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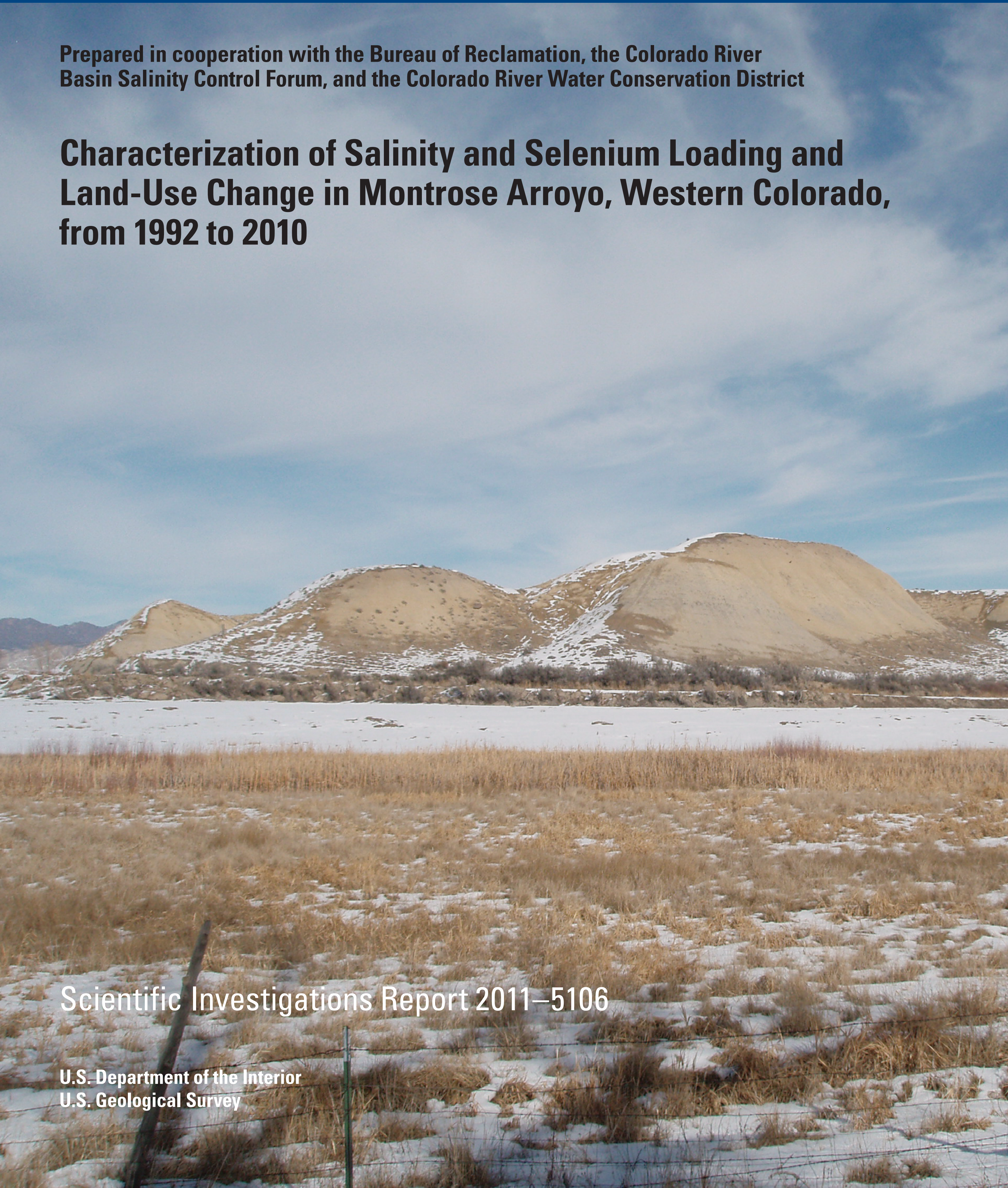
Prepared in cooperation with the Bureau of Reclamation, the Colorado River Basin Salinity Control Forum, and the Colorado River Water Conservation District

Characterization of Salinity and Selenium Loading and Land-Use Change in Montrose Arroyo, Western Colorado, from 1992 to 2010



Scientific Investigations Report 2011–5106

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

Front Cover:
Montrose Arroyo mancos shale outcropping. Photograph by Jennifer Moore, January 20, 2011.

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KEN SALAZAR, Secretary

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Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Conversion Factors

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	0.4047	hectare (ha)
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
acre-foot (acre-ft)	1,233	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	0.9072	megagram (Mg)

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).

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

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

CDPHE	Colorado Department of Public Health and Environment
CRBSCF	Colorado River Basin Salinity Control Forum
BLM	U.S. Department of the Interior, Bureau of Land Management
FSA	U.S. Department of Agriculture, Farm Service Agency
GIS	Geographic information system
NAIP	National Agriculture Imagery Program
NIWQP	National Irrigation Water Quality Program
NWQL	National Water Quality Laboratory
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Characterization of Salinity and Selenium Loading and Land-Use Change in Montrose Arroyo, Western Colorado, from 1992 to 2010

By Jennifer L. Moore

Abstract

Salinity and selenium are naturally occurring and pervasive in the lower Gunnison River Basin of Colorado, including the watershed of Montrose Arroyo. Although some of the salinity and selenium loading in the Montrose Arroyo study area is from natural sources, additional loading has resulted from the introduction of intensive irrigation in the watershed. With increasing land-use change and the conversion from irrigated agricultural to urban land, land managers and stakeholders need information about the long-term effects of land-use change on salinity and selenium loading. In response to the need to advance salinity and selenium science, the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, Colorado River Basin Salinity Control Forum, and Colorado River Water Conservation District, developed a study to characterize salinity and selenium loading and how salinity and selenium sources may relate to land-use change in Montrose Arroyo. This report characterizes changes in salinity and selenium loading to Montrose Arroyo from March 1992 to February 2010 and the magnitude of land-use change between unirrigated desert, irrigated agricultural, and urban land-use/land-cover types, and discusses how the respective loads may relate to land-use change. Montrose Arroyo is an approximately 8-square-mile watershed in Montrose County in western Colorado. Salinity and selenium were studied in Montrose Arroyo in a 2001 study as part of a salinity- and selenium-control lateral project. The robust nature of the historical dataset indicated that Montrose Arroyo was a prime watershed for a follow-up study.

Two sites from the 2001 study were used to monitor salinity and selenium loads in Montrose Arroyo in the follow-up study. Over the period of 2 water years and respective irrigation seasons (2008–2010), 27 water-quality samples were collected and streamflow measurements were made at the historical sites MA2 and MA4. Salinity and selenium concentrations, loads, and streamflow were compared between the pre-lateral-project and post-growth periods and between the post-lateral-project and post-growth periods.

No significant differences in streamflow, salinity (concentration and load), or selenium (concentration and load) were found at MA4 between the pre-lateral project and post-growth periods or between the post-lateral-project and post-growth periods. The statistical analysis indicated no significant differences in streamflow or salinity (both concentration and load) between the pre-lateral-project and post-growth periods or between the post-lateral-project and post-growth periods at MA2; however, selenium concentrations and loads were significantly greater between the pre-lateral-project and post-growth periods and between the post-lateral-project and post-growth periods at MA2. Land-use change between MA4 and MA2 may have contributed to the determined differences in selenium values, but the specific mechanisms causing the increases between periods are unknown.

The size of the urbanized area in Montrose Arroyo was quantified for 1993, 2002, and 2009 by using a geographic information system (GIS) with imagery from the specified years. The greatest change in land use from 1993 to 2009 was the increase of urban land due to conversion from irrigated agricultural land. The conversion of previously unirrigated desert to urban land or irrigated agriculture could become more common if urbanization and development expands into the eastern part of the watershed because a majority of the un-urbanized land in eastern Montrose Arroyo is unirrigated desert.

By applying GIS to the City of Montrose 2008 comprehensive growth plan, it was estimated that approximately 786 acres of previously irrigated agricultural land will be converted to urban land and 689 acres of unirrigated desert will be converted to urban land under the plan scenario. New development on previously unirrigated land in shale areas would likely increase the potential for mobilization of selenium and salinity from new sources to Montrose Arroyo and the Lower Gunnison River Basin.

Introduction

Salinity and selenium are known water-quality impairments to streams in the Lower Gunnison Basin (fig. 1) of western Colorado. Salinity (or the dissolved-solids concentration) is a concern because of its adverse effects on agricultural, municipal, and industrial users (Butler, 2001). Selenium, a trace element, can dissolve in oxygenated water and move through the aquatic environment, where it can bioaccumulate in organisms and potentially reach toxic levels (Lemly, 2002). Salinity and selenium in the lower Gunnison River Basin are naturally occurring and pervasive. Many water bodies in the lower Gunnison River Basin, including the lower Gunnison River and Uncompahgre River, exceed the State chronic aquatic-life selenium standard of 4.6 micrograms per liter (Thomas, 2009). The Gunnison River Basin annually contributes roughly 1.1 million tons of salinity to the Colorado River (Leib, 2008). Although some of the salinity and selenium loading in the study area is from natural sources, additional loading has resulted from the introduction of intensive irrigation in the watershed. Additionally, irrigation canals and laterals delivering water are commonly unlined and, consequently, some irrigation water seeps into the ground and becomes "deep percolation," which has been defined as any water infiltrating below the top 12 inches of soil (Mayo, 2008). Salinity and selenium concentration can increase as the seepage from a given canal or lateral moves through the groundwater system and ultimately to a stream (Butler, 2001).

