grasses in a given subdivision also would likely reduce deep percolation and minimize the mobilization of selenium and salinity to ground water that drains to tributaries in the Grand Valley and ultimately the Colorado River.

Data collected as part of this study, as well as historical data collected in the subbasin tributaries, may give some insight into the effects of residential development on water use and water quality. For this study, the main objective in considering land-use change was to investigate the effects of converting agricultural land use to urban land use. Investigation of the effects of land-use change in the previously unirrigated areas was beyond the scope of this report.

Water-Quality Trends in Lewis Wash Subbasin

In the Lewis Wash subbasin, there is more residential development per square mile than in Adobe Creek and Persigo Wash subbasins combined. Analysis of the data collected in this study and the historical data collected as part of USBR hydrosalinity investigations, as well as the USGS streamflow-gaging network and the National Irrigation Water Quality Program, indicate that selenium and salinity loads in Lewis Wash are substantially lower than in the other two subbasins. The data also indicate that streamflow and salinity loads in Lewis Wash declined from the 1970s to the early 2000s. The historical streamflow record and the concentrations and loads of salinity in Lewis Wash were analyzed to determine if a statistically significant shift in streamflow and salinity had occurred during the period of record (1973–2006). No analysis was made for selenium because of a lack of historical data from the 1970s. Data from the 1970s was crucial to this analysis because this period predated the period (1980 to present) when the vast majority of salinity control work was done by the Natural Resource Conservation Service (NRCS, ‘on-farm’; James Currier, Natural Resources Conservation Service, oral commun., 2007) and USBR (‘off-farm’; USBR, 1986) in the

Grand Valley salinity control unit. The largest percentage of off-farm work by the USBR was done from 1983 to 1996; on-farm work by the NRCS is still ongoing but was most intensive in the 1980 and 1990's. Data from the 1970s were also important to this analysis because aerial photographs from that period show that land use in the Lewis Wash subbasin was predominantly agricultural at that time (Mesa County, 2006). The results of this analysis were used to determine the potential effects of land-use change on salinity loading in Lewis Wash subbasin.

Instantaneous streamflow and salinity-concentration data were retrieved from the USGS NWIS database for the Lewis Wash historical streamflow-gaging station (09106200, site LW1) for water years 1973 to 1979 and 1991 to 2006. Daily streamflow data were retrieved for the period of record (water years 1973 to 1979 and 2002 to 2004), though only partial records were available for water years 1973, 2002, and 2004. Data were analyzed and compared for various periods. For the purposes of this study, "early period" data are those data collected before 1980, and "later period" data are any data collected after 1990. USGS LOADEST software (Runkel and others, 2004) was used to estimate concentrations and loads of salinity for the early and later periods. LOADEST uses regression to estimate daily average concentrations or loads that can be combined to represent seasonal (irrigation or nonirrigation season) and annual estimates. A step-trend analysis was used to determine if a significant difference ($p < 0.05$) existed between early (4–23–1977 to 3–19–1979) and later (4–23–2002 to 3–19–2004) periods for streamflow and for concentrations and loads of salinity. Step-trend analysis also was done for the only complete water years available for comparison (1978 and 2003). Date ranges for the early period were chosen to match date ranges available for the later period of data collection in order to characterize and compare similar climatic conditions (drought). Water years 1977 and 2002 are two of the driest water years recorded at streamflow-gaging stations on the Colorado River (U.S. Geological Survey, 2002) (fig. 3*A*). By selecting these periods, it was thought that the salinity-load estimates for the two periods would be more comparable.

A graph relating instantaneous streamflow to salinity concentration in Lewis Wash for the early and later periods is shown in figure 10*A*. The distribution of salinity concentrations during the irrigation and nonirrigation seasons is shown in figure 10*B*. Figure 10*A* shows a shift in the relation of salinity concentration to streamflow toward lower salinity concentrations and streamflows during the later period of data collection. The shift in the data is likely more apparent during the nonirrigation season because the irrigation companies spill and (or) divert irrigation water to Lewis Wash during the irrigation season in order to fulfill the various calls for water. Therefore, the nonirrigation season best represents the effect of seepage and deep percolation on base flow in Lewis Wash. It is likely that the amount of irrigation water diverted to Lewis Wash subbasin has remained about the same for the past 30 years because Colorado Water Law dictates that water rights can be lost if decreed water is not put to beneficial use (Colorado Division of Water Resources, 2003).

