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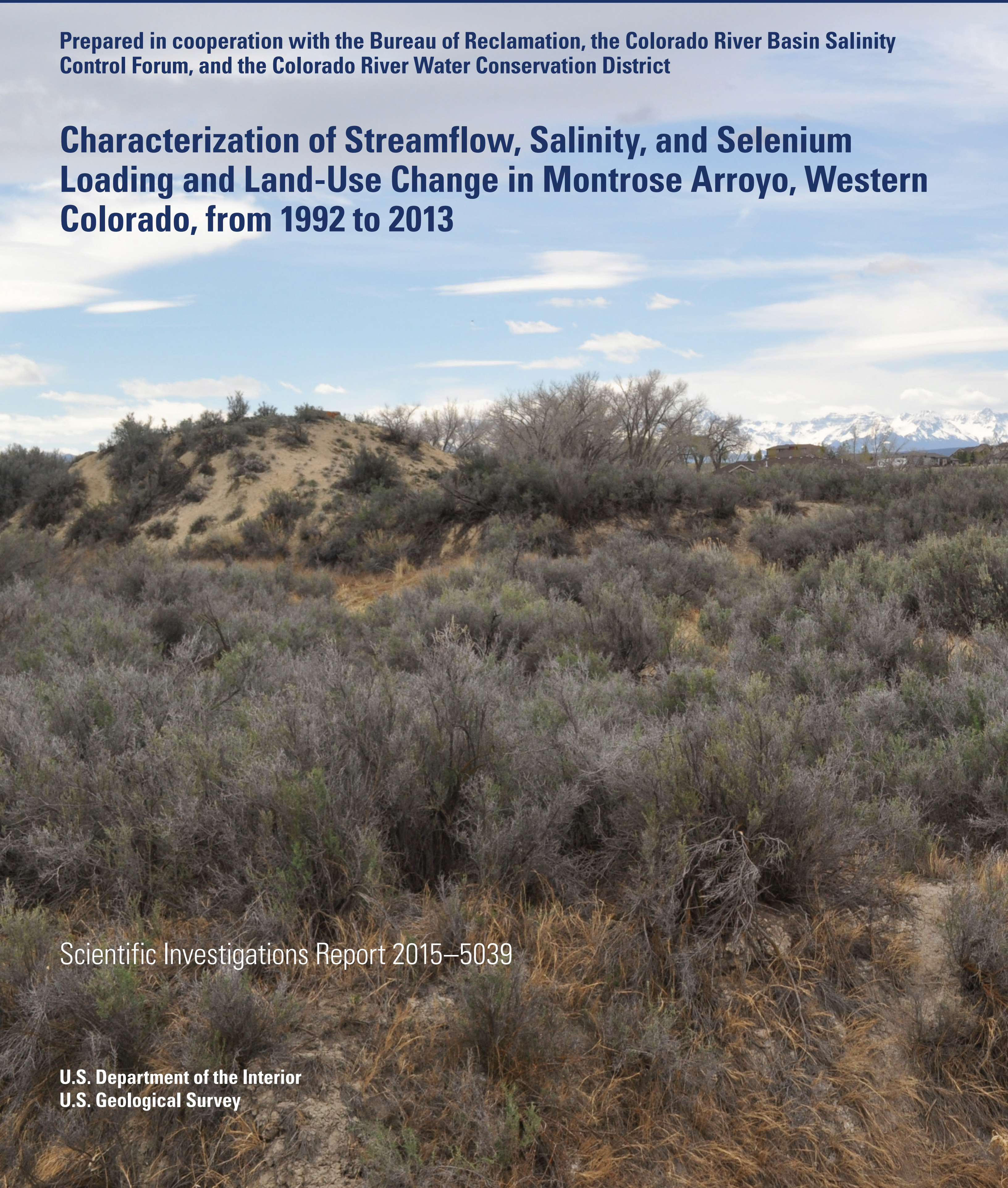
Characterization of Streamflow, Salinity, and Selenium Loading and Land-Use Change in Montrose Arroyo, Western Colorado, from 1992 to 2013



Scientific Investigations Report 2015–5039

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

Cover: Undeveloped land within Montrose Arroyo with Urban development and San Juan Mountains in the background. Photograph by Jennifer Moore, taken April 17, 2012.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound avoirdupois (lb)	0.4536	kilogram (kg)
ton per day (ton/d)	0.9072	metric ton per day

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

Streamflow is given in cubic feet per second (ft^3/s).

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

Dissolved selenium is given in micrograms per liter (µg/L).

Total dissolved solids (salinity) are given as milligrams per liter (mg/L).

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

Abbreviations

ADV	Acoustic Doppler Velocimeter
CRBSCF	Colorado River Basin Salinity Control Forum
CRWCD	Colorado River Water Conservation District
GIS	Geographical Information Systems
NAIP	National Agricultural Imagery Program
NWQL	National Water Quality Laboratory
QA/QC	Quality Assurance/Quality Control
TDS	Total Dissolved Solids
USBR	Bureau of Reclamation
USGS	U.S. Geological Survey

Characterization of Streamflow, Salinity, and Selenium Loading and Land-Use Change in Montrose Arroyo, Western Colorado, from 1992 to 2013

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Abstract

Salinity and dissolved selenium are known water-quality impairments in the lower Gunnison River watershed of western Colorado. Salinity is a concern because of its adverse effects on agricultural land and equipment, and on municipal and industrial users. The Montrose Arroyo watershed in Montrose, Colorado, contains agricultural and residential areas as well as undeveloped land and has undergone substantial land-use change since the early 1990s. Previous sampling efforts indicated salinity concentrations and loads have remained constant since land-use change began in the early 1990s; however, recent sampling also indicated that dissolved-selenium concentrations and loads have begun to increase. In response to the potential increasing dissolved-selenium concentrations and loads, the U.S. Geological Survey—in cooperation with the Bureau of Reclamation; Colorado River Basin Salinity Control Forum; and Colorado River Water Conservation District—continued to monitor salinity and dissolved-selenium concentrations and loads in the Montrose Arroyo watershed. This report characterizes salinity and dissolved-selenium loads in Montrose Arroyo from 1992 to 2013 at three sites: Montrose Arroyo at East Niagara Street (MA2, U.S. Geological Survey site identification number 382802107513301), Montrose Arroyo at 6700 Road (MA3, U.S. Geological Survey site identification number 382711107500501), and Montrose Arroyo at 6750 and Ogden Roads (MA4, U.S. Geological Survey site identification number 382702107493701). A detailed land-use change analysis was also characterized in the MA3 subwatershed.

The three sites were used to monitor salinity and dissolved-selenium concentrations and loads in Montrose Arroyo. Over a period from December 2011 through September 2013, 46 water-quality samples and streamflow measurements were collected at sites MA2, MA3, and MA4. Streamflow, salinity concentrations and loads, and selenium concentrations and loads were characterized and compared between the pre-lateral (before April 1999) and post-growth periods (March 2008 through September 2013) and between post-lateral (April 1999 through October 2000) and post-growth periods.

Results from a previous USGS study on the characterization of salinity and selenium loading and land-use change in Montrose Arroyo from 1992 to 2010 indicated that there was no change in salinity load at site MA2 and a significant increase in dissolved-selenium load from the pre-lateral period to the post-growth period. Data associated with this report indicate the selenium loads at site MA2 show no significant change from the pre-lateral period to the post-growth period. In addition, both salinity load and dissolved-selenium load at site MA3 show significant decreases in salinity and dissolved-selenium load for both periods that are potentially associated with land-use change.

Land use was characterized for 1992, 2002, and 2009 for site MA3. The common land-use change in the MA3 subwatershed was a conversion from previously irrigated agricultural land to urban land use. The MA3 subwatershed had 124 acres of irrigated land use converted to urban land use and 27.1 acres of unirrigated desert converted to urban land use from 1992 to 2009. Consistent with findings in previous land-use change reports, salinity and dissolved-selenium loading at site MA3 showed significant decreases as irrigated land was converted to urban land use.

Introduction

Salinity and dissolved selenium are known water-quality impairments in the lower Gunnison River watershed (fig. 1) of western Colorado. Salinity is composed of dissolved mineral salts and solids in water (Hem, 1959) and is a concern because of its adverse effects on agricultural land and equipment, and on municipal and industrial users (Butler, 2001). The trace element selenium is soluble in oxygenated water and can bioaccumulate in organisms to toxic levels in aquatic environments (Lemly, 2002). Salinity and selenium in the lower Gunnison River watershed are naturally occurring in the Cretaceous marine deposits, such as the Mancos Shale, but there has been an increase in mobilization and loading of these constituents resulting from land-use changes in the region. Salinity and dissolved-selenium concentrations have the potential to increase in a stream when excess irrigation water seeps into the groundwater system and discharges to a stream (Butler, 2001).