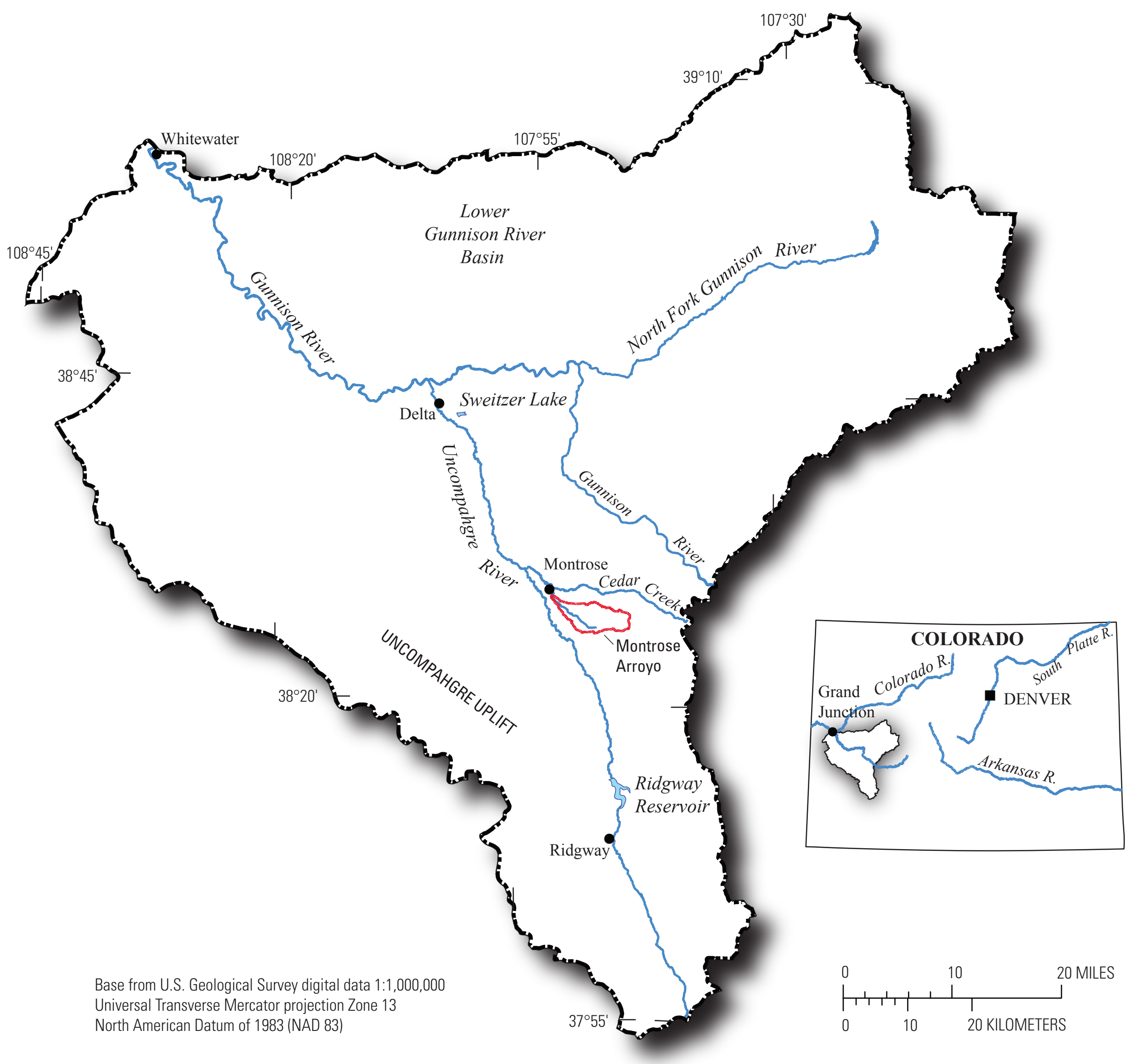


Figure 1. Overview of the Lower Gunnison River Basin, Colorado.

In the Montrose Arroyo watershed, Montrose County, Colo., surface water and groundwater discharge to ditches and natural drainages that, in turn, discharge to the Uncompahgre and Gunnison Rivers and eventually to the Colorado River. Montrose Arroyo watershed (referred to hereafter simply as “Montrose Arroyo”) and surrounding areas have experienced rapid population growth and thus a change in land use. Historically, land use in Montrose Arroyo was primarily agricultural. Mayo (2008) documented, on a site-specific basis, a decrease in water use and deep percolation associated with the conversion of agricultural lands to urban land use. (The term “urban” in this report refers to land use as residential development, industrial facilities, commercial development, and public parks.) The conversion of land from irrigated agricultural to urban results in substantially lower irrigation-water application, reduced deep percolation, and less salinity loading per developed acre, with the exception of unlined ponds (Mayo, 2008). The conversion of previously unirrigated land to irrigated agricultural land or urban land is associated with increases in the mobilization of salinity and selenium (Fahy and others, 2000). With increasing land-use change and the conversion from irrigated agricultural to urban land, land managers and stakeholders need information about the long-term effects of land-use change on salinity and selenium loading.

A robust historical dataset of regional water quality indicated that Montrose Arroyo was a prime watershed for a follow-up study. Salinity and selenium were studied in Montrose Arroyo in 2001 (Butler, 2001) as part of a salinity- and selenium-control project. In response to the need to advance salinity and selenium science, the U.S. Geological Survey (USGS)—in cooperation with the Bureau of Reclamation; Colorado River Basin Salinity Control Forum (CRBSCF); and Colorado River Water Conservation District—developed a study to characterize salinity and selenium loading and how salinity and selenium sources may relate to land-use change in Montrose Arroyo. The study was designed to collect water-quality and streamflow samples at two identical sites from the original eight sites used by Butler (2001) and to determine whether salinity and selenium loading has changed over time.

Purpose and Scope

This report characterizes changes in salinity and selenium loading to Montrose Arroyo from March 1992 to February 2010 and discusses how changes in loads may relate to land-use change. The water-quality and streamflow data were collected and evaluated by the USGS. The data were used to detect salinity and selenium trends throughout the study period. The report also includes a detailed analysis to determine the magnitude of land-use change between unirrigated desert, irrigated agricultural land, and urban land-use types. Throughout this report, the use of the term “selenium” refers to dissolved selenium, in micrograms per liter, and the use of the term “salinity” refers to dissolved-solids concentration, in milligrams per liter.

Salinity and Selenium Control Efforts in the Colorado River Basin

The history of salinity control efforts in the Colorado River Basin dates back to the 1970s when the Salinity Control Act, Public Law 93–320, prompted the creation of the CRBSCF to investigate, plan, and construct projects to reduce salinity loading to the Colorado River (Bureau of Reclamation, 2009). The Bureau of Reclamation (2003) estimates that 47 percent of the salinity load in the Colorado River Basin is derived from natural sources, including geological formations, saline springs, and surface runoff. Approximately 37 percent of the salinity load in the Colorado River Basin results from irrigation, and the remaining 16 percent results from reservoir-storage effects and municipal and industrial practices.

Selenium concerns are more recent than salinity concerns in the Colorado River Basin. The existence of a selenium toxicity issue in the United States was first brought to light in 1983 at Kesterson Reservoir in the western San Joaquin Valley in California (Ohlendorf and others, 1990). The U.S. Fish and Wildlife Service (USFWS) discovered incidences of mortality, deformities, and decreased reproduction in fish and aquatic birds at the reservoir attributed to selenium toxicity induced by irrigation. In order to quantify the biological effects of selenium, the National Irrigation Water Quality Program (NIWQP) was formed in 1985. NIWQP is a multiagency program within the Department of the Interior; it has done investigations at various irrigation projects in the Western United States to determine whether irrigation drainage was having adverse effects on water quality and on fish and wildlife (Butler and Leib, 2002). In 1988, NIWQP studies were initiated in the Uncompahgre River Basin. A robust historical dataset exists as a result of the NIWQP studies. More attention was given to the selenium issue in Colorado in 1997, when the Colorado State Water Quality Control Commission revised chronic aquatic-life criterion for dissolved selenium from 17 µg/L to 4.6 µg/L. In cooperation with NIWQP, the Gunnison Basin Selenium Task Force (Task Force) was established in 1998 as a group of private, local, State, and Federal interests to develop ideas and projects for reducing selenium levels in the Gunnison River Basin.

Previous Studies

In 1999, the USGS, in cooperation with the Bureau of Reclamation and the Salinity Control Program, began a study (hereafter, 2001 study) to assess the effect of piping irrigation canals and laterals to reduce salinity and selenium loading in Montrose Arroyo (Butler, 2001). Five open-ditch laterals in the Montrose Arroyo watershed were piped as part of the project (hereafter, lateral project). Approximately 8.5 miles of open laterals were replaced with about 7.5 miles of polyvinyl chloride (PVC) pipe. The lateral project significantly decreased salinity loads (by 16 percent) and selenium loads (by 28 percent) in Montrose Arroyo.

In 2007, the USGS published a report analyzing selenium loads from 1978 to 2005 in the Lower Gunnison Basin (Thomas and others, 2008) in support of the development of Total Maximum Daily Loads (TMDLs) for selenium. Results for the Uncompahgre River indicated that a reduction of 69 percent of the mean annual load of selenium for water years 2001–2005 would be needed to meet the water-quality standard for the Uncompahgre River at Delta, Colo., streamflow-gaging station.

In 2008, the USGS published a report of salinity trends (1986–2003) in the upper Colorado River Basin upstream from the Grand Valley Salinity Control Unit (Leib and Bauch, 2008). The report details results for trends in salinity concentrations, loads, and selected major ions at selected USGS streamflow-gaging stations near the Grand Valley Salinity Control Unit. Downward trends in salinity load (average trend slope of 11,200 tons per year) were observed at the Gunnison River near Grand Junction, Colo., streamflow-gaging station.

Also in 2008, the USGS studied the effects of land-use change on deep percolation in the Grand Valley (Mayo, 2008). The report from the study presents estimates of the effects of conversion of agricultural land to urban land on deep percolation of irrigation water in the Grand Valley. Effects on the amounts of applied irrigation water and salt loading in the Colorado River also are discussed. The report concludes that the conversion of land from agricultural to residential subdivisions results in reduced irrigation-water application, reduced deep percolation, and reduced salt loading per developed acre, with the exception of unlined ponds.

A third USGS study in 2008 analyzed salinity and selenium trends (concentrations and loads) in the Upper Colorado River Basin, specifically, in three tributaries to the Colorado River in the Grand Valley (Leib, 2008). The report states that a reduction in annual salinity load in Lewis Wash of approximately 2,450 tons may have occurred as a result of either salinity-control work or land-use change, particularly the conversion of agricultural land to residential development.

In 2009, the USGS analyzed selenium loading from contributing sources (surface water and groundwater) to Sweitzer Lake, which is listed on the Colorado Department of Public Health and Environment (CDPHE) 303d list for selenium impairment (Thomas, 2009). The report concluded that the selenium load from Garnet Canal and the Diversion Drain would need to be reduced (73 and 40 percent, respectively) in an effort to meet the chronic aquatic-life standard.

Description of Study Area

Montrose Arroyo is an approximately 8-square-mile watershed located in Montrose County in western Colorado (fig. 2). Montrose Arroyo is a tributary to Cedar Creek, which is a tributary to the Uncompahgre River. The primary land use in the study area is agriculture and unirrigated desert; however, residential and commercial development is increasing with population growth. Public lands managed by the U.S. Department of the Interior, Bureau of Land Management (BLM) account for approximately 30 percent of Montrose Arroyo (City of Montrose, 2010).

The major population center is the City of Montrose (population 17,834) (City of Montrose, 2010). The population in Montrose increased 21 percent from 2000 to 2008 (U.S. Census Bureau, 2010). Changes in land use have resulted in a shift from unirrigated desert and irrigated agricultural land to residential and urban land use, as well as the use of independent septic drainage systems (Thomas and others, 2008). In 1997–98, golf course construction began in the area between the two sample sites MA2, Montrose Arroyo at East Niagara Street (USGS site identification number 382802107513301), and MA4, Montrose Arroyo at 6750 and Ogden Roads (USGS site identification number 382702107493701) (fig. 2). Another change in the watershed was the Montrose Arroyo demonstration project in 1998–2000, by which the Salinity Control Forum funded a project to replace about 8.5 miles of open laterals with PVC piping.

Climate in the study area is semiarid, with an average annual precipitation in Montrose of approximately 9.5 inches (Western Regional Climate Center, 2010). Average annual high and low temperatures range from 63 to 34 degrees Fahrenheit in Montrose.

The geology of Montrose County is dominated in the west by the Uncompahgre Uplift. The Uncompahgre Uplift forms the Uncompahgre Plateau and is an asymmetrical anticline that plunges northwest to southeast (Thomas, 2009). The Uncompahgre Plateau is bordered on the east by the Uncompahgre River. On the east side of the Uncompahgre River are gray and yellow slopes of Mancos Shale, a marine deposit of the Late Cretaceous age. The Mancos Shale layer, which contains high levels of salinity and selenium, underlies and is interspersed with alluvium and gravels in the fertile floodplain of the Uncompahgre River. Most of the eastern part of Montrose Arroyo is underlain by Mancos Shale (8,896 acres) (fig. 2).