Mean-monthly streamflow and LOADEST estimates of mean-monthly concentrations and loads of salinity at site LW1 during the nonirrigation season are shown in figures 11*A–C* for water years 1978, 1979, 2003, and 2004. Figure 11*C* indicates a shift between early and later periods for nonirrigation-season salinity loads from December through March, where later period salinity loads appear to be lower. Shifts in streamflow and salinity concentration are not as apparent (figs. 11*A* and *B* respectively). Estimates of streamflow and salinity concentrations and loads for various years and seasons are listed in table 3.

A step-trend analysis was done to determine if a significant difference existed between the early and later period data. Two types of statistical tests, the t-test and the Wilcoxon Signed Rank Test (sign test), were used to determine if step trends were present in the dataset. Results of t-tests and sign tests for the instantaneous streamflow data and LOADEST outputs are provided in table 3. The tests were structured so that the alternative hypothesis for each test was whether the difference (early period data minus the later period data for a given period or season) was greater than zero at a significance level less than or equal to 5 percent (p value < or = 0.05). Thus, if the p value was less than or equal to 0.05, then the alternative hypothesis that the difference between the early and later periods was greater than zero was accepted. All data sets for the t-tests were assumed to be from a Gaussian (or normal) distribution because the data sets were normalized in LOADEST as part of the requirements for LOADEST analysis (Runkel and others, 2004). A Gaussian distribution was not required for the sign test, which is a robust test that is not influenced heavily by the presence of outliers in the data.

The t-test results indicate there was no significant change in the annual or seasonal streamflow rate at site LW1, with the exception of the irrigation season for the 1977 versus 2002 water-year comparison. The additional t-tests for concentrations and loads of salinity indicate that salinity concentration and load were lower during the later period of data collection for all water years and seasons tested. The only exception was for salinity concentration during the 1978 versus 2003 water years where salinity concentration (3,960 versus 3,910 mg/L, respectively) was not significantly higher during the early period of data collection for the nonirrigation season. The sign tests, unlike the t-tests, indicated there was a significant decrease in streamflow during the nonirrigation season for all periods tested. The test differences most likely resulted from the fact that the nonirrigation season does not always begin on November 1. Commonly it takes several days for the canal system to drain after being shutoff, which in turn does not allow tributaries to the Colorado River (such as Lewis Wash) to immediately return to base-flow conditions. Because of the nature of the sign test, streamflow values elevated beyond a base-flow condition in early November have less leverage, so the dataset is skewed less by values that do not represent a true base-flow condition. Therefore, the sign test, rather than the