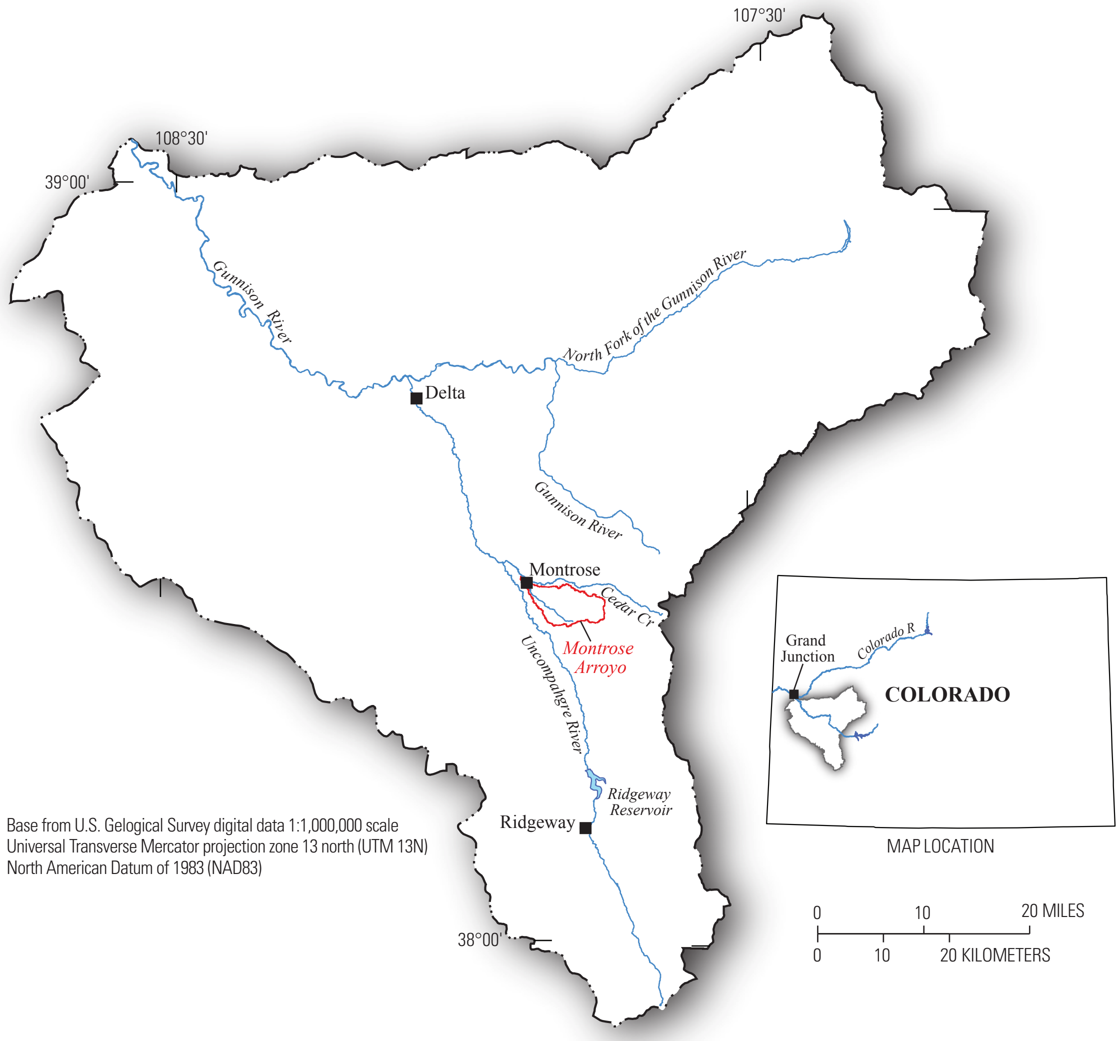

Figure 1. Overview of the lower Gunnison River watershed, Colorado.

The Montrose Arroyo watershed in Montrose, Colo., contains agricultural and residential areas as well as undeveloped land. The watershed has undergone substantial land-use change since the early 1990s. Land use in the watershed was historically agricultural with a small amount of urban land use. Beginning in the mid-2000s, the Montrose Arroyo watershed (hereafter Montrose Arroyo) has undergone large scale land-use change through the conversion of agricultural land to urban land (Moore, 2011). Previous studies on the conversion of irrigated agricultural land to urban land use reported that water application was more efficient on urban land than on agricultural land. Higher water application efficiency leads to reduced deep percolation resulting in reduced salinity and selenium mobilization; some locations with unlined ponds are the exception (Mayo, 2008). Conversion of previously unirrigated land to an urban land-use setting, however, may increase the potential for salinity and dissolved-selenium mobilization (Fahy and others, 2000).

Previous water-quality sampling and analyses through 2010 in the Montrose Arroyo indicated salinity concentrations and loads have remained constant since land-use change began in the early 1990s. However, results from recent sampling indicate that dissolved-selenium concentrations and loads have begun to increase (Moore, 2011). These results were unexpected because the majority of land-use change was from irrigated agricultural land to urban land. Additionally, these results were unexpected because of a large salinity/selenium control project that was implemented in Montrose Arroyo (Butler, 2001). In response to the increasing dissolved-selenium concentrations and loads, the U.S. Geological Survey (USGS)—in cooperation with the Bureau of Reclamation (USBR); Colorado River Basin Salinity Control Forum (CRBSCF); and Colorado River Water Conservation District (CRWCD)—continued to monitor salinity and dissolved-selenium concentrations and loads in Montrose Arroyo. Water-quality samples were collected and streamflow measured at three of the eight sites sampled in the

Butler study (2001). The three sites are Montrose Arroyo at East Niagara Street (MA2, USGS site identification number 382802107513301), Montrose Arroyo at 6700 Road (MA3, USGS site identification number 382711107500501), and Montrose Arroyo at 6750 and Ogden Roads (MA4, USGS site identification number 382702107493701). Sampling at these sites also is a continuation of previous sampling reported in *Characterization of Salinity and Selenium Loading in Land-use Change in Montrose Arroyo, Western Colorado, from 1992 to 2010* (Moore, 2011), which included samples collected from March 1992 to February 2010. Analytical results from samples collected in this study were compared to previously collected samples to characterize trends in streamflow, salinity concentration and load, and dissolved-selenium concentration and load.

Purpose and Scope

This report documents the characterization of salinity and dissolved-selenium loading at three sites on Montrose Arroyo from March 1992 through September 2013 based on data previously collected from March 1992 through February 2010 (Moore, 2011; U.S. Geological Survey, 2015a) and data collected December 2011 through September 2013 for this report. The data were used to detect step trends in streamflow, salinity concentration and load, and dissolved-selenium concentration and load throughout the study period. The study period was divided into three time periods: the pre-lateral period (before April 1999), the post-lateral period (April 1999–October 2000), and the post-growth period (March 2008–September 2013). This report also includes an analysis of land-use change of the sampling site MA3 subwatershed. This analysis corresponds with the same time frame of land-use change analysis that was reported in Moore (2011).

Previous Studies

Salinity and dissolved-selenium sources, transport, and loading have been investigated in Montrose Arroyo by the USGS since 1998. Results of this work are reported in two reports: Butler (2001) and Moore (2011). Butler (2001) characterized the effects of a salinity-control demonstration project designed around the lining and piping of five laterals in the Montrose Arroyo watershed. In the Butler (2001) study, three main-stem water-quality sampling sites along with two sites on drainage ditches were monitored to quantify the effects of the lining and piping of laterals on dissolved-selenium and salinity loading in Montrose Arroyo. Sampling began in June 1998 and continued through October 2000, and the report compared dissolved-selenium and salinity concentrations from before and after the lining and piping of laterals. Butler (2001) reported that lining and piping the laterals significantly reduced the dissolved-selenium and salinity loads in Montrose Arroyo, with dissolved-selenium loads being reduced by as much as 37 percent and salinity loads reduced by as much as 17 percent at main-stem sites. The reduction in dissolved-selenium and salinity loading in Montrose Arroyo were a result of reduced canal leakage into the shallow groundwater system and subsequent reduced groundwater discharge to Montrose Arroyo (Butler, 2001).

Moore (2011) characterized salinity and dissolved-selenium concentrations and loads at two sites in Montrose Arroyo that were previously described in Butler (2001). Moore (2011) also analyzed the magnitude of land-use change that had taken place in Montrose Arroyo from 1992 to 2010. From 1992 to 2010, streamflow, salinity concentration and load, and dissolved-selenium concentration and load, remained statistically unchanged from data reported in Butler (2001) at the most upstream site, MA4. However, dissolved-selenium concentration and load showed a statistically significant increase at the downstream site (MA2). The increase at site MA2 was contrary to what was expected to be either no change or a decrease in dissolved-selenium load, based on the conversion of agricultural to urban land use in the MA2 subwatershed (Mayo, 2008). The study documented in this report was designed to further investigate the increase in dissolved-selenium concentration and load in downstream areas from the Montrose Arroyo.

Description of Study Area

The study area is Montrose Arroyo, which drains an approximately 18-square-mile watershed in western Colorado (fig. 1). Montrose Arroyo is a tributary to Cedar Creek, which is itself a tributary to the Uncompahgre River (fig. 1). The climate in Montrose Arroyo is semiarid, with an average annual precipitation of approximately 9.6 inches. The average annual high and low temperatures in Montrose are 63.4 degrees Fahrenheit and 34.6 degrees Fahrenheit, respectively (Western Regional Climate Center, 2013). The geology of the Montrose Arroyo study area is primarily Mancos Shale bedrock overlain by weathered shale alluvium or gravels. The gravels typically are more common along the existing and historical Uncompahgre River channel and flood plain (Tweto, 1979).

The primary land cover in the study area is agriculture and unirrigated desert; however, residential and commercial land use is increasing with population growth. The major population center in Montrose Arroyo is the city of Montrose (fig. 1) with a population of approximately 19,000 (U.S Census Bureau, 2013). The population in Montrose increased approximately 35 percent from 1999 to 2012 (U.S. Census Bureau, 2013). The majority of urban growth around Montrose Arroyo occurred between 1999 and 2008 based on aerial imagery (U.S. Department of Agriculture, 2010), defining the post-growth period of the analysis as data collected from March 2008 through September 2013. Changes in land use have resulted in a shift from unirrigated desert and irrigated agricultural land to urban land use. In 1997–98, a golf course was constructed in Montrose Arroyo and was centered in an area of residential growth. Coinciding with the development of the golf course, in 1998–2000 a salinity-control project converted approximately 8.5 miles (mi) of open-ditch irrigation laterals to polyvinyl chloride (PVC) pipe (Bureau of Reclamation, 2013).

Montrose Arroyo is a highly regulated system driven by agricultural recharge and management of the irrigation delivery system (canals and laterals). Because there is significant irrigation management, variability in streamflow is fairly low and predictable. Irrigation water is delivered from Blue Mesa Reservoir, the largest water storage facility in Colorado (not shown in fig. 1, but about 46 mi east of the city of Montrose). The water from the reservoir contains trace amounts of selenium and is typical of alpine runoff for salinity concentrations. In all but the driest years, a full allotment of irrigation water is delivered to water users in the region. Water is supplied through various conveyances beginning in April and the supply remains constant through October (Butler, 2001; U.S. Geological Survey, 2015c). Delivery of irrigation water through the system during these months causes the creeks and arroyos to flow an order of magnitude or higher than during base-flow months. However, with the exception of infrequent precipitation events, the annual volume and timing of streamflow in these creeks and arroyos is consistent from year to year. The infrequent snowmelt and (or) rain occurrences are not well characterized, but these occurrences make up a small portion of the annual streamflow and load. Based on observations of nearby arroyos that lack irrigation effect (Richards and others, 2014), it can be surmised that Montrose Arroyo would be dry the vast majority of the year without the presence of irrigated agriculture.

Methods for Analysis of Salinity and Selenium Loading

Streamflow and Water-Quality Data Collection

Salinity and dissolved-selenium concentrations and loads were monitored at three sites in Montrose Arroyo: site MA2 (USGS site identification number 382802107513301) Montrose Arroyo at East Niagara Street, MA3 (USGS site identification number 382711107500501) Montrose Arroyo at 6700 Road, and MA4 (USGS site identification number 382702107493701) Montrose Arroyo at 6750 and Ogden Roads (fig. 2). From December 2011 through September 2013, 46 water-quality samples and streamflow measurements were collected at sites MA2, MA3, and MA4. The upgradient control site (MA4) and the outflow site (MA2) were the same sites used in the Butler (2001) study and the more recent salinity and dissolved-selenium loading analysis in Moore (2011). Site MA3 was added for this study to investigate increases in dissolved-selenium concentrations and loads in Montrose Arroyo reported in Moore (2011) and to determine if changes in salinity and dissolved-selenium concentrations and loads are related to land-use change in the MA3 subwatershed.