Methods for Analysis of Salinity and Selenium Loading

Data Collection

Two sites were used to monitor salinity and selenium loads in Montrose Arroyo. Over the period of 2 water years and respective irrigation seasons (2008–2010), 27 water-quality samples and streamflow measurements were collected at the historical sites MA2 and MA4 (fig. 2). The control site (MA4) and the outflow site (MA2) were the same sites as used in the Butler study that assessed the effects of the lateral project (2001). The current study collected data at the same locations to determine whether concentrations and loads had

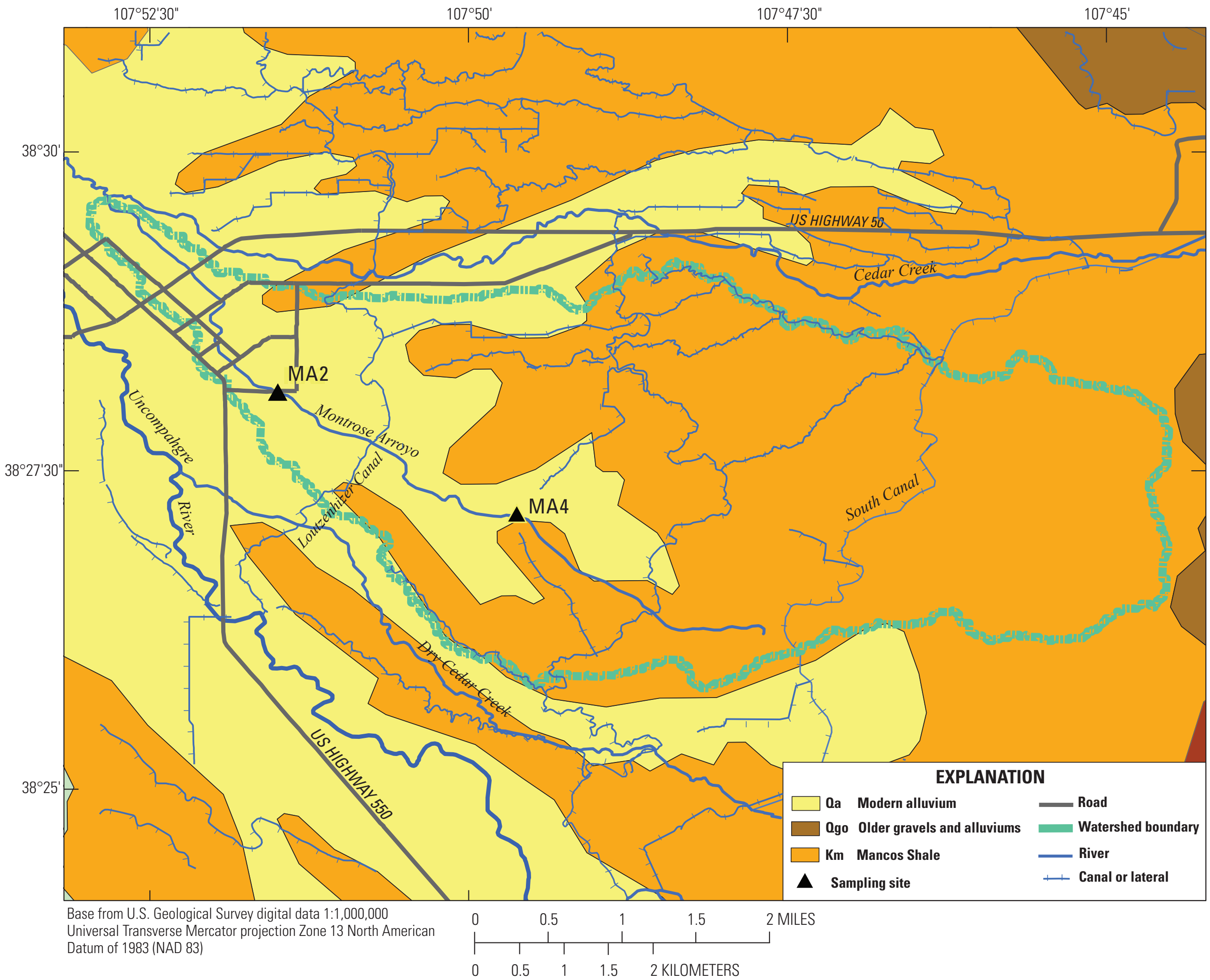


Figure 2. Montrose Arroyo study area, sampling sites, and surficial geology in Montrose, Colorado (from Tweto, 1979; location within Colorado is shown in fig. 1).

changed. Butler's study (2001) analyzed data from water years 1992–2000.

Instantaneous streamflow was measured by using methods described by Rantz and others (1982). Streamflow was measured with every sample collected to enable computation of loads. Salinity concentrations were determined by using the dissolved solids sum of constituents method, which computes the salinity concentration by summing the major-ion concentrations. Water-quality samples were analyzed by using standard USGS techniques and procedures (U.S. Geological Survey, variously dated).

Approximately 10 percent of the samples collected were quality-control samples, which included equipment blanks and replicate samples. No detections were found in blank samples. All concentrations in replicate pairs were within 5 percent of each other. The percent difference is calculated using the following equation:

$$\text{Percentage difference} = (R_1\text{-}R_2) / ((R_1+R_2)/2) \times 100 \tag{1}$$

where

R_1 = replicate 1
R_2 = replicate 2

All samples were analyzed by the National Water Quality Laboratory (NWQL) in Lakewood, Colo. Major ions were analyzed by using methods described in Fishman and Friedman (1989). General quality control for the NWQL is described in Pritt and Raese (1992).

Load Calculations

Salinity and selenium loads were calculated by using the streamflow and concentration data. Instantaneous load is calculated by multiplying the streamflow by the concentration and then by a conversion factor. Salinity loads are reported in tons per day, and selenium loads are reported in pounds per day. For the loading analysis, samples for each site were separated into a pre-lateral-project period (all data before April 1999), a post-lateral-project period (April 1999–October 2002), and a post-growth period (March 2008–February 2010).

Trend Calculations

To determine whether the concentrations and loads were significantly different between time periods, a step-trend two-sample t-test (Helsel and Hirsch, 2002) was used on the data. Because some of the data were nonparametric (did not have a normal distribution), a two-sample Mann-Whitney test (Helsel and Hirsch, 2002) also was used. Both tests were set up so that the calculated probability is the likelihood that the true difference between the mean values of each time-period comparison is equal to zero. Salinity and selenium concentrations, loads, and the streamflow were compared between the pre-lateral-project period and the post-growth period and between the post-lateral-project period and the 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 less than 0.01) and "significant" when the trend test reports a confidence level greater than 95 percent (p-value of 0.05). Statistically significant trend directions were determined on the basis of increasing or decreasing mean and median values.

Methods for Analysis of Land Use

The size of the urbanized area in Montrose Arroyo was quantified for the years 1993, 2002, and 2009 by using GIS with imagery from the specified years. Land-use orthoquads for 1993 were obtained from the USGS Seamless Data Warehouse (U.S. Geological Survey, 2010). Land-use imagery for 2002 was acquired from the City of Montrose GIS department (City of Montrose, 2010). Land-use imagery for 2009 was obtained from the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA) under the National Agriculture Imagery Program (NAIP), which is aerial imagery taken during the agricultural growing season (U.S. Department of Agriculture, 2010).

Categories of land use were consolidated into three major groups (irrigated agricultural, unirrigated desert, and urban land). All detailed land-use data were manually classified in ArcGIS (ESRI, 2006) to fit into the three major land-use classes. The image was scaled to 1:6,000, and individual plots of land were identified and classified by their apparent land use. Interpretive errors can be associated with this method of land-use classification. Errors with comparison between the specified years also exist because resolution and color conventions were not consistent between the three sets of imagery.

Land use in riparian or wetland areas surrounded by unirrigated desert was classified as unirrigated desert. Land use in riparian or wetland areas surrounded by irrigated agricultural land was classified as irrigated agricultural land because the adjacent irrigated land is assumed to be leaching irrigation water through the adjacent riparian and wetland areas. Small-acreage farms, including lawns and gardens, surrounded by irrigated agricultural fields were classified as irrigated agricultural land. Urban parks and golf courses were classified as urban land. Land that was irrigated agricultural in 1993, dormant in 2002, and urban land in 2009 was classified as irrigated agricultural land in 1993 and 2002 and classified as urban land in 2009. This classification scenario for dormant land was used because previously irrigated land, which typically sits dormant for only a short time before being developed as residential property, has previously been irrigated and leached and does not represent a true desert scrub landscape (previously unirrigated land) during the intermediate time period.

Salinity and Selenium Loading

Levels of salinity and selenium loading in Montrose Arroyo are an ongoing concern for local, State, and Federal agencies, local water providers, and landowners. As mentioned previously, Montrose Arroyo is a tributary to the Uncompahgre River and was studied to better understand salinity and selenium loading in the lower Gunnison Basin. Within Montrose Arroyo, several land-use changes had the potential to affect salinity and selenium loading. Throughout the land-use study period (1993–2009), urban areas expanded consistently within the watershed (fig. 3). This urban growth generally occurred to the northwest of site MA4. Again, within the statistical analysis, salinity and selenium data for each site were separated into a pre-lateral-project period (all data before April 1999), a post-lateral-project period (April 1999–October 2002), and a post-growth period (March 2008–February 2010) (figs. 4–5). The lateral piping project in 1998–2000 was implemented between sites MA4 and MA2 as a salinity- and selenium-control effort. Individual-sample data for MA2 and MA4 can be found in the National Water Information System database at *http://waterdata.usgs.gov/usa/nwis/rt* .

No significant trends in streamflow, salinity (concentration and load), or selenium (concentration and load) were found at MA4 between the pre-lateral-project and post-growth periods or the post-lateral-project and post-growth periods (table 1). Site MA4 was a control site with minimal land-use change and management change upstream. At MA2, the trend analysis indicated no significant differences in streamflow or salinity (both concentration and load) between the pre-lateral-project and post-growth periods and between the post-lateral-project and post-growth periods; however, selenium concentrations and loads were significantly greater between the pre-lateral-project and post-growth periods and between the post-lateral-project and post-growth periods (table 2).