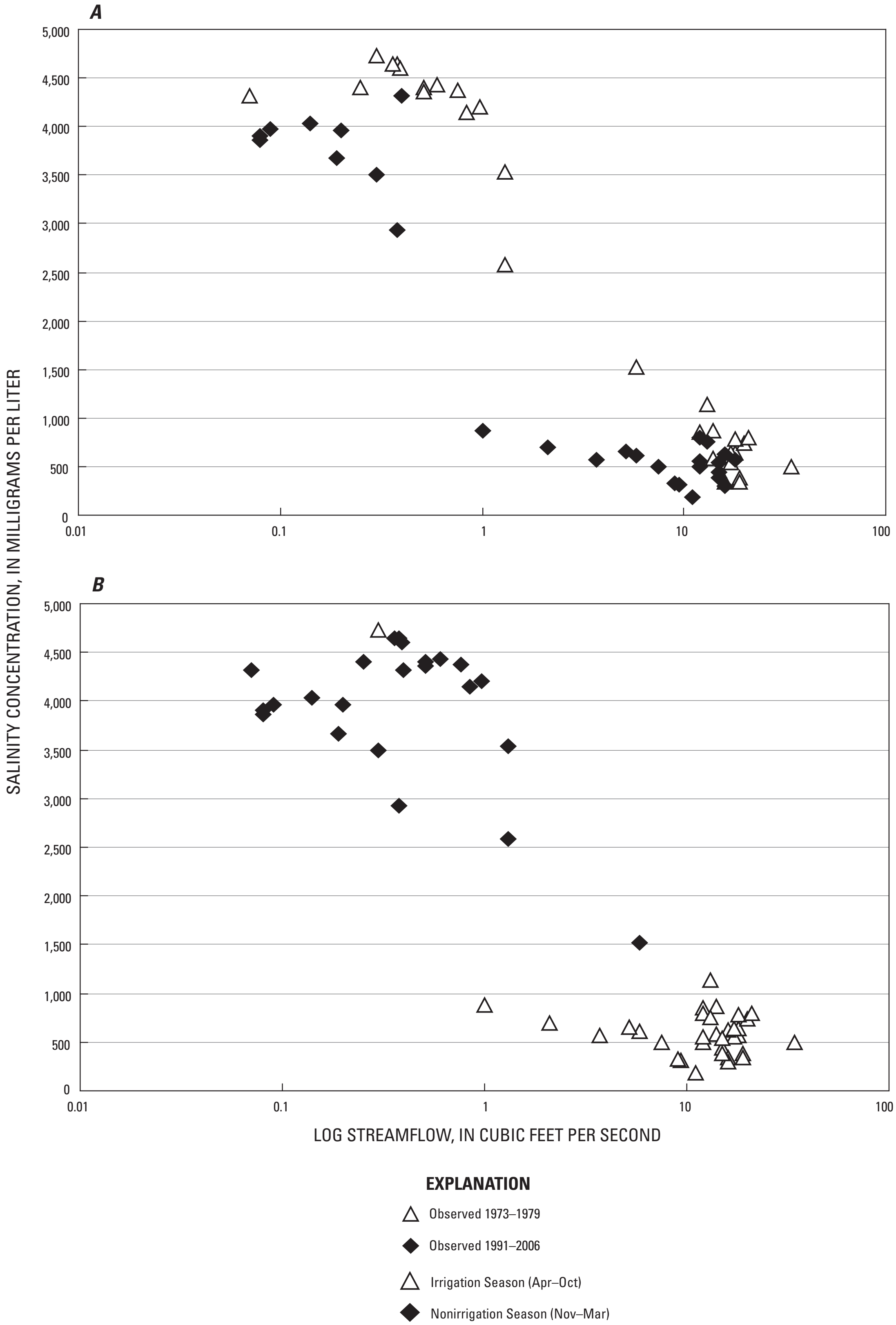


Figure 10. (*A*) Log-transformed streamflow related to salinity concentration for early and later periods, and (*B*) log-transformed streamflow related to salinity concentration showing irrigation and nonirrigation seasons for early and later periods.

Table 3. Early and later period streamflows and salinity levels at site LW1 in Lewis Wash, Grand Valley.

[NT, no trend; S, significant trend where p value is greater than .01 and less than .05; HS, highly significant trend where p value is less than .01; ft^3/s, cubic feet per second; mg/L, milligrams per liter; tons/d, tons per day; tons/yr, tons per year]

Early period					Later period					Results from t-test/ signed rank test		
Water year	Mean-daily streamflow (ft^3/s)	Mean-daily salinity concentration (mg/L)	Mean-daily salinity load (tons/d)	Mean-annual or seasonal salinity load (tons)	Water year	Mean-daily streamflow (ft^3/s)	Mean-daily salinity concentration (mg/L)	Mean-daily salinity load (tons/d)	Mean-annual or seasonal salinity load (tons/yr)	Mean-daily streamflow (ft^3/s)	Mean-daily salinity concentration (mg/L)	Mean-daily salinity load (tons/d)
Irrigation and nonirrigation season combined												
Apr 1977–Mar 1979	6.61	2,250	17.2	6,280	Apr 2002–Mar 2004	6.67	1,940	10.6	3,869	NT/HS	HS/HS	HS/HS
1978	7.09	2,210	17.8	6,500	2003	7.54	1,960	11.1	4,050	NT/NT	HS/HS	HS/HS
Nonirrigation Season (Nov–Mar)												
1978–1979	1.30	3,800	8.36	1,262	2003–2004	1.68	3,560	4.77	720	NT/HS	HS/HS	HS/HS
1978	1.00	3,960	8.09	1,220	2003	0.81	3,910	3.59	542	NT/HS	NT/NT	HS/HS
1979	0.78	4,070	7.37	1,110	2004	1.18	3,750	4.43	668	NT/HS	HS/S	HS/HS
Irrigation Season (Apr–Oct)												
1977–1978	10.7	984	24.0	5,136	2002–2003	10.7	583	15.3	3,274	NT/NT	HS/HS	HS/HS
1977	8.6	1,030	20.8	4,450	2002	7.76	620	12.3	2,630	S/S	HS/HS	HS/HS
1978	12.6	941	26.9	5,760	2003	13.4	553	18.0	3,852	NT/NT	HS/HS	HS/HS