Instantaneous streamflow at all sites was measured using a YSI FlowTracker Acoustic Doppler Velocimeter (ADV) using methods described by Turnipseed and Sauer (2010). Streamflow was measured during the collection of each water-quality sample to enable estimation of salinity and dissolved-selenium loads. Water-quality samples were collected in 1-liter (L) polyethylene bottles and composited in a 4-L churn. Samples were filtered through a 0.45-micrometer (µm) capsule filter into 250-milliliter (mL) polyethylene bottles for laboratory analysis. Nitric acid was used to preserve water-quality samples for cation and trace metal analysis. All samples were collected and processed while wearing powderless surgical gloves to prevent contamination during handling. Collection of all samples followed standard USGS techniques and procedures (U.S. Geological Survey, variously dated).

All samples were analyzed by the USGS National Water Quality Laboratory (NWQL), in Lakewood, Colo., following methods described in Fishman and Friedman (1989). Quality assurance and quality control (QA/QC) for the water-quality sampling consisted of three replicate samples and two field blank samples. QA/QC samples were sent to the laboratory along with environmental samples. Approximately 10 percent of the samples collected during the study period were QA/QC samples. Streamflow, salinity concentration (Total Dissolved Solids [TDS] as sum of constituents), and dissolved-selenium concentration sample data can be found in the USGS National Water Information System database at http://waterdata.usgs.gov/nwis/qw.

Salinity and Dissolved-Selenium Load Estimation

Instantaneous loads for salinity and dissolved selenium were estimated by multiplying streamflow by concentration and a units-conversion factor. Instantaneous salinity and dissolved-selenium loads were assumed to be constant for the day on which samples were collected. Salinity loads were reported in tons per day, whereas dissolved-selenium loads were reported in pounds per day. Load estimations for each site were separated into three time periods: the pre-lateral period (March 1992–April 1999), post-lateral period (April 1999–October 2000), and post-growth period (March 2008–September 2013).

Streamflow, Salinity, and Dissolved-Selenium Step-Trend Estimations

To determine whether mean and median concentrations and loads were significantly different between the pre-lateral, post-lateral, and post-growth time periods, a step-trend two-sample test (Helsel and Hirsch, 2002) was performed on the data. Because some of the data appeared to be non-normally distributed, a nonparametric, two-sample Wilcoxon Rank-Sum test (Helsel and Hirsch, 2002) also was done on the data. Streamflow and salinity and dissolved-selenium concentrations and loads at the three sites

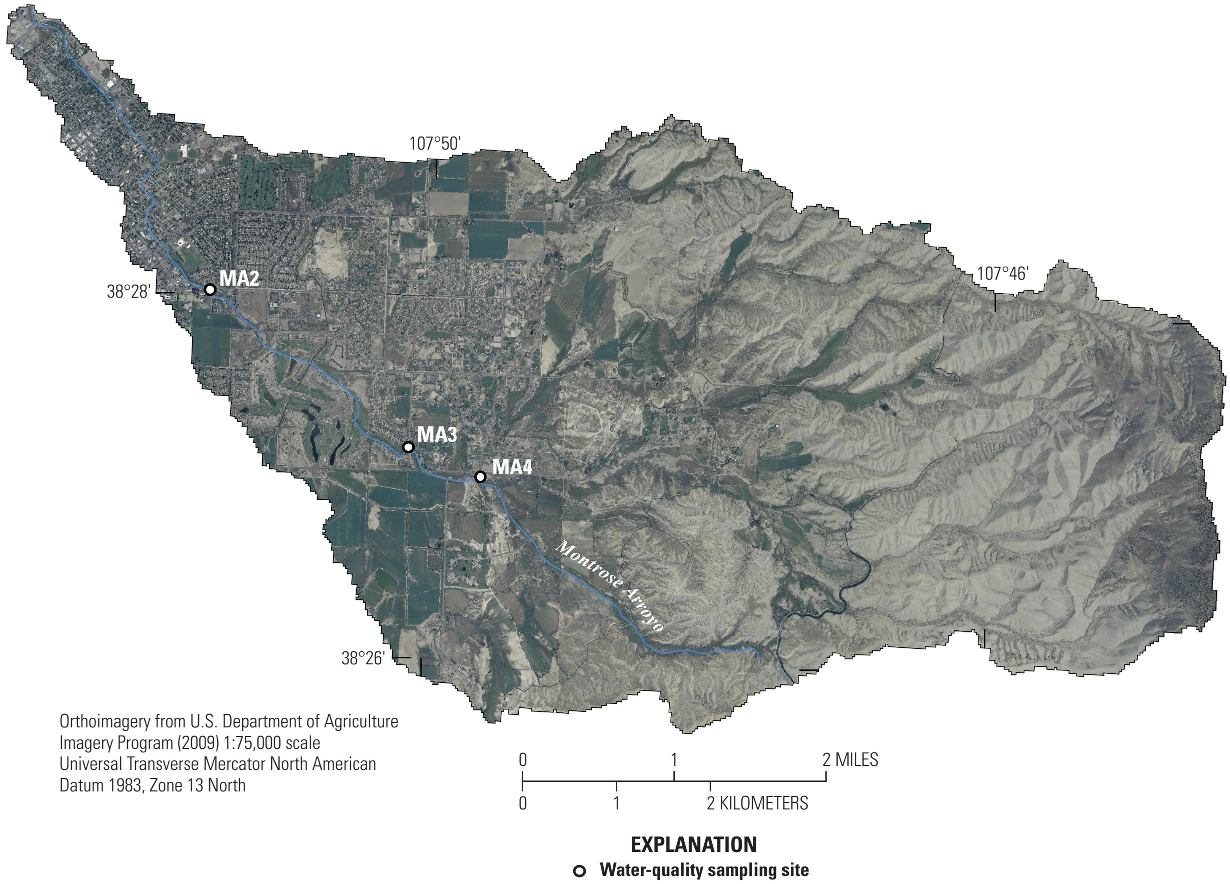

Figure 2. Montrose Arroyo study area and sampling sites, Montrose, Colorado.

were compared between the pre-lateral period and post-growth period and between post-lateral period and post-growth period. Trends were evaluated on the basis of statistical significance and are considered "highly significant" when the trend test reports a confidence level greater than 99 percent (p-value of 0.01 or less) and "significant" when the trend test reports a confidence level greater than 90 percent (p-value of 0.10 or less). Statistically significant trends were determined on the basis of increasing or decreasing mean and median values.

Land Use

Land use in Montrose Arroyo was characterized for 1992, 2002, and 2009 using aerial imagery obtained from the U.S. Department of Agriculture, National Agricultural Imagery Program (NAIP) imagery program during the agricultural growing season (U.S. Department of Agriculture, 2010) in a Geographic Information System (GIS). Land use in the subwatersheds for sites MA2 and MA4 are summarized for these years in Moore (2011). This study documents land use and land-use changes in the subwatershed which drains to the MA3 sampling site, for the previously mentioned years (fig. 3). All detailed land-use information for the MA3 subwatershed was manually classified in ArcGIS (Esri, 2006) into three groups: irrigated agriculture, unirrigated desert, and urban.

Areas classified as riparian or wetlands that were surrounded by unirrigated desert with no apparent irrigation effects were classified as unirrigated desert. Riparian and wetland areas surrounded by irrigated agriculture were classified as irrigated agricultural land, with the assumption that irrigation is the water source for these riparian and wetland areas. Occasionally, irrigated agricultural land was left fallow prior to a change in land use. This was typically seen when irrigated agricultural land was being converted to urban land use. Irrigated agricultural land that was in a fallow state was classified as irrigated agriculture and was considered to be leached during its previously irrigated state; therefore, it did not represent true unirrigated or desert land use.

Streamflow, Salinity, and Dissolved-Selenium Loading Step Trends

The streamflow, salinity (concentration and load), and dissolved-selenium (concentration and load) step trends discussed in Moore (2011) were re-evaluated with the data collected from December 2011 through September 2013. Site MA4 was a control site with minimal land-use change upstream. Site MA3 was used to determine changes in streamflow, salinity (concentration and load), and dissolved selenium (concentration and load)

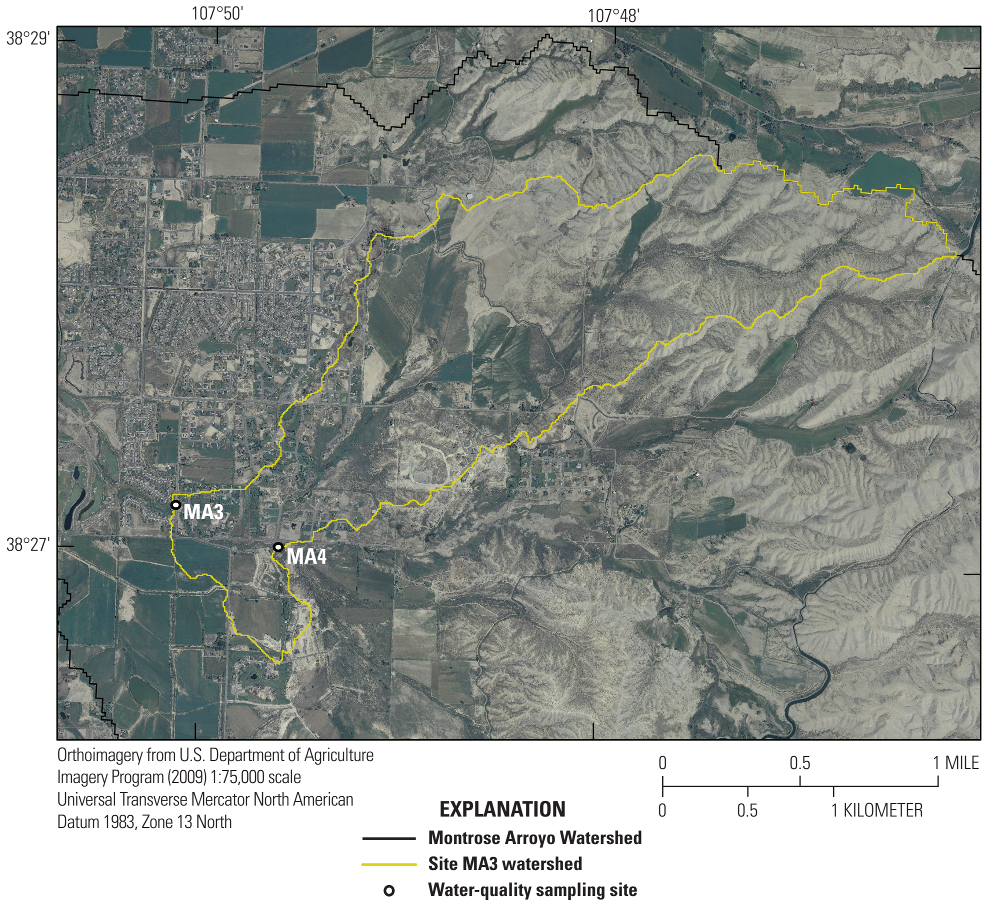

Figure 3. The MA3 subwatershed and sampling site within the Montrose Arroyo study area, Montrose, Colorado.

and the effects of land-use change upstream from site MA2 and assist in characterizing the step trends in salinity and dissolved selenium at site MA2 discussed in Moore (2011). Step-trend analysis was continued at site MA2 to characterize reported step trends in Moore (2011) with the additional sample information collected from December 2011 through September 2013. Step trends detected at upstream sites (MA3 or MA4) were considered when assessing step trends at downstream sites (MA2 or MA3), because the effect of the upstream step trend should propagate downstream.