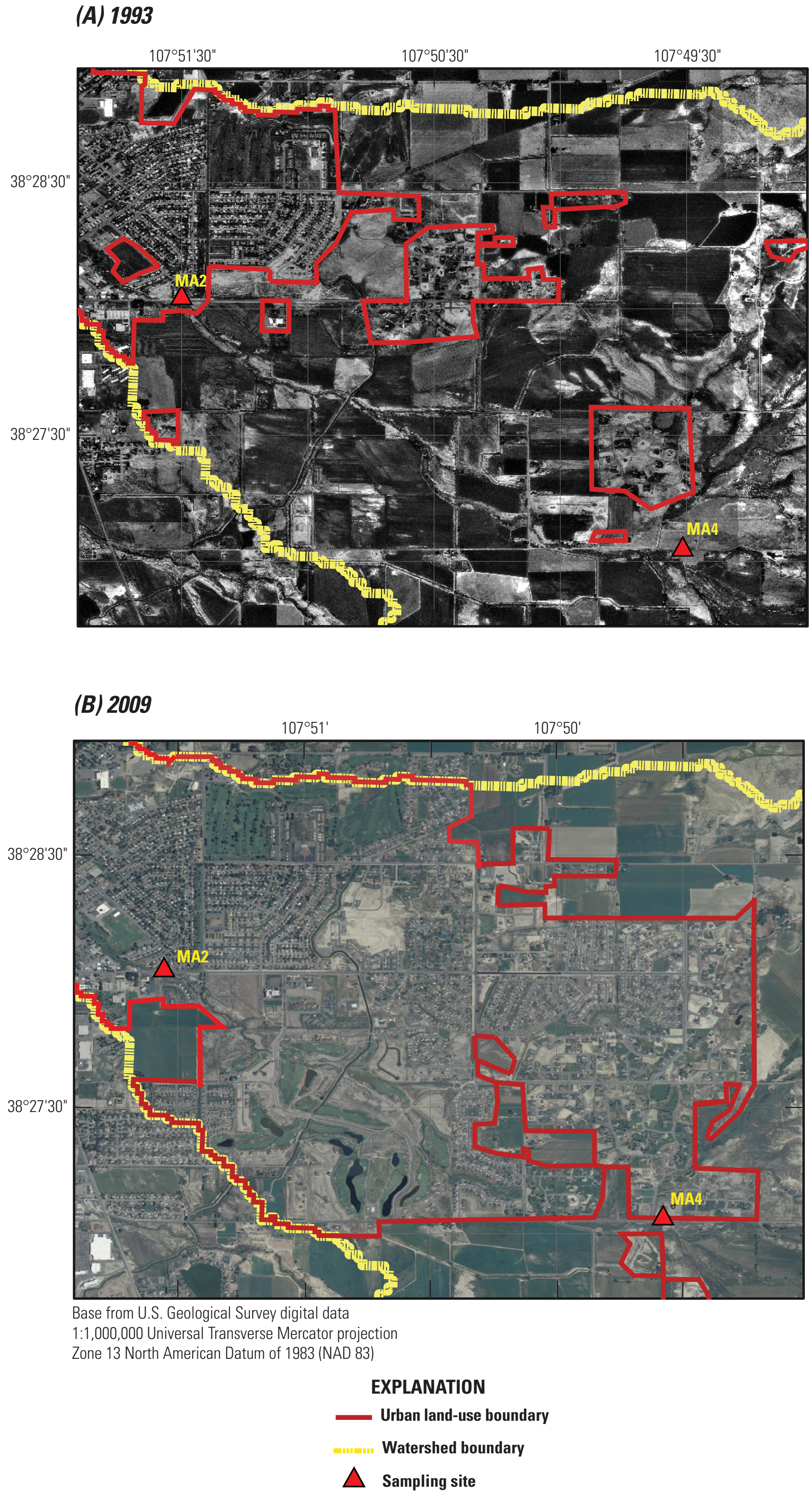


Figure 3. Land use in Montrose Arroyo, Montrose, Colorado, in (*A*) 1993 and (*B*) 2009.

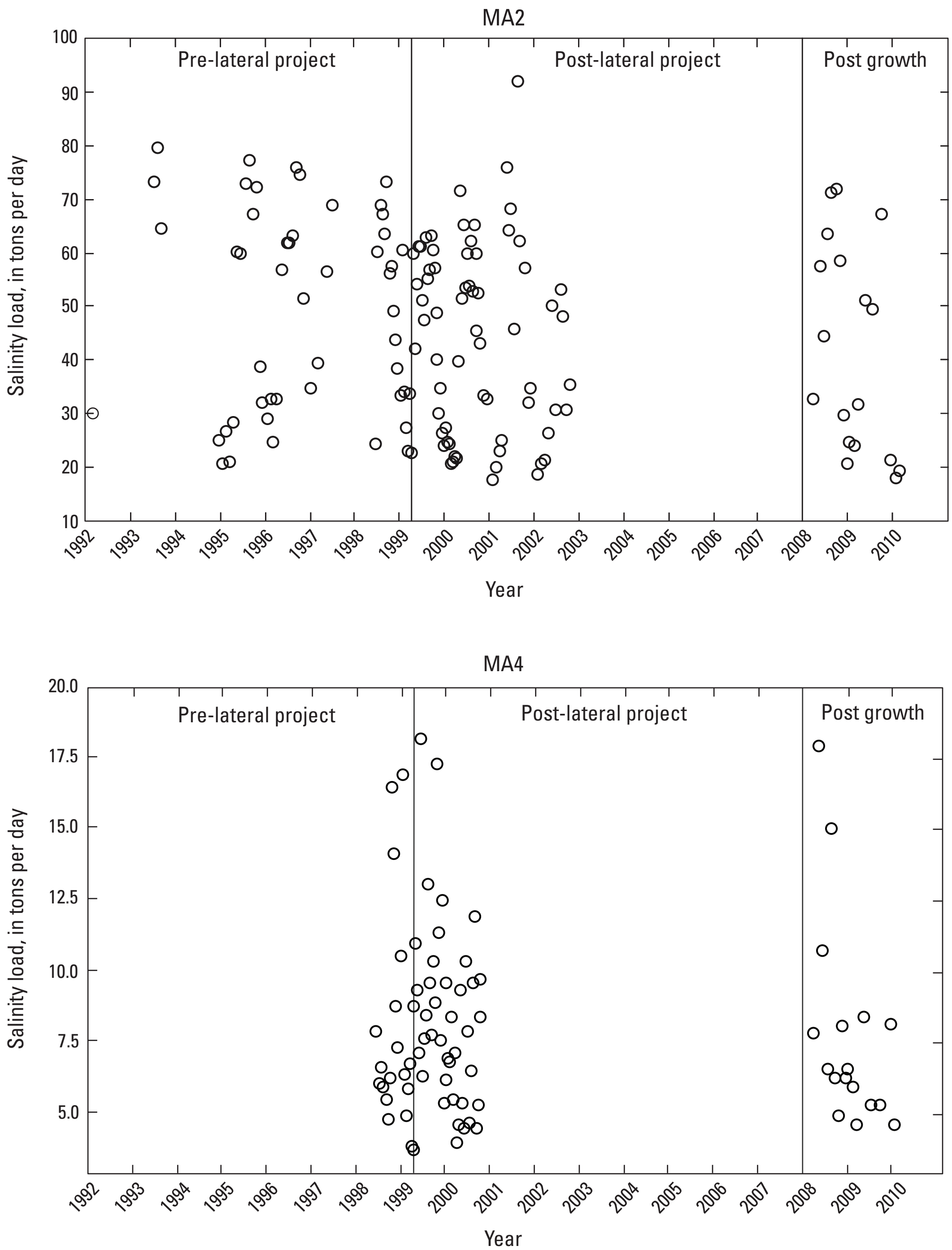
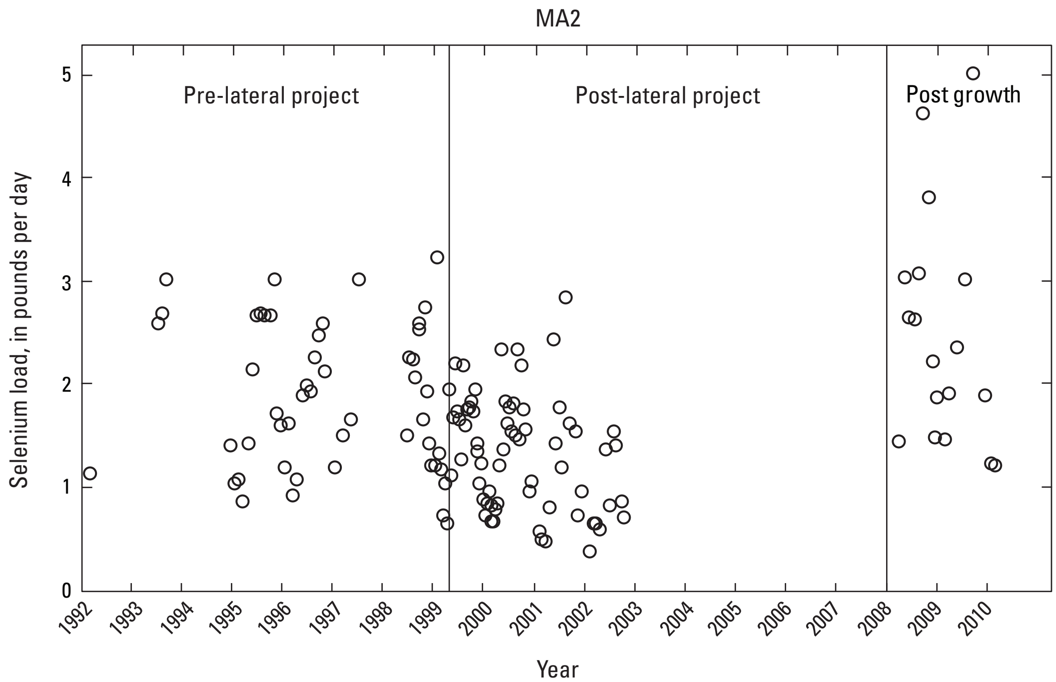


Figure 4. Scatterplot of daily average salinity loads at MA2 and MA4 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.



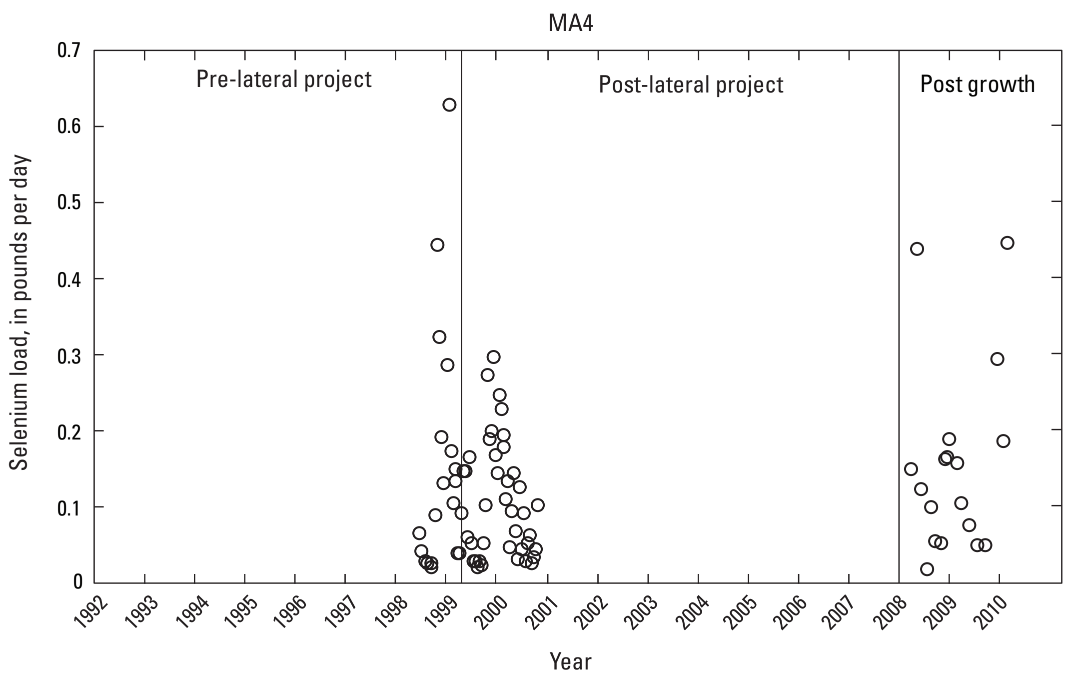


Figure 5. Scatterplot of daily average selenium loads at MA2 and MA4 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.

Table 1. Mann-Whitney and step-trend assessment at 95-percent confidence interval for salinity and selenium at MA4 in Montrose Arroyo, Colorado.