t-test, is better for determining the presence of step trends and changes in base flow during the nonirrigation season.

The results from the trend tests indicate that the cause for the decrease in salinity load is due to a combination of reductions in streamflow and salinity concentration. The nonirrigation-season sign-test results for streamflow indicate that a reduction in base flow occurred. A change in the amount of base flow also was likely present during the irrigation season but was not directly tested because of the presence of irrigation water fed by the canal systems. Salinity sources may have changed along with base flow if some areas of the ground-water system dried up. This, in turn, could cause a reduction in salinity concentrations in Lewis Wash.

The reduction in streamflow, salinity concentration, and salinity load in Lewis Wash may have resulted from several anthropogenic influences. The first possibility is the effect of salinity control projects by the USBR or NRCS. The USBR lined approximately 16.6 mi of canals and laterals (off-farm improvements) on the Government Highline Canal system (Mike Baker, U.S. Bureau of Reclamation, written commun., 2007) and the NRCS improved irrigation systems on about 15 percent of the agricultural fields (on-farm improvements) throughout Lewis Wash subbasin (James Currier, Natural Resources Conservation Service, oral commun., 2007).

The off-farm improvements by the USBR were estimated to result in a salinity-load reduction of about 7,000 ton/yr from Lewis Wash subbasin (Mike Baker, written commun., 2007). This estimate is larger than the average salinity reduction observed for site LW1 for this study. Using the results from table 3, a reduction in salinity load was calculated for water years 1978 compared to 2003 that was approximately 2,450 ton/yr. This number was obtained by subtracting the value for annual salinity load for water year 1978 from that of water year 2003. The values for annual and seasonal salinity loads for the early 1977–1979 and later 2002–2004 periods are presented in table 3 for trend-test purposes only and are not directly comparable to the annual estimates of salinity reduction by the USBR because of the use of partial water years.

The USBR off-farm estimates for annual salinity reductions resulting from lining canals and laterals in Lewis Wash subbasin may have been higher than the USGS-LOADEST estimates because of the presence of the cobble aquifer. The cobble aquifer (and the reach in which the tracer injectate was lost) is downgradient from where the canal lining work was done. Canal and lateral seepage from the Government Highline Canal system may have occurred predominately as direct ground-water recharge to the Colorado River; therefore, the majority of the original salinity load and any reduction in salinity load that likely occurred from off-farm improvements was not measured in the surface water at site LW1. Nevertheless, a part of the reduction in salinity load observed between early and later periods at site LW1 may still be attributable to salinity control work done by the USBR in Lewis Wash subbasin; however, further analysis would be needed to determine what part of the reduction was due to off-farm improvements.

No estimate of salinity reductions was available for the on-farm improvements done by the NRCS in Lewis Wash subbasin; therefore, no comparison is made to the estimated reductions in salinity load estimated for water years 1978 compared to 2003. It is likely that a change did occur at site LW1 from this type of salinity control work because the work was done throughout Lewis Wash subbasin and not just upgradient from the cobble aquifer (James Currier, 2007, Natural Resources Conservation Service, oral commun.). Therefore, it is assumed that a portion of the reduction in salinity load seen at site LW1 is from on-farm work done by the NRCS.