Streamflow Step Trends

No significant step trend in streamflow was observed at site MA4 from the pre-lateral period to the post-growth period, or from the post-lateral period to the post-growth period (table 1, fig. 4). Site MA3 showed no significant step trend in streamflow from the pre-lateral period to the post-growth period, but showed a statistically significant decrease in streamflow from the post-lateral period to the post-growth period (table 2, fig. 4). At site MA2, the streamflow step-trend analysis indicated a significant decrease in streamflow from the pre-lateral period to the post-growth period and from the post-lateral period to the post-growth period (table 3, fig. 4).

Salinity and Dissolved-Selenium Concentration and Load Step Trends

No step trends in salinity concentration and load were observed at the upstream control site MA4 from the pre-lateral period to the post-growth period, or from the post-lateral period to the post-growth period (table 1, fig. 5). Similarly, no step trends in dissolved-selenium concentration and load were observed at site MA4 from the pre-lateral period to the post-growth period or the post-lateral period to the post-growth period (table 1, fig. 5). The salinity and dissolved-selenium step trend at site MA4 responded as expected for a background site; there was no statistically significant change in streamflow or salinity and dissolved-selenium concentrations and loads. Because site MA4 is considered a background site for the study, it was assumed that background conditions were not changing over time and any changes seen at sites MA3 and MA2 were a result of additional processes within the watershed (such as land-use change or management practices).

Site MA3 showed no statistically significant change in salinity concentration from the pre-lateral period to the post-growth period or from the post-lateral period to the post-growth period. A statistically significant downward step trend was observed in salinity load for both periods (table 2, fig. 6).

Table 1. Two-sample t-test and Wilcoxon Rank-Sum trend assessment at 90-percent confidence level for streamflow, salinity, and selenium (concentration and load) at site MA4 in Montrose Arroyo, Montrose, Colorado.

[p, less than 0.10 considered significant; p, less than 0.01 considered highly significant; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; lbs, pounds]

Constituent	Units	Time period[1]	Two sample t-test (two-sided) p-value	Mean	Significance	Wilcoxon Rank-Sum (two-sided) p-value	Median	Significance
Streamflow								
Streamflow	ft^3/s	1–3	0.175	0.661; 0.880	Not significant	0.980	0.640; 0.525	Not significant
Streamflow	ft^3/s	2–3	0.925	0.896; 0.880	Not significant	0.480	0.765; 0.525	Not significant
Salinity								
Concentration	mg/L	1–3	0.487	5,060; 4,534	Not significant	0.463	6,305; 4,465	Not significant
Concentration	mg/L	2–3	0.957	4,498; 4,534	Not significant	0.702	3,710; 4,465	Not significant
Load	tons/day	1–3	0.666	7.98; 7.44	Not significant	0.734	6.41; 6.42	Not significant
Load	tons/day	2–3	0.408	8.25; 7.44	Not significant	0.249	7.79; 6.42	Not significant
Selenium								
Concentration	µg/L	1–3	0.885	52.2; 50.1	Not significant	0.625	64.5; 22.8	Not significant
Concentration	µg/L	2–3	0.236	35.7; 50.1	Not significant	0.602	18.0; 22.8	Not significant
Load	lbs/day	1–3	0.443	0.162; 0.127	Not significant	0.650	0.118; 0.090	Not significant
Load	lbs/day	2–3	0.449	0.107; 0.127	Not significant	0.797	0.093; 0.090	Not significant

[1]Time period 1 refers to pre-lateral period (March 1992 through April 1999), time period 2 refers to post-lateral period (April 1999 through October 2000), time period 3 refers to post-growth period (March 2008 through September 2013).

Statistically significant downward step trends in dissolved-selenium concentration were observed from the pre-lateral period to the post-growth period, but no statistically significant step trend in dissolved-selenium concentration was observed from the post-lateral period to the post-growth period. Statistically significant downward step trends in dissolved-selenium load were observed for both periods (table 2, fig. 6). The statistically significant decreases in both salinity and dissolved-selenium loads at site MA3 were consistent with the expected response of converting previously irrigated land to urban land use as reported in Mayo (2008). These decreases may also be a continuation of the effects of lateral piping in the area that was completed in April 1999 in conjunction with conversion of land use in Montrose Arroyo. An additional factor may have been drought conditions in 2012 (Western Regional Climate Center, 2013); however, downward step trends in streamflow were not detected at the background site MA4.

Site MA2 showed no statistically significant change in salinity concentration from the pre-lateral period to the post-growth period or the post-lateral period to the post-growth period. A statistically significant downward step trend was observed in salinity load from the pre-lateral period to the post-growth period. However, there was no statistically significant salinity load step trend observed from the post-lateral period to the post-growth period (table 3, fig. 7). A statistically significant upward step trend was observed in dissolved-selenium concentration for both periods. There was no statistically significant step trend observed in the dissolved-selenium load from the pre-lateral period to the post-growth period, but there was a statistically significant upward step trend observed in dissolved-selenium load from the post-lateral period to the post-growth period (table 3, fig. 7).

At site MA2, the statistically significant downward step trend in salinity load for the pre-lateral period to the post-growth period appears to be dominated by streamflow. Step trends in salinity concentrations remained statistically insignificant from the pre-lateral period to the post-growth period, as well as the post-lateral period to the post-growth period. Decreases in streamflow from the pre-lateral period to the post-growth period could be a result of different factors, including improved efficiency of irrigation water use as a result of piping and lining of laterals in Montrose Arroyo, land-use change within the MA2 subwatershed, and a reduction of irrigation water delivered to the system as a result of drought periods. As a result of the decrease in streamflow, there was an increase in the median value of the salinity concentration; however, the step-trend test indicated no significance. This increase in concentration resulted in an insignificant step trend in salinity load from the post-lateral period to the post-growth period. There was a significant downward step trend in salinity load for the pre-lateral period to the post-growth period. This result indicates that salinity load reduction occurred primarily between the pre-lateral period and the post-lateral period likely as a result of canal piping and lining projects. It should be recognized that some of the salinity load decrease observed at site MA2 is a result of salinity load decreases in the MA3 subwatershed and not a direct result of changing conditions in the MA2 subwatershed.

Step trends in dissolved-selenium concentration and load at site MA2 do not seem to be associated with streamflow in the same manner as salinity. The statistically significant upward step trend in dissolved-selenium concentration from the pre-lateral period to the post-growth period and the post-lateral period to the post-growth period corresponds to the statistically significant decrease in streamflow for the same period. The observed increase in dissolved-selenium concentration is potentially a result of decreased water deliveries

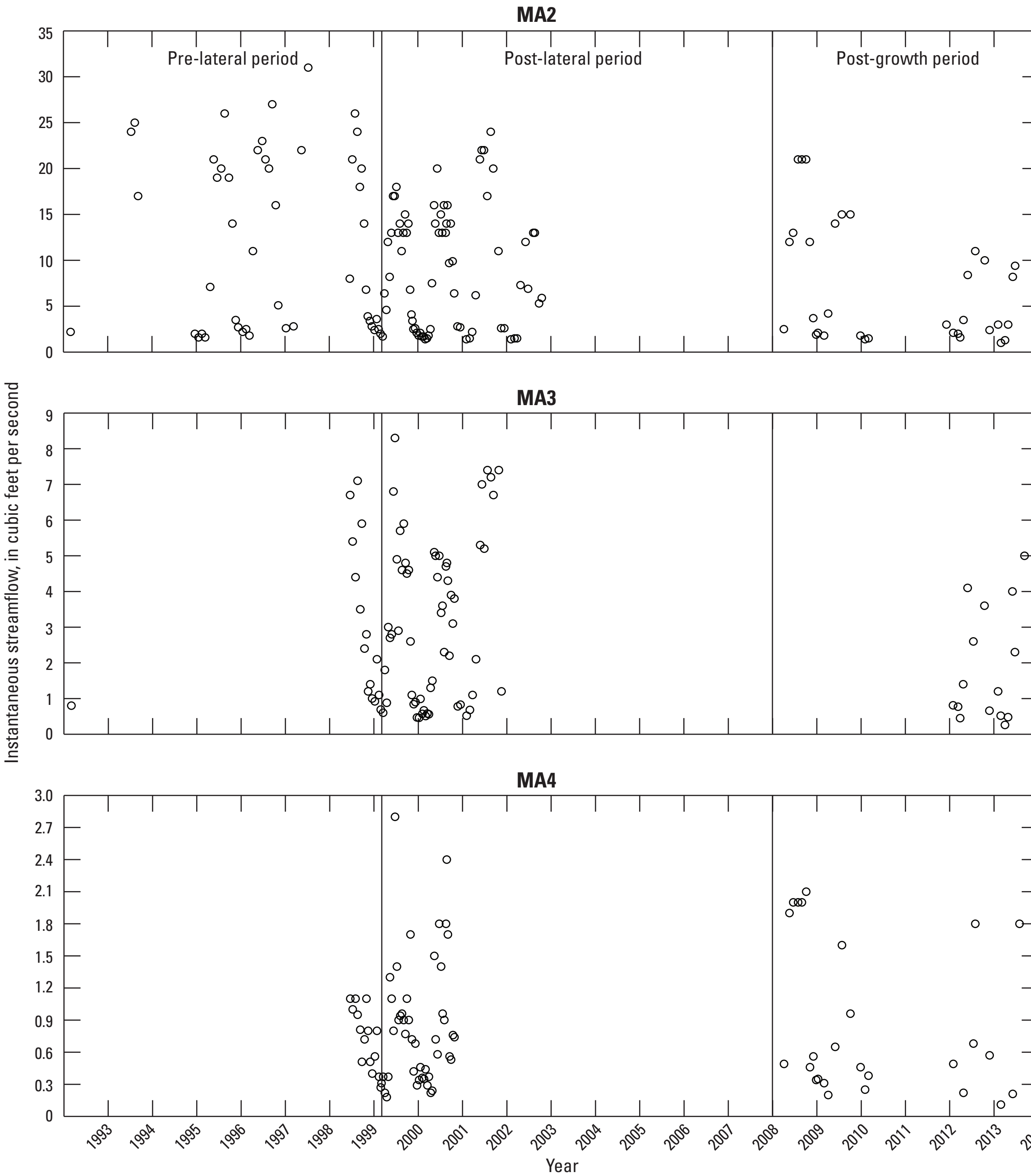

Figure 4. Scatterplot of periodic streamflow at sites MA2, MA3, and MA4 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013.