[p, probability that the true difference between the mean values of each time-period comparison are equal to zero; ft^3/s, cubic feet per second; mg/L, milligrams per liter; lb, pounds; µg/L, micrograms per liter]

Constituent	Units	Time period[1]	Paired t-test (two-sided) p	Mean	Significance	Mann-Whitney (two-sided) p	Median	Significance
Streamflow								
Streamflow	ft^3/s	1–3	0.149	0.66; 0.95	Not significant	0.7637	0.64; 0.53	Not significant
Streamflow	ft^3/s	2–3	0.808	0.90; 0.95	Not significant	0.8339	0.77; 0.53	Not significant
Salinity								
Load	tons	1–3	0.849	7.99; 7.74	Not significant	1.000	6.41; 6.47	Not significant
Load	tons	2–3	0.609	8.25; 7.74	Not significant	0.3074	7.79; 6.47	Not significant
Concentration	mg/L	1–3	0.596	5,061; 4,652	Not significant	0.6809	6,305; 5,015	Not significant
Concentration	mg/L	2–3	0.820	4,498; 4,652	Not significant	0.9803	3,710; 5,015	Not significant
Selenium								
Load	lb	1–3	0.927	0.16; 0.16	Not significant	0.6127	0.12; 0.14	Not significant
Load	lb	2–3	0.123	0.11; 0.16	Not significant	0.1278	0.09; 0.14	Not significant
Concentration	µg/L	1–3	0.600	52.2; 61.2	Not significant	0.7637	64.5; 48.4	Not significant
Concentration	µg/L	2–3	0.104	35.7; 61.2	Not significant	0.1741	18.0; 48.4	Not significant

[1]Time period 1 refers to pre-lateral-project period (before April 1999), period 2 refers to post-lateral-project period (April 1999–October 2000), and period 3 refers to post-growth period (March 2008–February 2010).

Table 2. Mann-Whitney and step-trend assessment at 95-percent confidence interval for salinity and selenium at MA2 in Montrose Arroyo, Colorado.

[p, probability that the true difference between the mean values of each time-period comparison are equal to zero; ft^3/s, cubic feet per second; mg/L, milligrams per liter; lb, pounds; µg/L, micrograms per liter]

Constituent	Units	Time period[1]	Paired t-test (two-sided) p	Mean	Significance	Mann-Whitney (two-sided) p	Median	Significance
Streamflow								
Streamflow	ft^3/s	1–3	0.226	11.9; 9.16	Not significant	0.1632	8.0; 8.1	Not significant
Streamflow	ft^3/s	2–3	0.881	9.46; 9.16	Not significant	0.7458	9.8; 8.1	Not significant
Salinity								
Load	tons	1–3	0.170	49.6; 42.1	Not significant	0.0910	56.3; 38.6	Not significant
Load	tons	2–3	0.683	44.2; 42.1	Not significant	0.6315	46.6; 38.6	Not significant
Concentration	mg/L	1–3	0.866	2,882; 2,806	Not significant	0.9335	1,820; 2,305	Not significant
Concentration	mg/L	2–3	0.680	2,634; 2,806	Not significant	0.9175	1,780; 2,305	Not significant
Selenium								
Load	lb	1–3	0.044	1.89; 2.49	Significant	0.0477	1.90; 2.28	Significant
Load	lb	2–3	0.000	1.33; 2.49	Highly significant	0.0000	1.36; 2.28	Highly significant
Concentration	µg/L	1–3	0.038	58.3; 90.9	Significant	0.0093	36.0; 73.0	Highly significant
Concentration	µg/L	2–3	0.002	40.9; 90.9	Highly significant	0.0001	27.0; 73.0	Highly significant

[1]Time period 1 refers to pre-lateral-project period (before April 1999), period 2 refers to post-lateral-project period (April 1999– October 2002), and period 3 refers to post-growth period (March 2008–February 2010).

Land-use change between MA4 and MA2 may have contributed to the trend in selenium values, but the specific mechanisms causing the increases between periods are unknown. Because no trend in streamflow was found at MA4 and MA2 but a trend of increasing load was found, much of the trend apparently can be attributed to increasing selenium concentrations. It is unclear why the trend analysis shows that selenium concentrations and loads at MA2 increased between study periods while salinity concentrations and loads remained unchanged.

Salinity and selenium concentrations at MA2 have a consistent seasonal pattern. Low-streamflow conditions (base flow) occur in November–March, when the irrigation system is shut off during the nonirrigation season (figs. 6–7). As irrigation begins in April, the concentrations decrease with the increase in irrigation-water delivery.

The monthly concentration plots for salinity at MA2 (fig. 6) do not show the same pattern as that in the selenium plot (fig. 7). The monthly concentration plots for selenium at MA2 show that selenium concentrations in most months during the post-growth period are elevated in comparison to historical data. It is apparent that selenium is being mobilized between sites MA4 and MA2 at a higher rate since sampling began in 1992. The increase in selenium concentrations could be attributed to increased groundwater load or changes in groundwater chemistry; however, such analysis was beyond the scope of this study.

Selenium concentrations correlated positively with specific conductance (fig. 8). The relation shows a shift in the intercept between the post-lateral-project and post-growth periods. This shift indicates that selenium concentrations increased relative to specific conductance during the period of growth in Montrose Arroyo. Specific conductance can be used as a surrogate for salinity concentration (Salt LOAD; Liebermann and others, 1987).

Trilinear diagrams or "Piper diagrams" are useful representations of the relative percentages of major ions within a water-quality sample and allow for the characterization of ionic chemistry between study periods. Trilinear diagrams are presented for MA2 and MA4 in figures 9 and 10. Separation of the data into three study periods allows for an examination of temporal variations in water chemistry at each site.

Temporal variations of major ions over the three study periods are not apparent. Relative concentrations of calcium, magnesium, and sodium plus potassium at both sites were consistent throughout the three study periods. Comparisons between sites showed similar distribution in relative percentages of the major ions. MA2 appeared to have greater variation in calcium plus magnesium and sulfate plus chloride in comparison to MA4.

Land-Use Change

Correlations between land-use change and water quality often are complex. As described in the previous section, selenium concentrations and loads increased in Montrose Arroyo (site MA2). An analysis of land use in Montrose Arroyo is presented here to parallel these results. No direct correlation between land use and selenium concentrations is given; however, previous studies have indicated that applying irrigation water to previously unirrigated land can potentially mobilize selenium (Fahy and others, 2000).

A common land-use change in the Montrose Arroyo watershed is from irrigated agricultural to urban land. Mayo's study in the Grand Valley, western Colorado, concluded that the conversion of agricultural land to residential urban subdivisions results in substantially lower irrigation-water application, reduced deep percolation, and less salt loading per developed acre (Mayo, 2008). It was assumed that the acreage of irrigated land would decrease because of the construction of impermeable surfaces such as roads and housing structures. Results from Mayo's study (2008) showed that mean season-total deep percolation decreased about 91 percent for all vegetation types when irrigated agricultural land was converted to urban land.

Previously unirrigated desert can be converted to irrigated residential or irrigated agricultural land. This land-use change could become more common if urbanization and development expands into the eastern part of the watershed because a majority of the undeveloped land in eastern Montrose Arroyo is unirrigated desert. The introduction of treated domestic water and the use of septic systems on previously unirrigated land have the potential to mobilize salinity and selenium in the soils and potentially result in increased selenium and salinity loads (Fahy and others, 2000; Mayo, 2008). New residential developments in Montrose Arroyo are connected to the city sewer system (Eric Svensen, City of Montrose, oral commun., 2010).

Land-use categorizations for 1993, 2002, and 2009 in Montrose Arroyo are shown in figures 11–13. Irrigated agricultural land in 2002 and 2009 was 3,074 and 2,032 acres, respectively (table 3). Unirrigated desert in 2002 and 2009 was 7,450 and 7,320 acres, respectively. Urban land in 2002 and 2009 was 2,040 and 3,212 acres, respectively. The greatest change in land use from 1993 to 2009 was the increase of urban land due to conversion from irrigated agricultural land (tables 3–4). The land-use change from unirrigated desert to urban land was 367 acres from 1993 to 2009. Those trends could intensify as development expands in the eastward direction and there is less and less irrigated agricultural land for development. There was also a small land-use change (34 acres) from 1993 to 2009 of irrigated agricultural to unirrigated desert. Some of this acreage could be attributed to irrigated agricultural land that has been taken out of agricultural production and has gone to scrub, even though housing-development plans have been proposed and some new roads and driveways have already been constructed.

Another land-use change of importance has been the construction of ponds. Ponds that are unlined and perched above the water table have the potential to seep. In Montrose Arroyo, ponds have been added in developed areas for recreational or

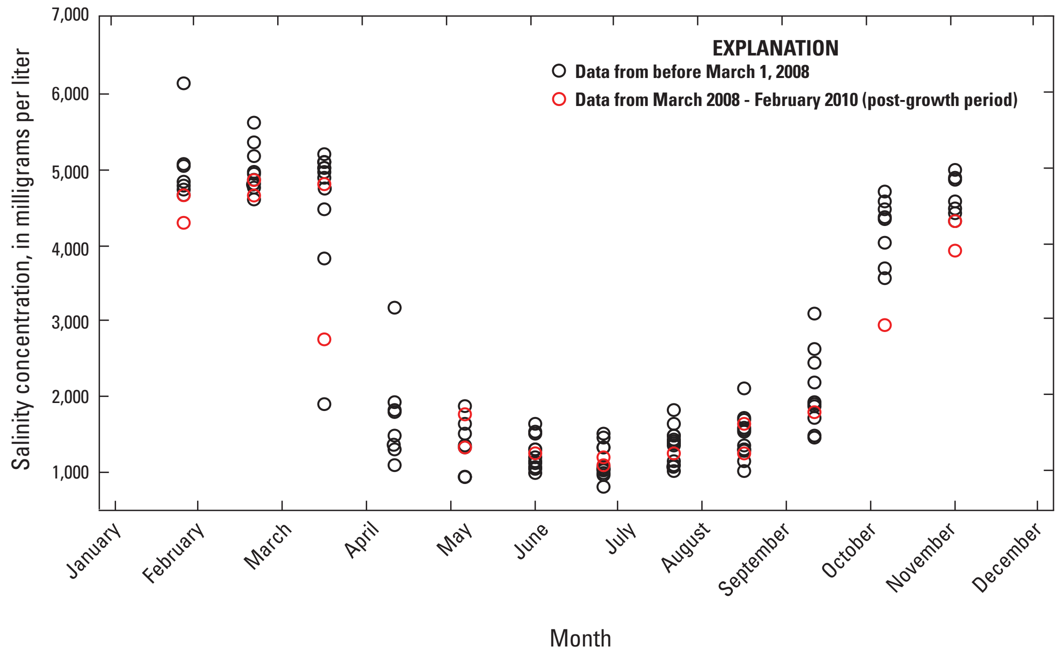


Figure 6. Scatterplot of monthly salinity concentrations at MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.