Another possible explanation for the reductions in salinity load at site LW1 is the conversion of agricultural land to residential land. A GIS analysis of the amount of irrigated land in the subbasin was done for years that had available GIS data layers (1993 and 2000). From 1993 to 2000, irrigated land was reduced by approximately 34 percent from 965 acres in 1993 to 635 acres in 2000. It is assumed for this report that no change in the amount of irrigation water delivered to Lewis Wash occurred during the last 30 years, but that there was a decrease in base flow (based on the results of the step-trend analysis from table 3). It is possible that the reduction in base flow may have resulted from a reduction in seepage and deep percolation after the onset of residential development. The investigation of seepage and deep percolation rates was beyond the scope of this report, but it is feasible that a reduction in seepage and deep percolation rates may have helped reduce the amount of salinity that was historically mobilized. Changes in seepage and deep percolation rates may result from higher efficiency irrigation systems and (or) less demand for irrigation water. Higher water delivery and irrigation efficiency likely would result from lined irrigation laterals to subdivisions and also the use of sprinkler irrigation of residential vegetation (turf grass, shrubs, and trees) instead of flood irrigation of traditional agricultural crops (grass hay, alfalfa, and corn). Less demand for irrigation water likely resulted from higher efficiency irrigation systems and an increase in impervious area, thus more of the irrigation water delivered to Lewis Wash subbasin remained in the canal system rather than being used for irrigation. The results for the step-trend tests provide some evidence to indicate that there was a reduction in the amount of streamflow during the combined and individual irrigation seasons in Lewis Wash after urban development. The step-trend test results, however, do not prove a reduction in demand and may be only indications of different water management strategies among the different periods tested. Therefore, it is possible that changes to base flow in Lewis Wash resulted predominately from the use of higher efficiency irrigation systems.

Summary

Elevated concentrations and loads of dissolved selenium in tributaries and main-stem reaches of the Colorado River in the Grand Valley region of western Colorado are an ongoing concern to local, State, and Federal agencies, local water providers, and landowners. The Colorado River (from the Gunnison River confluence to the Utah border) and tributaries to the Colorado River in the Grand Valley are on the 2006 State of Colorado 303(d) list of impaired water bodies. These tributaries and segments of the Colorado River are listed as impaired because dissolved selenium values at these locations exceed the State of Colorado chronic standard of 4.6 micrograms per liter at the 85th percentile level.

A local watershed initiative to address the selenium issue was established in 2002 with the formation of the Grand Valley Selenium Task Force (GVSTF). This group, consisting of local, State, and Federal interests, examines potential remediation scenarios and best management practices designed to help address the selenium issue in the Grand Valley. In response to the needs identified by the GVSTF, the U.S. Geological Survey, in cooperation with Mesa County and the City of Grand Junction, developed a study to characterize selenium-loading sources in three tributaries to the Colorado River in order to determine selenium sources and how these sources may relate to land-use changes in the Grand Valley.

The purpose of this report is to describe the study methods and results of a characterization study of concentrations and loads of selenium in three tributaries to the Colorado River in the Grand Valley—Persigo Wash, Adobe Creek, and Lewis Wash—each representing transitional agricultural to urban, agricultural, and urban land-use types, respectively. These subbasins represent different land-use types, and the tributaries that drain each subbasin contribute moderate to high concentrations and loads of selenium to the Colorado River. Six water-quality synoptic-sampling events—two in each subbasin—were conducted from December 2004 through March 2006 to characterize selenium sources and variations in water quality during the nonirrigation season. Water samples were collected for analysis of dissolved selenium, total nitrogen, and total dissolved solids (salinity). Streamflow was measured by either tracer-dilution, standard current-meter, or volumetric method.

In general, selenium concentrations in Persigo Wash decreased or remained constant downstream whereas selenium loads increased. Sample data indicate that effluent from the Persigo Wash wastewater treatment plant diluted selenium concentrations in Persigo Wash and increased the selenium load. Concentrations and loads of salinity generally increased downstream in Persigo Wash, and salinity concentrations were similar at the beginning and the end of the nonirrigation season. Concentrations and loads of total nitrogen increased downstream in Persigo Wash. Concentrations and loads of selenium had a good correlation to concentrations and loads of total nitrogen (R^2 = 0.80 and 0.83, respectively). Concentrations and loads of total nitrogen also correlated well with streamflow (R^2 = 0.89 and 0.99, respectively).