that would dilute concentrations. Furthermore, no significant step trend in the dissolved-selenium load from the pre-lateral period to the post-growth period was detected, also indicating that the increase in dissolved-selenium concentration may have resulted from losses in dilution water. However, the statistically significant upward step trend in dissolved-selenium load from the post-lateral period to the post-growth period along with a statistically significant decrease in streamflow and increase in concentration indicates that there are other factors contributing to the upward step trend in dissolved-selenium concentration other than just a reduction in streamflow. This finding also indicates that dissolved-selenium loads are responding differently than salinity loads to changing conditions at site MA2 and there are additional processes controlling salinity and dissolved selenium in the MA2 subwatershed relative to the MA3 subwatershed.

A potential explanation for why the post-lateral period to the post-growth period is exhibiting this behavior could be attributed to the nature of salinity and dissolved selenium in Montrose Arroyo and the region in general. Given a small,

Table 2. Two-sample t-test and Wilcoxon Rank-Sum trend assessment at 90-percent confidence level for streamflow, salinity, and selenium (concentration and load) at site MA3 in Montrose Arroyo, Montrose, Colorado.

[p, less than 0.10 considered significant; p, less than 0.01 considered highly significant; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; lbs, pounds]

Constituent	Units	Time period[1]	Two sample t-test (two-sided) p-value	Mean	Significance	Wilcoxon Rank-Sum (two-sided) p-value	Median	Significance
Streamflow								
Streamflow	ft^3/s	1–3	0.189	2.77; 1.88	Not significant	0.140	1.95; 1.20	Not significant
Streamflow	ft^3/s	2–3	0.010	3.29; 1.88	Highly significant	0.020	3.05; 1.20	Significant
Salinity								
Concentration	mg/L	1–3	0.983	4,410; 4,390	Not significant	0.832	5,480; 4,145	Not significant
Concentration	mg/L	2–3	0.211	3,303; 4,390	Not significant	0.615	2,140; 4,145	Not significant
Load	tons/day	1–3	0.015	20.0; 13.2	Significant	0.003	18.4; 10.8	Highly significant
Load	tons/day	2–3	0.028	17.9; 13.2	Significant	0.007	17.7; 10.8	Highly significant
Selenium								
Concentration	µg/L	1–3	0.017	75.8; 34.1	Significant	0.009	82.0; 21.7	Highly significant
Concentration	µg/L	2–3	0.725	37.8; 34.1	Not significant	0.167	21.0; 21.7	Not significant
Load	lbs/day	1–3	0.003	0.673; 0.198	Highly significant	0.000	0.491; 0.129	Highly significant
Load	lbs/day	2–3	0.009	0.376; 0.198	Highly significant	0.000	0.362; 0.129	Highly significant

[1]Time period 1 refers to pre-lateral period (March 1992 through April 1999), time period 2 refers to post-lateral period (April 1999 through October 2000), time period 3 refers to post-growth period (March 2008 through September 2013).

Table 3. Two-sample t-test and Wilcoxon Rank-Sum trend assessment at 90-percent confidence level for streamflow, salinity, and selenium (concentration and trend) at site MA2 in Montrose Arroyo, Montrose, Colorado.

[p, less than 0.10 considered significant; p, less than 0.01 considered highly significant; ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; lbs, pounds]

Constituent	Units	Time period[1]	Two sample t-test (two-sided) p-value	Mean	Significance	Wilcoxon Rank-Sum (two-sided) p-value	Median	Significance
Streamflow								
Streamflow	ft^3/s	1–3	0.008	11.9; 7.12	Highly significant	0.020	8.00; 3.50	Significant
Streamflow	ft^3/s	2–3	0.092	9.46; 7.12	Significant	0.080	9.80; 3.50	Significant
Salinity								
Concentration	mg/L	1–3	0.565	2,882; 3,116	Not significant	0.281	1,820; 2,800	Not significant
Concentration	mg/L	2–3	0.189	2,634; 3,116	Not significant	0.255	1,780; 2,800	Not significant
Load	tons/day	1–3	0.013	49.6; 39.1	Significant	0.024	56.3; 35.0	Significant
Load	tons/day	2–3	0.182	44.2; 39.1	Not significant	0.218	46.6; 35.0	Not significant
Selenium								
Concentration	µg/L	1–3	0.010	58.3; 86.4	Highly significant	0.001	36.0; 73.0	Highly significant
Concentration	µg/L	2–3	0.000	40.9; 86.4	Highly significant	0.000	27.0; 73.0	Highly significant
Load	lbs/day	1–3	0.532	1.89; 2.02	Not significant	0.981	1.90; 1.88	Not significant
Load	lbs/day	2–3	0.001	1.34; 2.02	Highly significant	0.000	1.36; 1.88	Highly significant

[1]Time period 1 refers to pre-lateral period (March 1992 through April 1999), time period 2 refers to post-lateral period (April 1999 through October 2000), time period 3 refers to post-growth period (March 2008 through September 2013).

highly concentrated point source (such as groundwater input, surface-water input, or others) it can be shown mathematically that changes to the in-stream water concentrations of salinity and dissolved selenium respond differently. An example shown in table 4 verifies that a small input of water with high concentrations of dissolved selenium effects the in-stream concentration by a higher percentage than the high salinity concentration. A similar unknown source may help explain why the downward step trend in dissolved-selenium concentrations and loads at site MA3 is not observed downstream at site MA2 for the pre-lateral period to the post-growth period and that there was a change from a downward step trend to an upward step trend for the post-lateral period to the post-growth period. Salinity exhibited a downward step trend and no step trend respectively for these periods. The actual mechanism(s) driving the salinity and dissolved-selenium step trends between sites MA3 and MA2 is not well understood and is outside the scope of this study. Future groundwater monitoring and characterization of the localized geochemistry would help address the mechanisms and sources controlling step trends in the Montrose Arroyo.

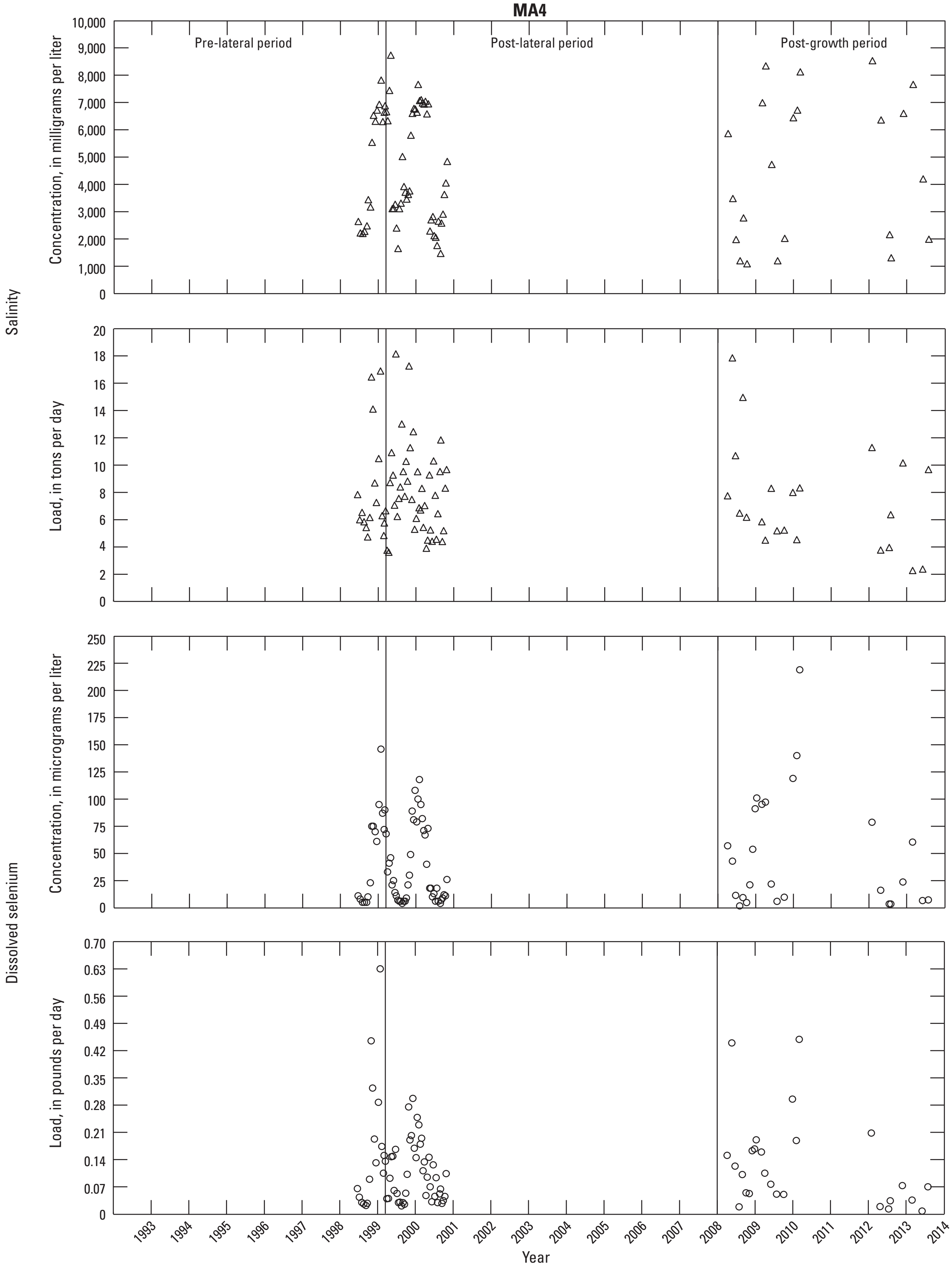

Figure 5. Scatterplot of salinity and selenium concentrations and loads at site MA4 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013.