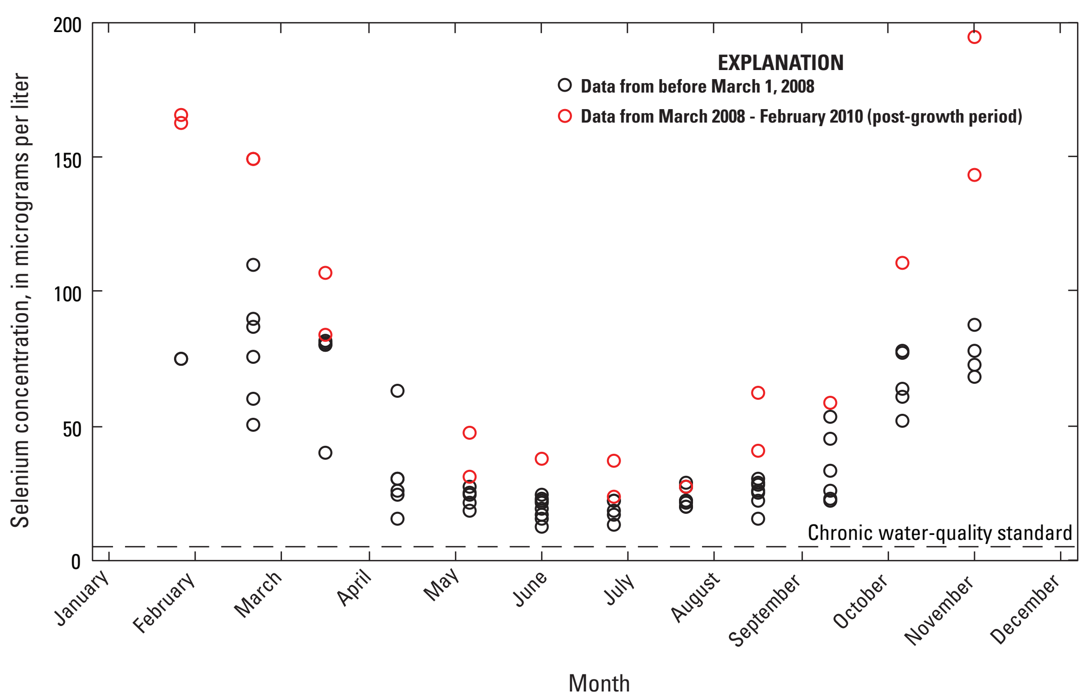


Figure 7. Scatterplot of monthly selenium concentrations at MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.

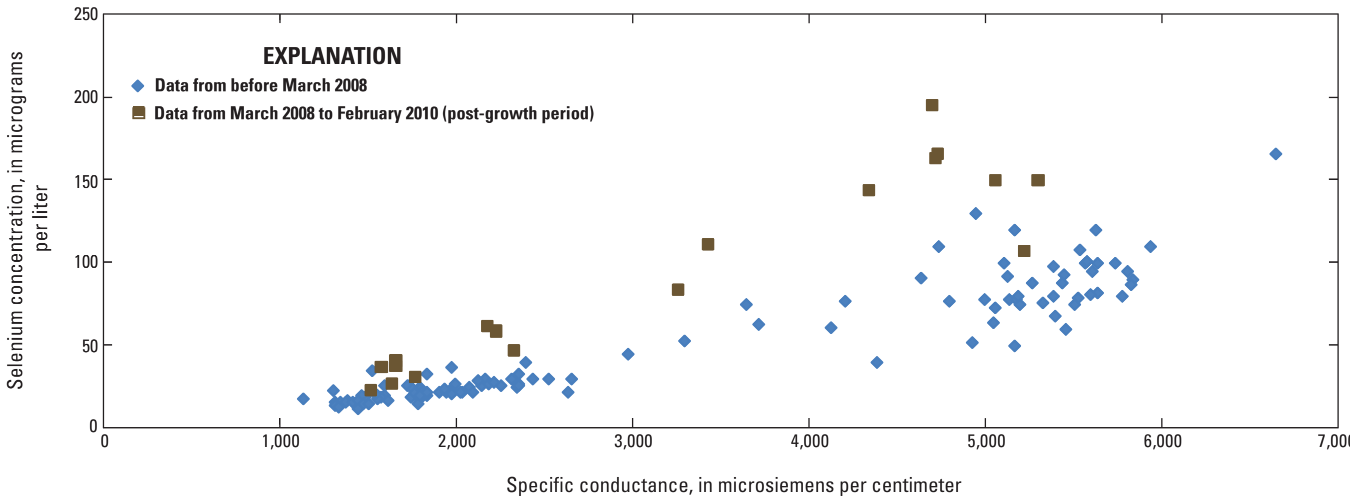


Figure 8. Relation of selenium concentration and specific conductance at MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.

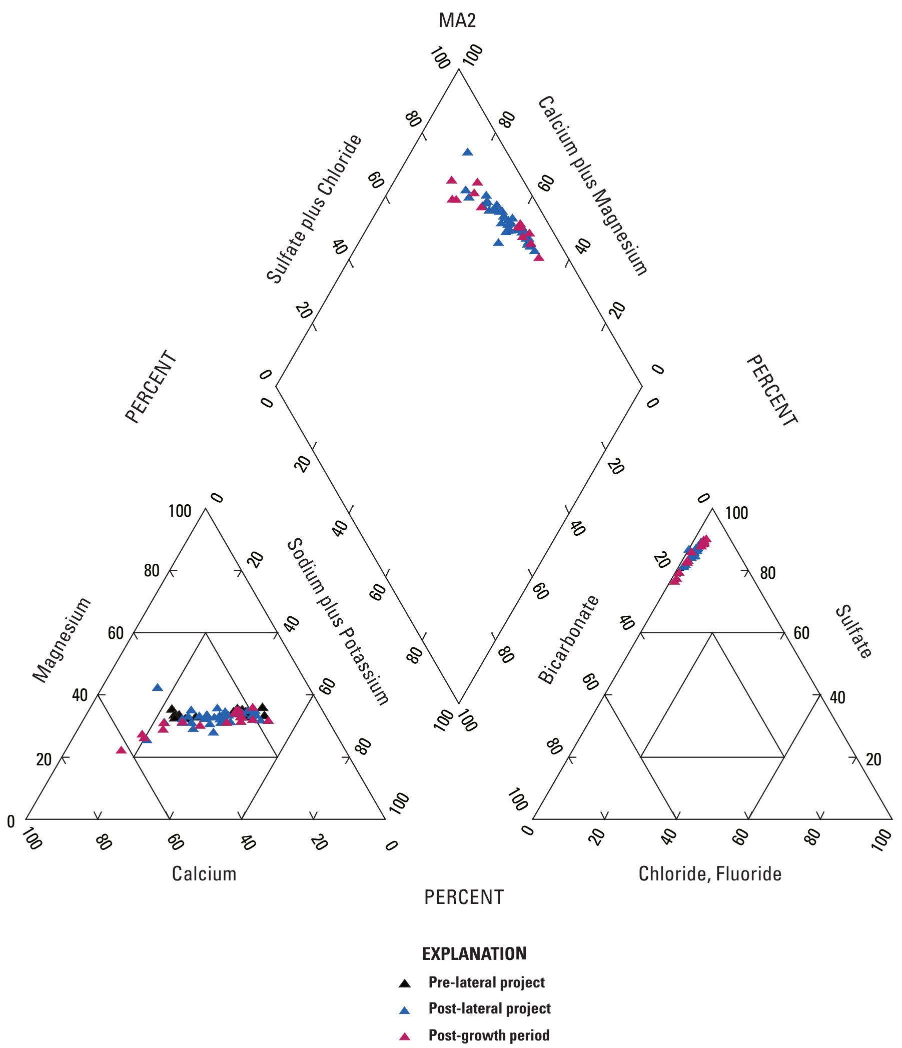


Figure 9. Trilinear diagrams of major-ion concentrations at MA2 in Montrose Arroyo, Montrose, Colorado, from March 1992, to February 2010.

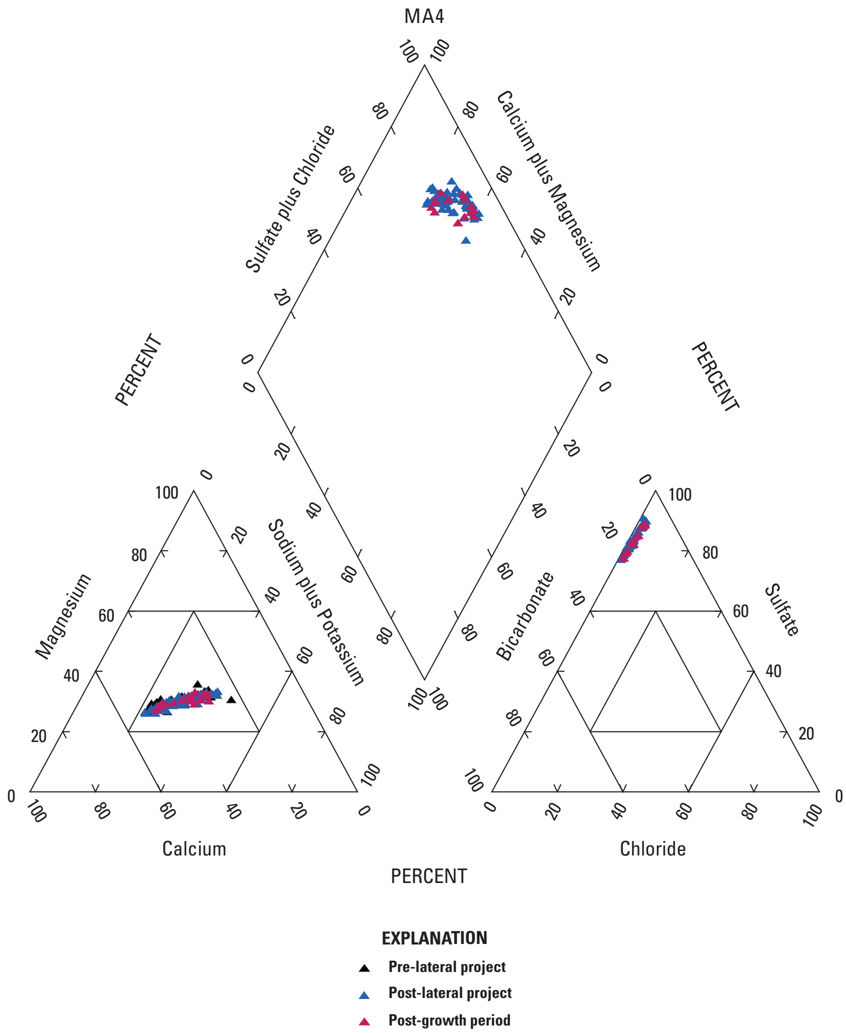
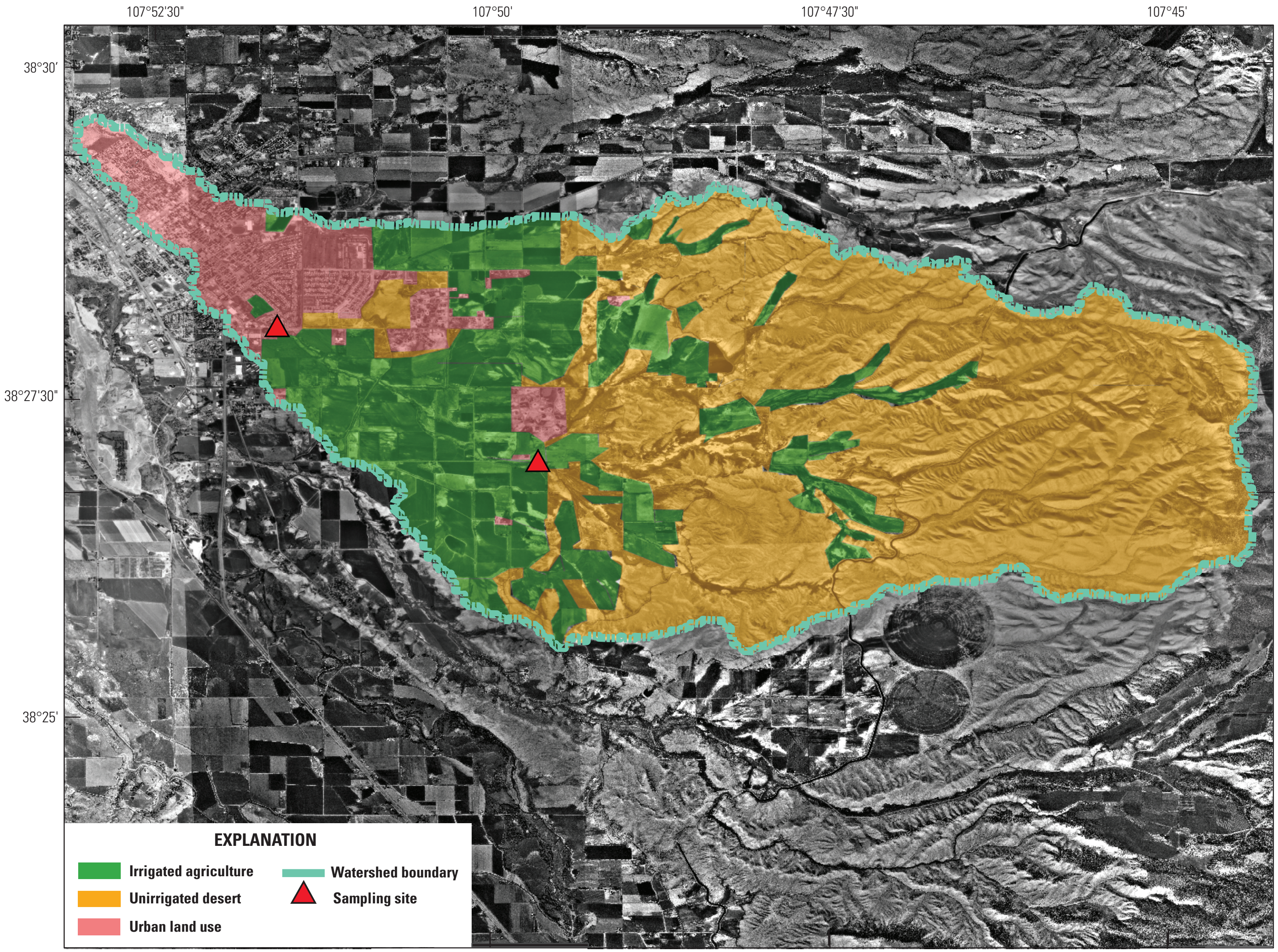