In general, concentrations and loads of selenium in Adobe Creek increased downstream. The largest selenium loads in Adobe Creek were observed between sites AC75 and AC65, where selenium load increased 0.72 pounds per day. The AC75 to AC65 reach is approximately 8,600 feet (1.6 miles) in length and accounted for about 81 percent of the total selenium load at the mouth of Adobe Creek (site AC1). Results from the synoptic-sampling events indicated that there was very little seasonal variation in selenium concentration in Adobe Creek during the nonirrigation season. Salinity concentrations were more variable than selenium concentrations during the nonirrigation season. Concentrations and loads of salinity generally increased downstream. Concentrations and loads of total nitrogen generally increased downstream in Adobe Creek. Concentrations and loads of selenium correlated well with concentrations and loads of total nitrogen (R^2 = 0.89 and 0.98, respectively). Streamflow also was related to concentrations and loads of total nitrogen. The results indicated a fair correlation for concentration (R^2 = 0.51) and a good correlation for load (R^2 = 0.95).

In general, concentrations and loads of selenium in Lewis Wash increased downstream. Selenium concentrations measured in Lewis Wash were lower than those observed in Persigo Wash or Adobe Creek; however, salinity concentrations were similar. Salinity concentrations also were similar among sites during each synoptic-sampling event. Salinity loads in Lewis Wash were highest during the beginning of the nonirrigation season. Concentrations and loads of total nitrogen generally increased downstream in Lewis Wash. There was a fair correlation for selenium and total nitrogen concentrations (R^2 = 0.71). Selenium loads and streamflow were not tested for a relation to total nitrogen loads because load and streamflow data were limited.

Step-trend analysis was used to determine if a significant difference ($p < 0.05$) existed between early (4–23–1977 to 3–19–1979) and later (4–23–2002 to 3–19–2004) periods for historical streamflow and salinity concentration and load data in Lewis Wash. Two types of statistical tests, the t-test and the Wilcoxon Signed Rank Test (sign test), were used to determine if step trends were present in the dataset. The t-test results indicate there was no significant decrease in the annual or seasonal (irrigation and nonirrigation season) streamflow rate at site LW1, with the exception of the irrigation season for the 1977 compared to 2002 water years. The t-tests for concentrations and loads of salinity indicate that both annual and seasonal salinity concentrations and loads were lower during the later period of data collection for all water years and seasons tested, with the exception of salinity concentration during water year 2003 compared to water year 1978. The sign tests, unlike the t-tests, indicated that there was a significant decrease in streamflow during the later period nonirrigation seasons that were tested. Sign-test results for concentrations and loads of salinity were generally the same as those for the t-test analysis.

The reduction in streamflow, salinity concentration, and salinity load in Lewis Wash from 1977 to 2004 may have resulted from several anthropogenic influences, including on-farm and off-farm salinity control projects and residential development.

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Appendix – Site Information for Persigo Wash, Adobe Creek, and Lewis Wash, Grand Valley, Western Colorado

Appendix. Site information for Persigo Wash, Adobe Creek, and Lewis Wash, Grand Valley, western Colorado.