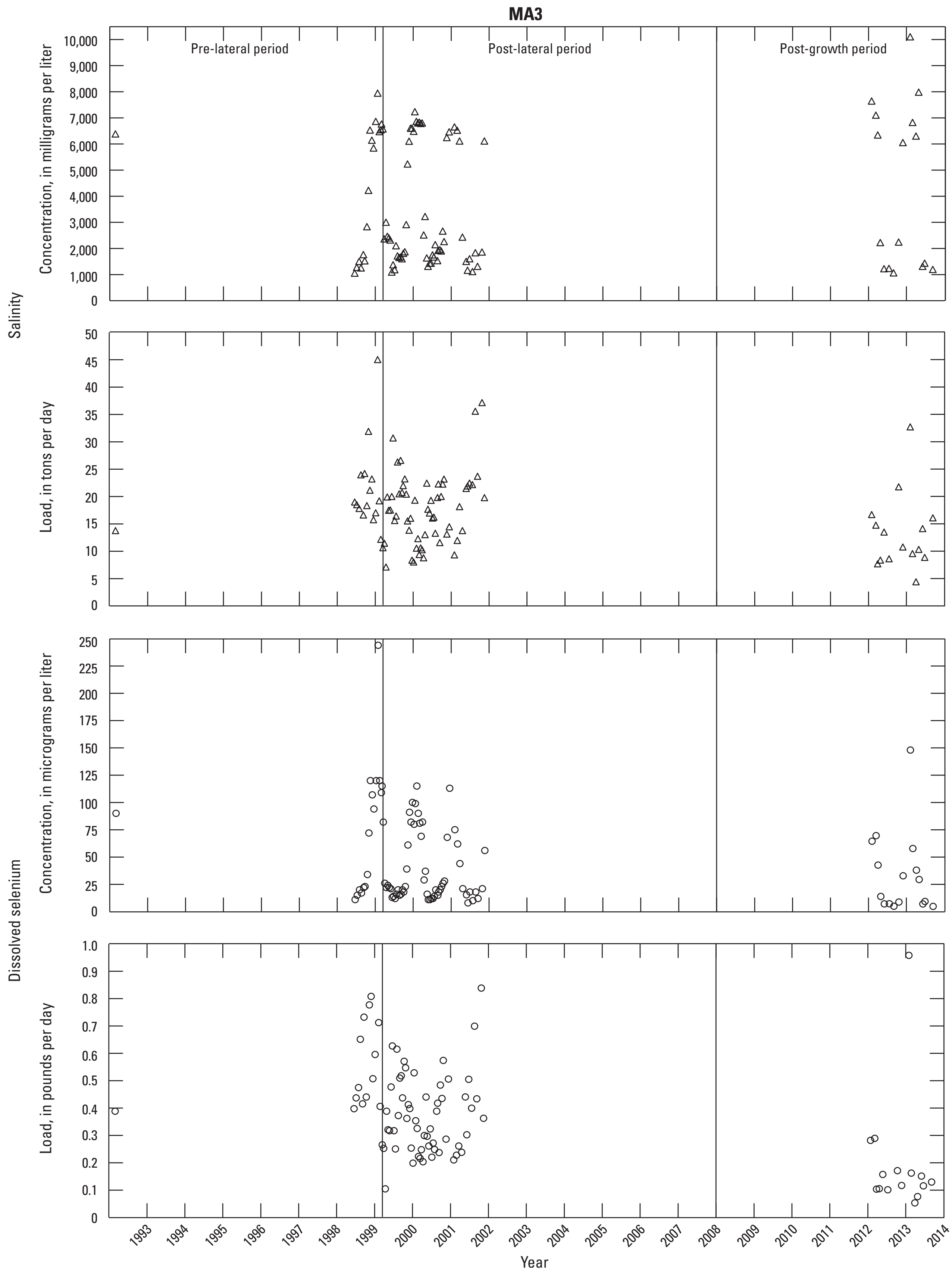

Figure 6. Scatterplot of salinity and selenium concentrations and loads at site MA3 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013.

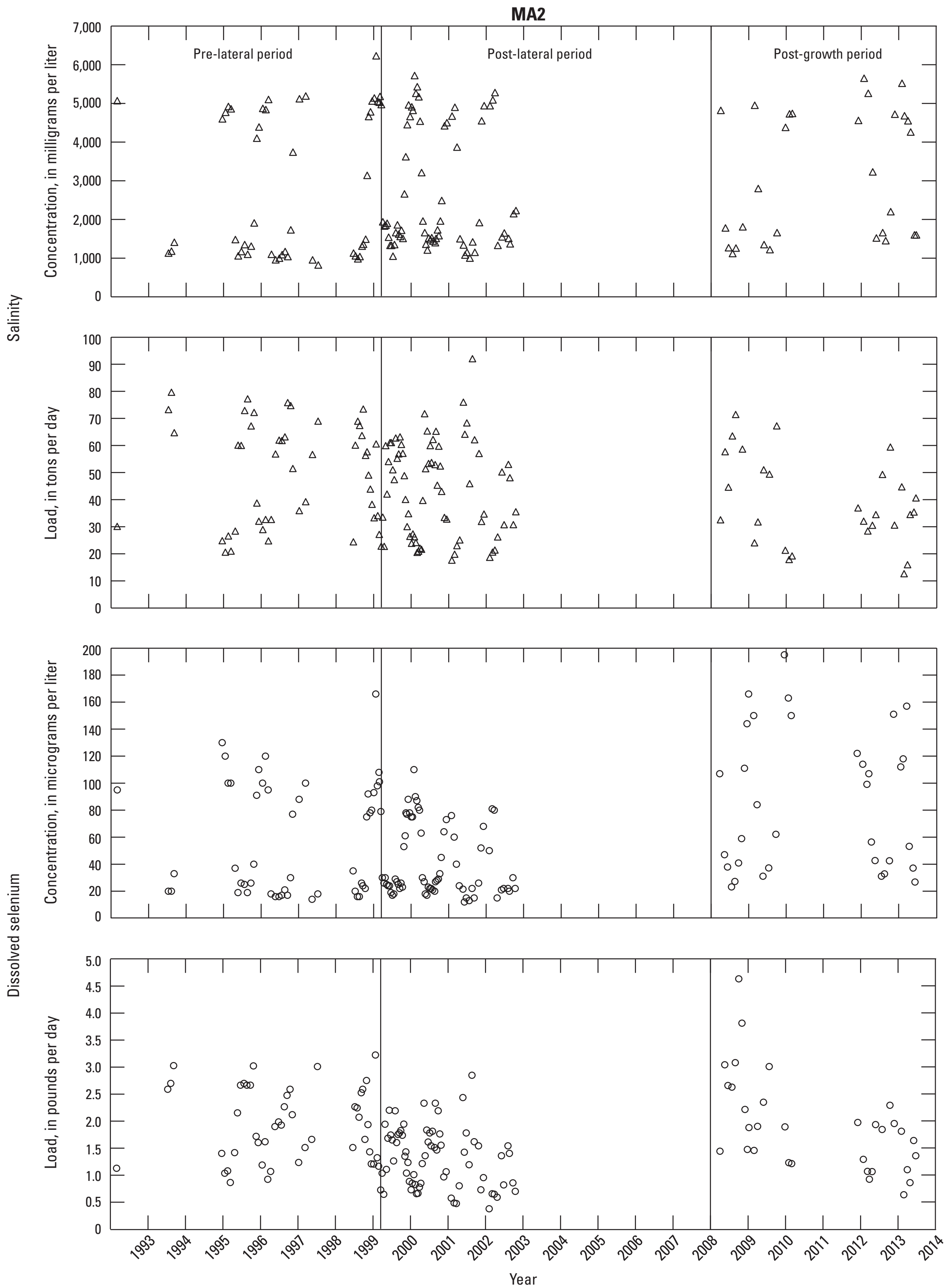

Figure 7. Scatterplot of salinity and selenium concentrations and loads at site MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013.

Seasonal salinity and dissolved-selenium concentrations at site MA2 follow a seasonal pattern. Samples collected from December 2011 to September 2013 were compared to historical samples collected before March 2008 and samples collected from March 2008 through February 2010. All salinity and dissolved-selenium concentrations follow a seasonal pattern of lower concentrations during the irrigation season (April–October) when irrigation water is being delivered and a higher concentration during base flow (November–March) (fig. 8). The relation of specific conductance to dissolved-selenium concentration indicated that the relation observed from March 2008 through February 2010 (Moore, 2011) had shifted back toward the historical relation in samples collected prior to March 2008 (fig. 9). It should be noted that specific conductance can be used as a surrogate for estimating salinity concentration and was compared to dissolved selenium in this case to match an actual in-situ measured value of specific conductance to dissolved selenium (Liebermann and others, 1987). The comparison can indicate how dissolved selenium and salinity may be interacting within the system. The mechanism that caused the change in water chemistry that occurred during the March 2008 through February 2010 period and is not well understood. There is potentially a response to land-use change and (or) reconfiguration of a golf course, which moved approximately 850,000 cubic yards of earth during construction (Nicklaus Design, 2014). Initial response to this disturbance potentially caused dissolved-selenium concentrations in Montrose Arroyo to increase. It appears that by December 2011 dissolved-selenium concentrations began to return to historic levels (fig. 9).

Land-Use Change

Land-use change in the MA3 subwatershed was investigated in this report. Land-use change for the MA2 and MA4 subwatersheds were previously documented in Moore (2011). The most common land-use change in MA3 was a conversion from irrigated agricultural land to urban land use. Based on results from Mayo (2008), conversion from irrigated agricultural land to urban land use increased water application efficiency and reduced the potential for deep percolation, resulting in a decrease in salinity loading. However, converting unirrigated desert to either irrigated agriculture or urban land use could potentially increase salinity and selenium loading (Fahy and others, 2000; Mayo, 2008).

Land use was characterized for 1992, 2002, and 2009 for the MA3 subwatershed (table 5). The majority of land-use change occurred between 1992 and 2002 with the majority of the land use changing from irrigated agriculture to urban land use (fig. 10; table 6). Irrigated agriculture land use in the MA3 subwatershed decreased from 644 acres in 1992, to 565 acres in 2002, and to 520 acres in 2009 (table 5). Urban land use increased from 40.6 acres, to 146 acres, to 192 acres, respectively. Unirrigated agriculture decreased from 1,050 acres to 1,023 acres from 1992 to 2002 and did not change from 2002 to 2009 (table 5). Overall, the MA3 subwatershed had 124 acres of irrigated land use converted to urban land use and 27.1 acres of unirrigated agriculture to urban land use from 1992 to 2009 (table 6). Consistent with findings in Mayo (2008), salinity and dissolved-selenium loading at site MA3 showed significant decreases from the pre-lateral period to the post-growth period as irrigated land was converted to urban land use (table 2).