Figure 10. Trilinear diagrams of major-ion concentrations at MA4 in Montrose Arroyo, Montrose, Colorado, from June 1998, to February 2010.



Base from U.S. Geological Survey digital data 1:1,000,000 Universal Transverse Mercator projection Zone 13 North American Datum of 1983 (NAD 83)

0 0.5 1 1.5 2 MILES

0 0.5 1 1.5 2 KILOMETERS

Figure 11. Land-use categorizations in Montrose Arroyo, Montrose, Colorado, 1993.

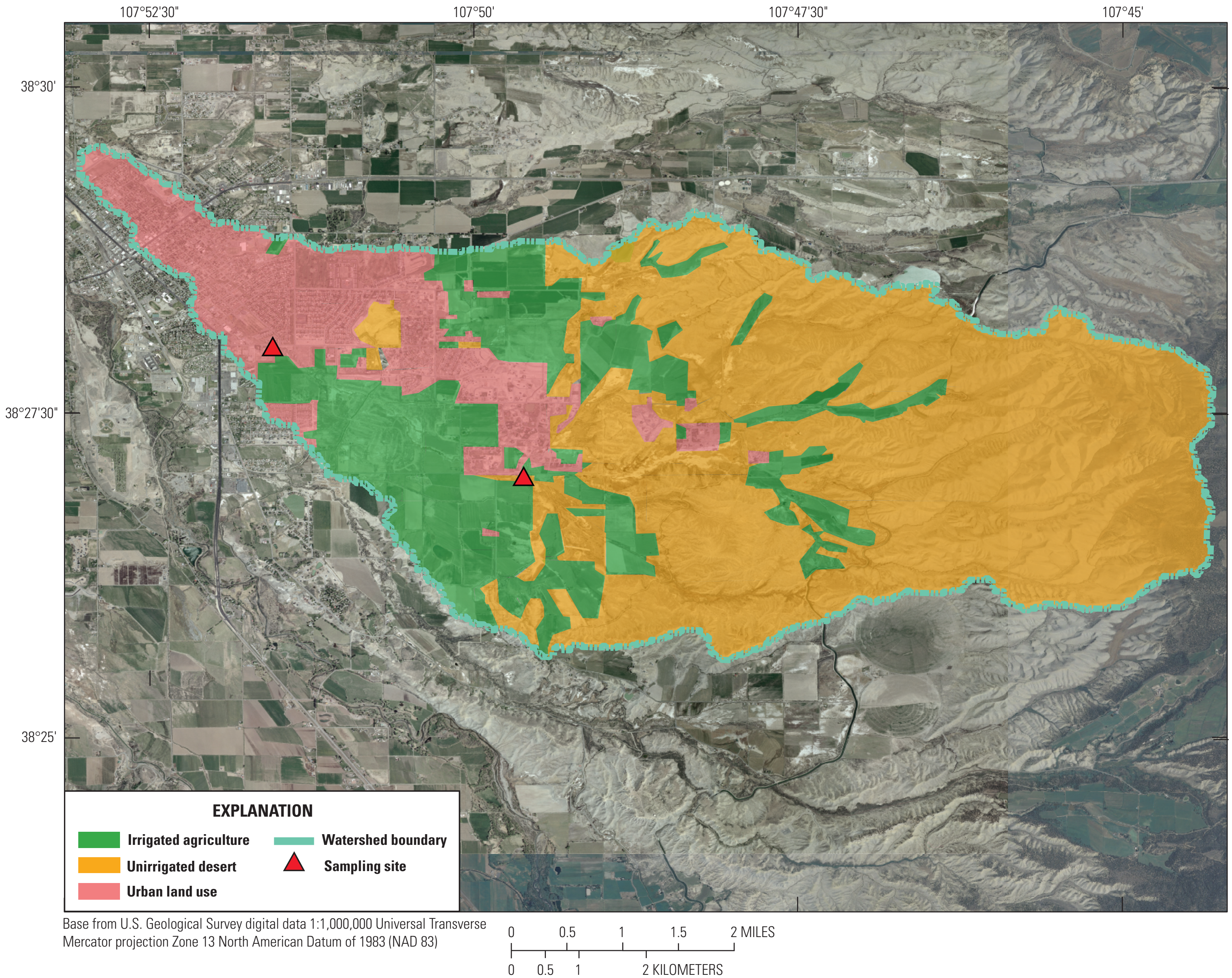


Figure 12. Land-use categorizations in Montrose Arroyo, Montrose, Colorado, 2002.

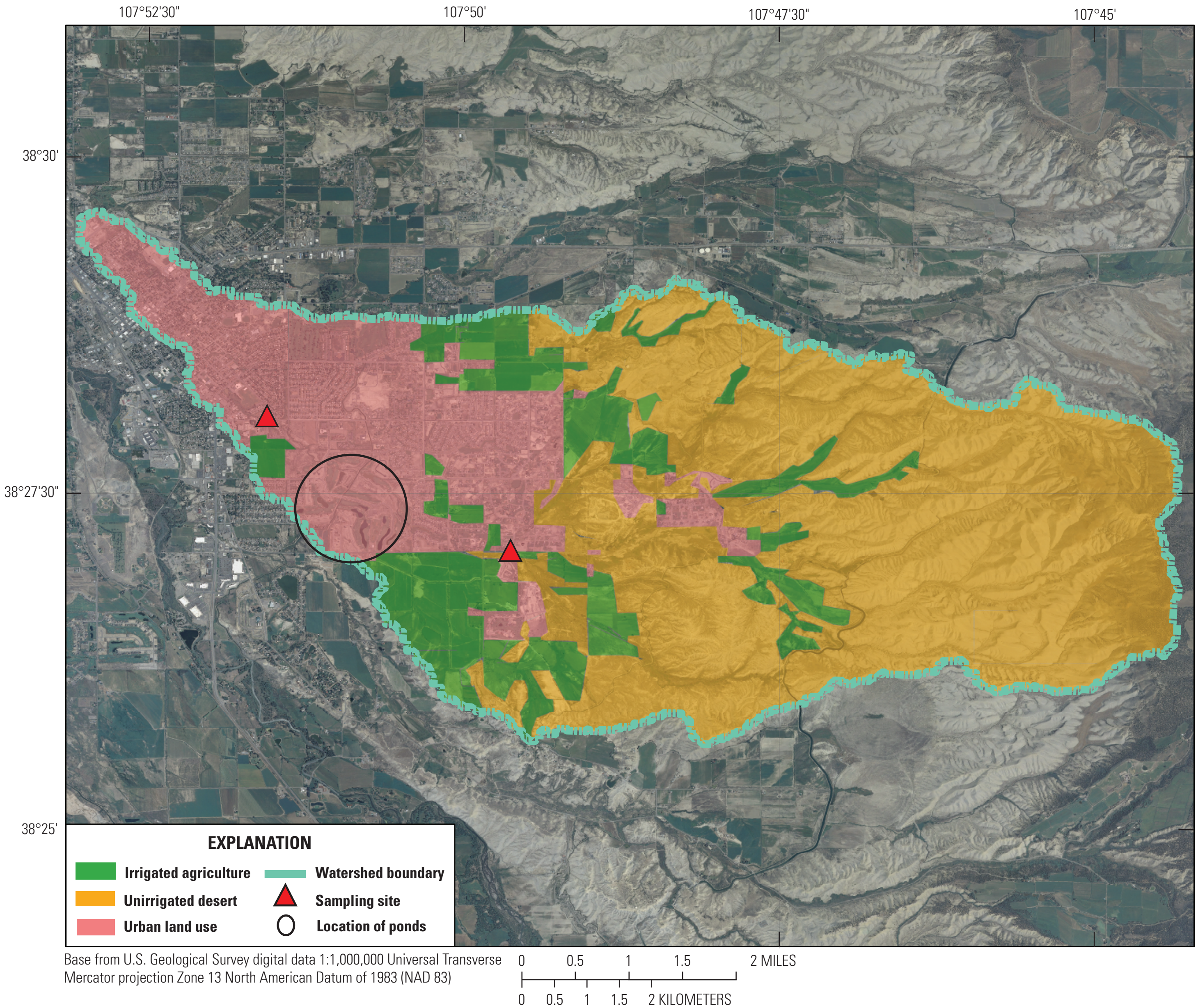


Figure 13. Land-use categorizations in Montrose Arroyo, Montrose, Colorado, 2009.

Table 3. Summary of land use in Montrose Arroyo, Colorado.

Land use	Area (acres)		
	1993	2002	2009
Irrigated agricultural	3,604	3,074	2,032
Unirrigated desert	7,653	7,450	7,320
Urban land	1,306	2,040	3,212

Table 4. Summary of land-use change in Montrose Arroyo, Colorado.