Site identification	Station name	Station number
	Persigo Wash	
P1	PERSIGO WASH AT MOUTH NR FRUITA, COLO	390633108393100
PT15	CITY OF GRAND JCT SEWAGE EFFLUENT AT PERSIGO WASH	390637108392100
P10	PERSIGO WASH BLW CITY OF GRAND JCT SEWAGE OUTFLOW	390637108392200
P20	PERSIGO WASH ABV GRAND JCT WATER TREATMENT OUTFLOW	390638108391900
P25	PERSIGO WASH AT RIVER ROAD	390645108390101
P40	PERSIGO WASH AT 22 RD NR FRUITA, COLO	390657108383900
P45	PERSIGO WASH AT H RD NR FRUITA, COLO	390715108382900
P47	PERSIGO WASH NR H RD NR FRUITA, COLO	390752108375900
P50	PERSIGO WASH AT 22.5 RD NR FRUITA, COLO	390805108380800
P55	PERSIGO WASH AT I.25 RD NR FRUITA, COLO	390818108373300
P60	PERSIGO WASH ABV MAIN LINE GRAND VALLEY CANAL	390828108372600
P65	PERSIGO WASH NR CROWN POINT CEMETARY	390844108371200
PT70B	UNNAMED TRIB TO PERSIGO WASH AT J RD, SITE B	390849108370900
PT70A	UNNAMED TRI TO PERSIGO WASH AT J RD, SITE A	390858108370900
P70	PERSIGO WASH BLW GRAND VALLEY CANAL NR FRUITA, COL	390847108370400
PT73	GRAND VALLEY CANAL SPILLWAY TO PERSIGO WASH NR JRD	390850108364400
P73	PERSIGO WASH AT GRAND VALLEY CANAL NR FRUITA, COLO	390852108364300
PT75	PERSIGO WASH TRIBUTARY AT J RD NEAR FRUITA, COLO	390860108363800
P75	PERSIGO WASH AT J ROAD	390859108364101
PT80	PERSIGO WASH TRIBUTARY NR 24 RD NR FRUITA, COLO	390903108364000
P80	PERSIGO WASH NR 24 RD NR FRUITA, COLO	390905108364200
P85	PERSIGO WASH AT 24 RD NR FRUITA, COLO	390926108362600
P90	PERSIGO WASH AT K RD BLW SF CONFLUENCE	390946108361100
	Adobe Creek	
AC90	ADOBE CREEK AT 22 RD NR FRUITA, CO	391119108384100
AC85	ADOBE CREEK AT 21.5 RD NR FRUITA, CO	391100108391400
AC80	ADOBE CREEK AT L RD NR FRUITA, CO	391043108394200
AC75	ADOBE CREEK ABV GRAND VALLEY CANAL NR FRUITA, CO	391026108395100
AC70	ADOBE CREEK AT K RD NR FRUITA, CO	390950108404500
AC65	ADOBE CREEK AT 20 RD NR FRUITA, CO	390932108405500
ACT65	INFLOW TO ADOBE CREEK NR 20 RD NR FRUITA, CO	390926108410100

Appendix. Site information for Persigo Wash, Adobe Creek, and Lewis Wash, Grand Valley, western Colorado.—Continued

Site identification	Station name	Station number
	Adobe Creek	
AC60	ADOBE CREEK AT 19.5 RD AND J RD NR FRUITA, CO	390858108412800
AC50	ADOBE CREEK AT 19 RD NR FRUITA, CO	390755108420200
AC1	ADOBE CR.AT MOUTH, ADOBE CR.BOTTOMLANDS AREA	390741108424301
	Lewis Wash	
LW90	LEWIS WASH AT F.50 RD NR CLIFTON, CO	390556108285000
LW85	LEWIS WASH ABV PRICE DITCH	390542108284600
LWT85	UNNAMED INFLOW TO LEWIS WASH ABV PRICE DITCH	390542108284500
LWT86	PRICE DITCH INFLOW TO LEWIS WASH NR CLIFTON, COLO	390541108284500
LW80	LEWIS WASH AT F ROAD NEAR CLIFTON, COLO	390529108284200
LW75	LEWIS WASH AT BOOKCLIFF AVE NR CLIFTON, COLO	390516108283800
LW70	LEWIS WASH AT E.50 ROAD NEAR CLIFTON, COLO	390504108283800
LW65	LEWIS WASH AT GRAND VALLEY CANAL NR CLIFTON, COLO	390447108283800
LWT63	TRIBUTARY INFLOW TO LEWIS WASH AT 31 RD NR CLIFTON	390445108283800
LW60	LEWIS WASH BELOW GRAND VALLEY CANAL NR CLIFTON, CO	390441108283800
LW55	LEWIS WASH AT GUNNISON RD NR CLIFTON, COLO	390427108283800
LWT55	STORM DRAIN TO LEWIS WASH NR GUNNISON RD	390426108283700
LW50	LEWIS WASH AT D.50 RD NR CLIFTON, COLO	390413108283800
LW45	LEWIS WASH NR CLORADO AVE NR CLIFTON,COLO	390400108283800
LW40	LEWIS WASH AT D ROAD NR CLIFTON, COLO	390348108283800
LW1	LEWIS WASH NEAR GRAND JUNCTION, CO.	09106200

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