Table 4. Results of two-component mixing model with variable inflow volumes on mean salinity and selenium loads at site MA2 in Montrose Arroyo, Montrose, Colorado.

[ft^3/s, cubic feet per second; mg/L, milligrams per liter; µg/L, micrograms per liter; ton/d, tons per day; lb/d, pounds per day]

Mean stream condition for post-growth period[1]					
	Salinity	**Selenium**			
Streamflow, in ft^3/s	7.12	7.12			
Concentration	3,116 mg/L	86 µg/L			
Load	39.1 ton/d	3.30 lb/d			
Salinity input[2]					
Inflow volume, in ft^3/s	0.0001	0.001	0.01	0.1	1.0
Concentration, mg/L	43,000	43,000	43,000	43,000	43,000
Load, ton/d	0.0116	0.116	1.16	11.6	116
Percent of stream load	0.0202	0.202	2.02	20.2	202
Selenium input[2]					
Streamflow, in ft^3/s	0.0001	0.001	0.01	0.1	1.0
Concentration, µg/L	3,000	3,000	3,000	3,000	3,000
Load, lb/d	0.00162	0.0162	0.162	1.62	16.2
Percent of stream load	0.0490	0.490	4.90	49.0	490

[1]Average stream condition observed at site MA2 for post-growth period (March 2008 through September 2013).

[2]Inputs concentrations are based on the average concentration of a groundwater well (USGS station ID 383907107571801 NB05101026DC1 Wetlands Middle 1) approximately 15 miles north of the Montrose Arroyo watershed and are considered to be representative of the potential concentration range of a high concentration point source (U.S. Geological Survey, 2015b).

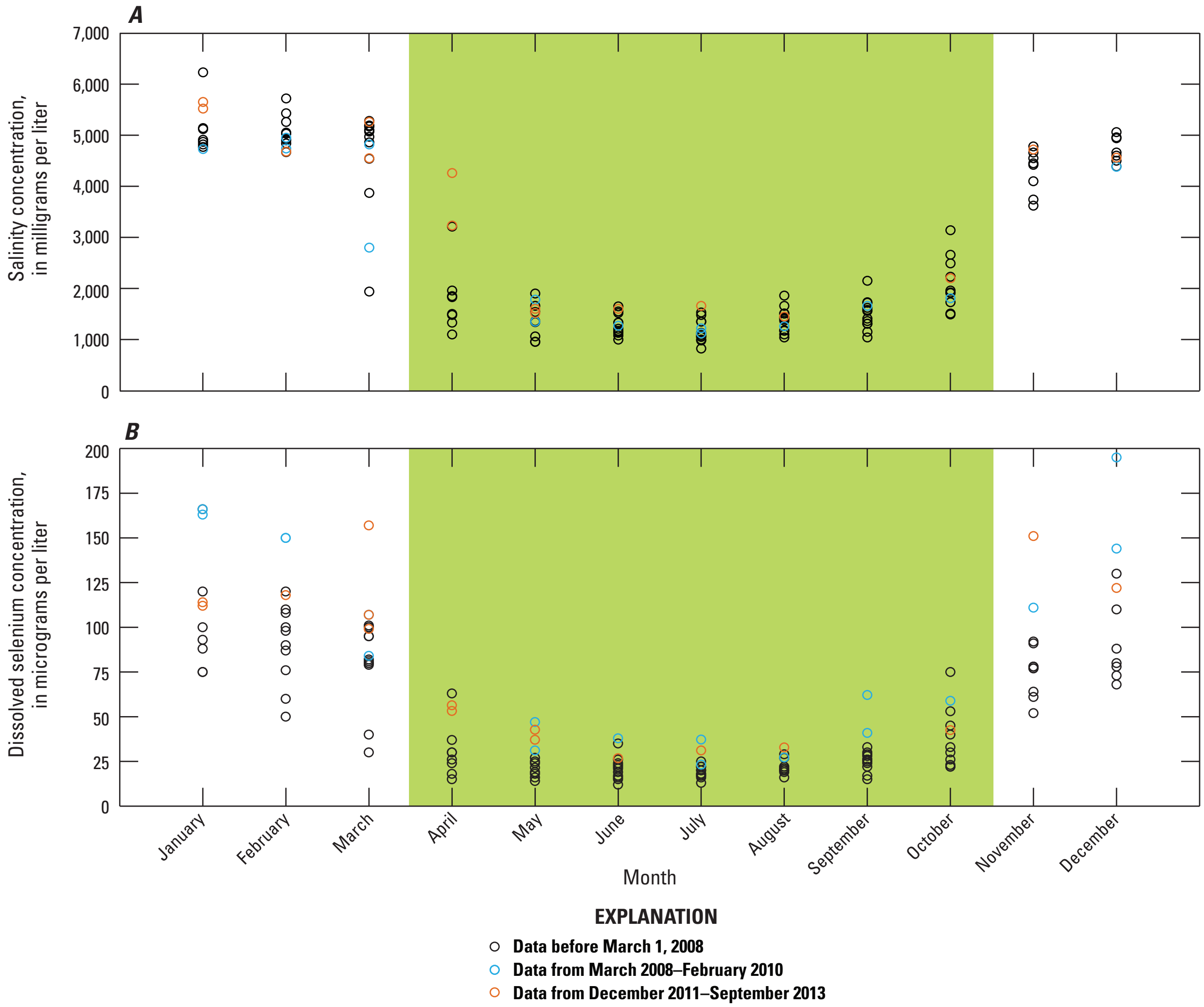

Figure 8. Scatterplot of monthly salinity and dissolved-selenium concentrations at site MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013 (green shading indicates irrigation season).

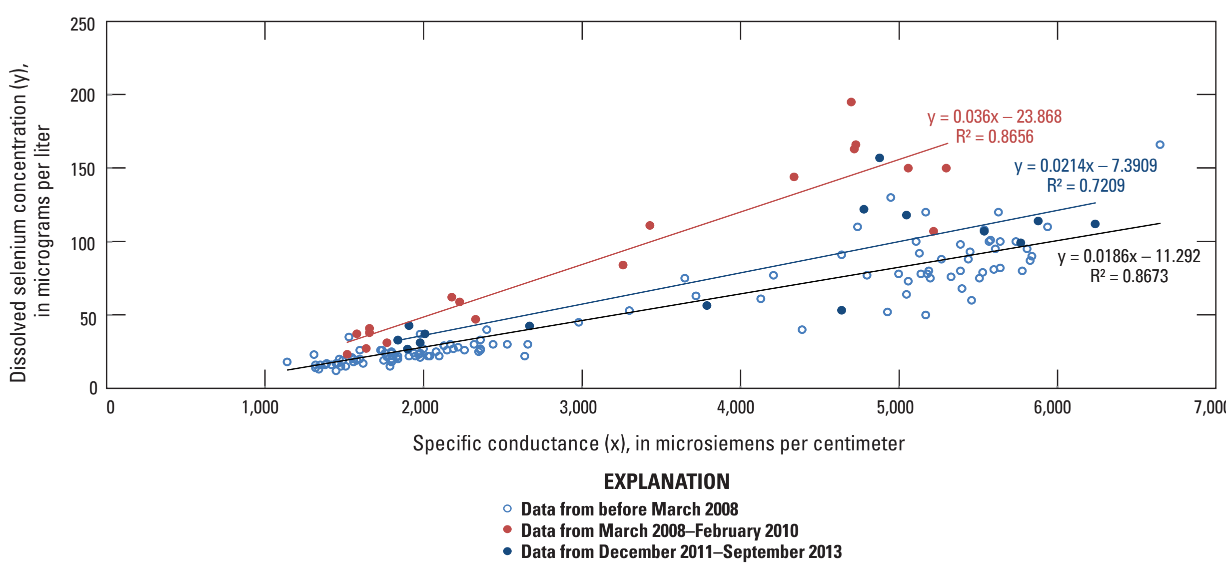

Figure 9. Relation of dissolved-selenium concentration and specific conductance at site MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992 through September 2013.

Table 5. Summay of land use in MA3 watershed.

Land use	Area (acres)			Percent of MA3 watershed		
	1992	2002	2009	1992	2002	2009
Irrigated agriculture	644	565	520	37.1	32.6	30.0
Unirrigated agriculture	1,050	1,023	1,023	60.6	59.0	59.0
Urban	40.6	146	192	2.3	8.4	11.0

The previous study by Moore (2011) indicated that there was no change in salinity load in Montrose Arroyo at site MA2 from the pre-lateral period to the post-growth period and a significant increase in dissolved-selenium load over the same period. The additional data in this report indicate the salinity loads at site MA2 show a significant decrease and dissolved-selenium loads had no significant change from the pre-lateral period to the post-growth period. In addition, both salinity load and dissolved-selenium load at site MA3 show significant decreases from the pre-lateral period to the post-growth period that are potentially associated with land-use change within the watershed. Land-use change in the MA3 subwatershed was primarily from agricultural to urban land use. Land-use changes in the MA2 subwatershed include the development of a golf course, several new ponds, and previously unirrigated land. This evidence indicates that land-use change may affect water quality positively and negatively in a relative sense, depending on the land-use type. Previously unirrigated land, or major reworking of soils and geology, can adversely affect water quality because these areas may not have been previously leached. Whereas, areas previously irrigated by agriculture may have experienced improvement in water quality because there is previous leaching of salinity and selenium from the soils and parent material, and the land-use type is more efficient where water application is concerned. Other mechanisms such as changes in water-table level and geochemical reactions (particularly where selenium is concerned) also may be controlling water quality in Montrose Arroyo watershed but have not been extensively explored. Note also that increases in selenium concentration and load at site MA2 (Moore, 2011) may have been even higher (for reasons not fully understood) had there not been salinity and selenium control projects in the watershed to offset some of the observed increases.

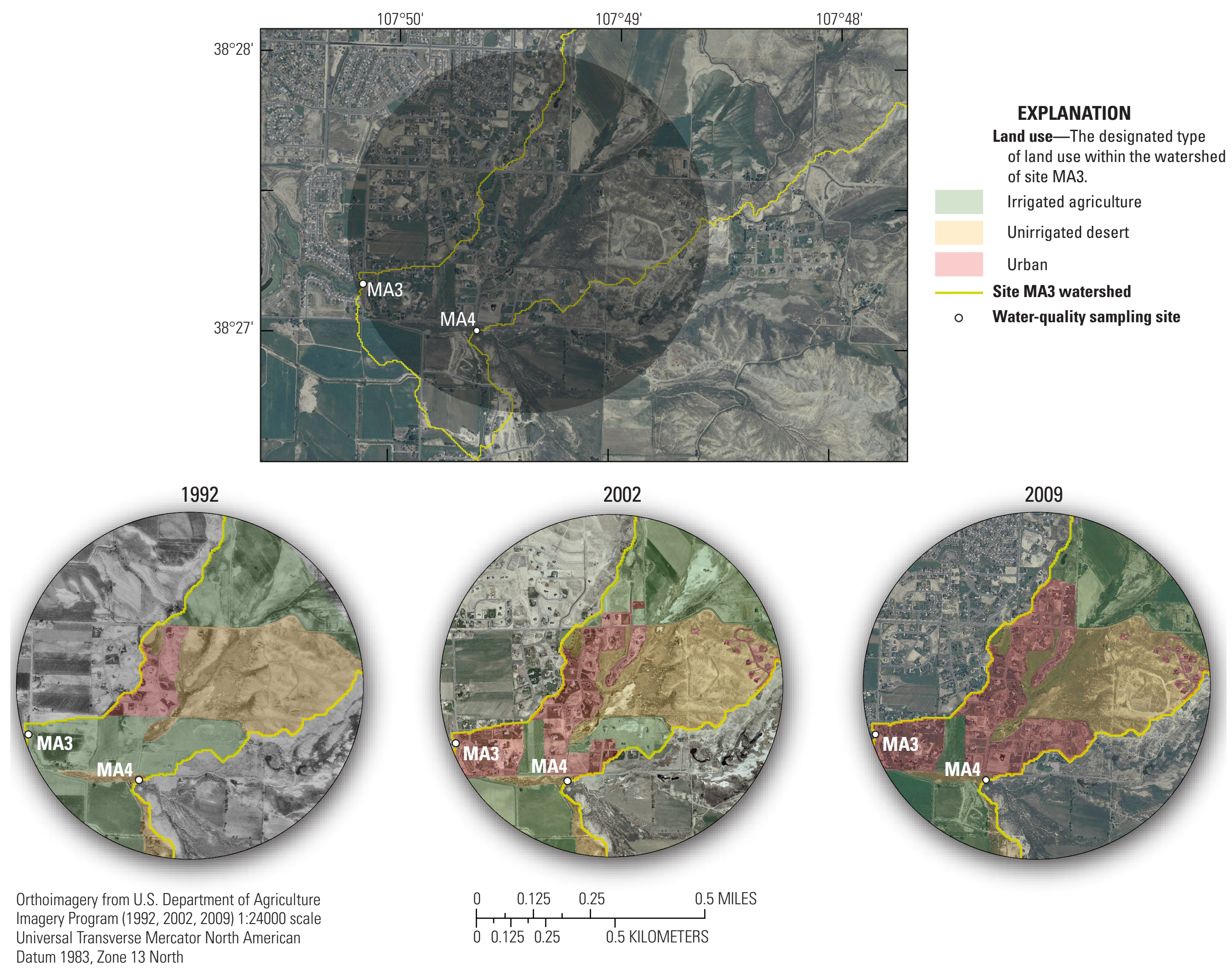

Figure 10. Summary of land use for years 1992, 2002, and 2009 in the MA3 subwatershed, Montrose Arroyo, Montrose, Colorado.

Table 6. Summary of land-use change in MA3 watershed.

Land-use change	Area (acres)		Percent of land-use change	
	1992–2002	1992–2009	1992–2002	1992–2009
Irrigated agriculture to urban land	78.6	124	12.3	19.3
Unirrigated to urban land	27.1	27.1	2.3	2.3
Irrigated agriculture to unirrigated land	0.0	0.0	0.0	0.0

Summary

Salinity and dissolved selenium are known water-quality impairments in the lower Gunnison River watershed of western Colorado. Salinity is a concern because of its adverse effects on agricultural land and equipment, and on municipal and industrial users. The trace element selenium is soluble in oxygenated water and can bioaccumulate in organisms to toxic levels in aquatic environments. Salinity and selenium in the lower Gunnison River watershed are naturally occurring in the Cretaceous marine deposits, such as the Mancos Shale, but there has been an increase in mobilization and loading of these constituents resulting from land-use changes in the region.

The Montrose Arroyo watershed in Montrose, Colorado, contains agricultural and residential areas as well as undeveloped land and has undergone significant land-use change since the early 1990s. Previous sampling efforts indicated salinity concentrations and loads have remained constant since land-use change began in the early 1990s; however, recent sampling has indicated that dissolved-selenium concentrations and loads have begun to increase. In response to the potential increasing dissolved-selenium concentrations and loads, the U.S. Geological Survey—in cooperation with the Bureau of Reclamation; Colorado River Basin Salinity Control Forum; and Colorado River Water Conservation District—continued to monitor salinity and dissolved-selenium concentrations and loads in the Montrose Arroyo watershed (hereafter, Montrose Arroyo). Water-quality samples were collected and streamflow was measured at three sites used in a previous U.S. Geological Survey study on the characterization of salinity and selenium loading in land-use change in Montrose Arroyo from 1992 to 2010.

This report characterizes salinity and dissolved-selenium loads in Montrose Arroyo from 1992 to 2013 at three sites: Montrose Arroyo at East Niagara Street (MA2, U.S. Geological Survey site identification number 382802107513301), Montrose Arroyo at 6700 Road (MA3, U.S. Geological Survey site identification number 382711107500501), and Montrose Arroyo at 6750 and Ogden Roads (MA4, U.S. Geological Survey site identification number 382702107493701). A detailed land-use change analysis was also characterized in the MA3 subwatershed. From December 2011 through September 2013, 46 water-quality samples and streamflow measurements were collected at sites MA2, MA3, and MA4. Streamflow, salinity concentrations and loads, and dissolved-selenium concentrations and loads were characterized and compared between the pre-lateral (before April 1999) and post-growth periods (March 2008 through September 2013) and between post-lateral (April 1999 through October 2000) and post-growth periods. These data were used to evaluate increases in dissolved selenium reported in a 2011 U.S. Geological Survey study and determine if changes in salinity and dissolved-selenium concentrations and loads are related to land-use change in the MA3 subwatershed.

No significant step trend in streamflow was observed at site MA4 from the pre-lateral period to the post-growth period, or from the post-lateral period to the post-growth period. Site MA3 showed no significant step trend in streamflow from the pre-lateral period to the post-growth period, but showed a statistically significant decrease in streamflow from the post-lateral period to the post-growth period. At site MA2, the streamflow step trend analysis indicated a significant decrease in streamflow from the pre-lateral period to the post-growth period and from the post-lateral period to the post-growth period. Step trends in salinity concentration and load and dissolved-selenium concentration and load were not observed at site MA4 from the pre-lateral period to the post-growth period, or from the post-lateral period to the post-growth period. The salinity and dissolved-selenium step trend at site MA4 responded as expected for a background site; there was no statistically significant change in streamflow or salinity and dissolved-selenium concentrations and loads. Because site MA4 is considered a background site for the study, it was assumed that background conditions were not changing over time.

Site MA3 showed no significant change in salinity concentration from the pre-lateral period to the post-growth period or from the post-lateral period to the post-growth period. A significant downward step trend was observed in salinity load for both periods. Significant downward step trends in dissolved-selenium concentration were observed from the pre-lateral period to the post-growth period, but no significant step trend in dissolved-selenium concentration was observed from the post-lateral period to the post-growth period. Significant downward step trends in dissolved-selenium load were observed for both periods. The statistically significant decreases in both salinity and dissolved-selenium loads at site MA3 were consistent with the expected response of converting previously irrigated land to urban land use, and may also be a continuation of the effects of lateral piping in the area that was completed in April 1999 in conjunction with conversion of land use in Montrose Arroyo.

Site MA2 showed no significant change in salinity concentration from the pre-lateral to the post-growth period or the post-lateral period to the post-growth period. A significant downward step trend was observed in salinity load from the pre-lateral period to the post-growth period. There was no significant salinity load step trend observed from the post-lateral period to the post-growth period. A significant upward

trend was observed in dissolved-selenium concentration for both periods. There was no significant step trend observed in the dissolved-selenium load from the pre-lateral period to the post-growth period, but there was a significant upward step trend observed in dissolved-selenium load from the post-lateral period to the post-growth period. The significant downward step trend in salinity load for the pre-lateral period to the post-growth period appears to be dominated by streamflow.

Step trends in dissolved-selenium concentration and load at site MA2 do not seem to be associated with streamflow. The observed increase in dissolved-selenium concentration is potentially a result of decreased water deliveries to the system that would dilute concentrations. A significant upward step trend in dissolved-selenium load from the post-lateral period to the post-growth period along with a statistically significant decrease in streamflow and increase in concentration indicates that there are other factors contributing to the increase in dissolved-selenium concentration other than just a reduction in streamflow.

Land use was characterized for 1992, 2002, and 2009 for the MA3 subwatershed. The common land-use change in MA3 was a conversion from previously irrigated agricultural land to urban land use. Based on results from a previous U.S. Geological Survey study, conversion from irrigated agriculture to urban land use increased water application efficiency and reduced the potential for deep percolation, resulting in a decrease in salinity loading. However, converting previously unirrigated agriculture to either irrigated agriculture or urban land use could potentially increase the salinity and selenium loading. The majority of land-use change occurred between 1992 and 2002 with the majority of land use changing from irrigated agriculture to urban land use. Irrigated agricultural land use in MA3 decreased from 644 acres in 1992, to 565 acres in 2002, to 520 acres in 2009. Urban land use increased from 40.6 acres, to 146 acres, to 192 acres, and unirrigated agriculture decreased from 1,050 acres to 1,023 acres from 1992 to 2002 and did not change from 2002 to 2009. Overall, the MA3 subwatershed had 124 acres of irrigated land use converted to urban land use and 27.1 acres of unirrigated desert to urban land use from 1992 to 2009.

Results from a previous U.S. Geological Survey study indicated that there was no change in salinity load in Montrose Arroyo at site MA2 from the pre-lateral period to the post-growth period and a significant increase in dissolved-selenium load over the same period. Additional data associated with this study indicate that the salinity loads at site MA2 show a significant downward step trend and dissolved-selenium loads had no significant change from the pre-lateral period to the post-growth period. Consistent with findings in previous land-use change reports, salinity and dissolved-selenium loading at site MA3 show significant downward step trend from the pre-lateral period to the post-growth period as irrigated land was converted to urban land use.

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