Land-use change	Area (acres)	
	1993–2009	2002–2009
Irrigated agricultural to urban land	1,539	1,042
Unirrigated desert to urban land	367	130
Irrigated agricultural to unirrigated desert	34	0

storage purposes, typically near or around subdivisions, parks, or golf courses. The GIS analysis of the aerial photos found only one new pond as part of a new subdivision between 1993 and 2010; however, nine ponds were developed as a result of the construction of a golf course in Montrose Arroyo. It is unknown whether these ponds are perched or lined with a synthetic liner. Irrigation on the golf course began in the summer of 2000. It is also unknown what the irrigation practices are at the golf course and whether they are comparable to previous practices when the land was irrigated agriculture. Results from Mayo's study (2008) indicate that the estimated amount of seepage from a 1.086-acre unlined pond in Mancos Shale derived soils is 11.70 acre-feet per season. Mayo stated that these ponds were perched above the water table; thus, groundwater inflow could be ignored. Mayo concluded from the pond dataset that unlined ponds contribute more seepage per unit area than either irrigated urban sites with bluegrass as cover or irrigated agricultural fields. Mayo suggested that control of seepage from unlined ponds could be an important factor to consider for minimizing irrigation-induced salinity loading to the river. Estimates of seepage and load from ponds in the Montrose Arroyo watershed are undetermined, and making such estimates was beyond the scope of this study.

A final exercise in the analysis of land-use change was a GIS comparison of growth projections in the City of Montrose 2008 Comprehensive Plan with acreage of non-Federal land outside the plan area (City of Montrose, 2008). The GIS estimated projections for Montrose Arroyo are that approximately 786 acres of previously irrigated agricultural land will be converted to urban land and 689 acres of unirrigated desert will be converted to urban land (table 5 and fig. 14). Outside of and primarily to the east of the area identified as potential land-use change (fig. 15) (according to the 2008 Comprehensive Plan) is approximately 3,954 acres of non-Federal land, of which 2,815 acres is unirrigated desert (fig. 15). This property could be developed in the future with approval from the City of Montrose. New development on previously unirrigated land in shale areas (fig. 2) would likely increase the potential to mobilize new selenium and salinity to Montrose Arroyo and the Lower Gunnison Basin. The remainder of property in eastern Montrose Arroyo (3,954 acres) is managed by the BLM.

Table 5. Summary of projected potential land-use change in Montrose Arroyo, Montrose, Colorado.

Potential land-use change	Area (acres)	
	Area identified in City of Montrose comprehensive plan	Additional potential growth outside comprehensive plan area
Irrigated agricultural to urban land	786	1,139
Unirrigated desert to urban land	689	2,815

Butler's study in 2001 and Mayo's study in 2008 indicated that salinity and selenium loads would decrease as a result of the lateral piping project and land-use change from irrigated agricultural to urban land in Montrose Arroyo. Results from the current study of the surface water indicate that, for unknown reasons, selenium loads have increased but salinity loads are unchanged. Studying the mechanisms of groundwater in Montrose Arroyo could possibly result in a better understanding of salinity and selenium interactions in the watershed.

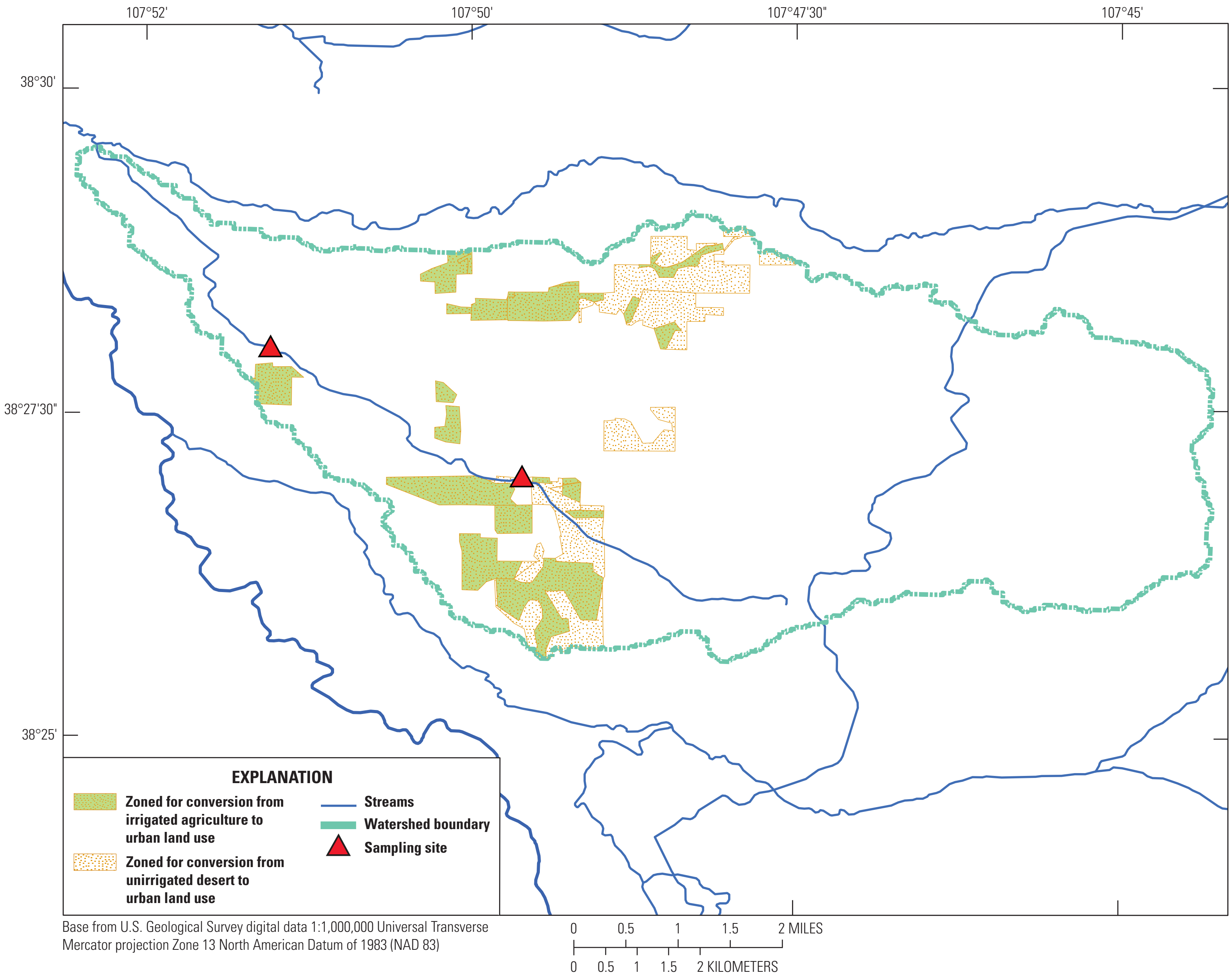


Figure 14. Area identified in the current (2008) City of Montrose comprehensive plan for potential land-use change in Montrose Arroyo, Colorado.

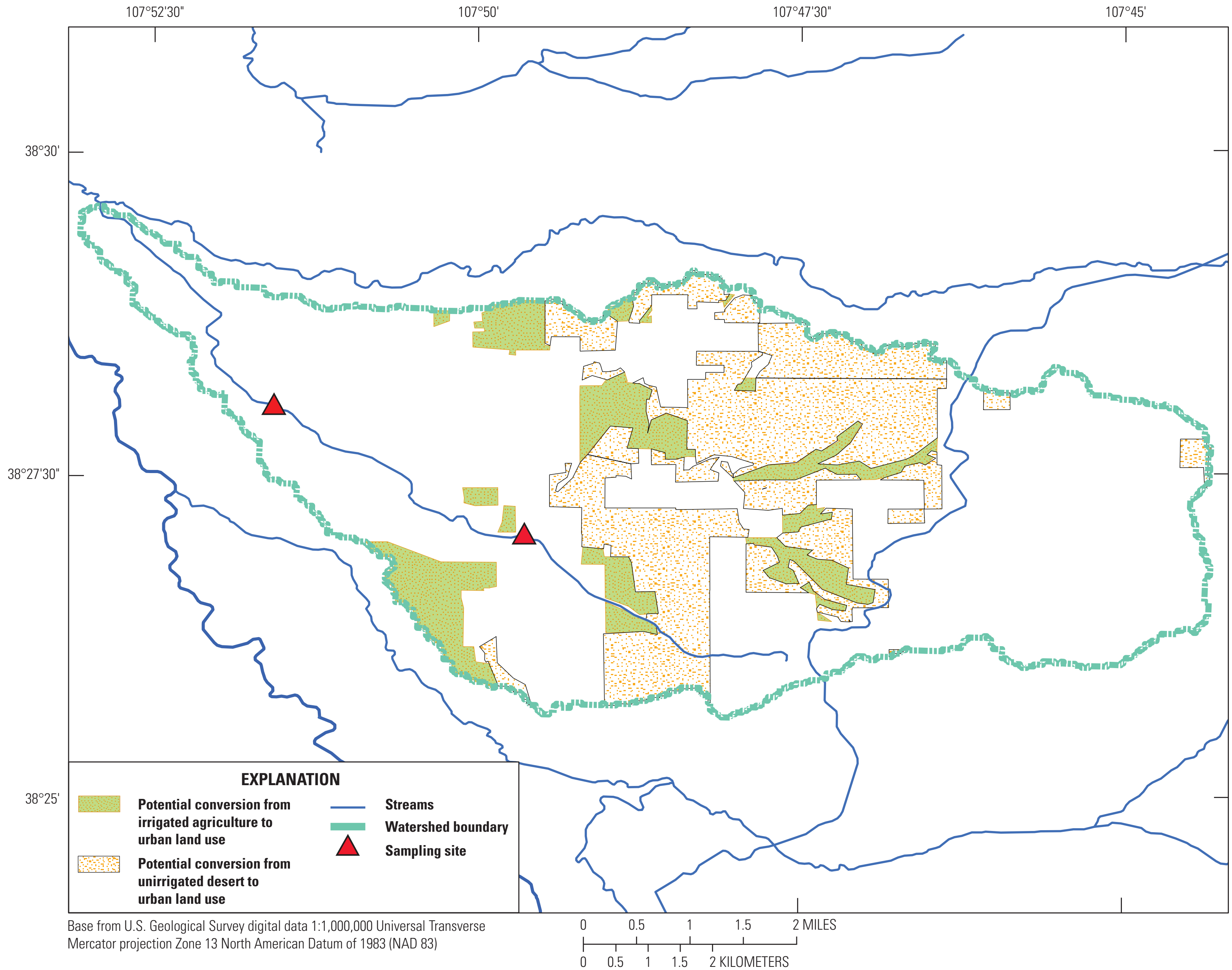


Figure 15. Potential for land-use change beyond the current (2008) Montrose City comprehensive plan in Montrose Arroyo, Colorado.

Summary

Salinity and selenium are known water-quality impairments to streams in the lower Gunnison River Basin of western Colorado. Many water bodies in the lower Gunnison River Basin, including the lower Gunnison River and Uncompahgre River, exceed the State chronic aquatic-life standard for selenium. Although some of the salinity and selenium loading in the study area is from natural sources, additional loading has resulted from the introduction of intensive irrigation in the watershed. In Montrose Arroyo, surface water and groundwater discharges to ditches and natural drainages that, in turn, discharge to the Uncompahgre and Gunnison Rivers and eventually to the Colorado River.

Salinity and selenium were studied in Montrose Arroyo in 2001 as part of salinity- and selenium-control lateral project. With increasing land-use change and the conversion from irrigated agricultural to urban land, land managers and stakeholders need information about the long-term effects of land-use change on salinity and selenium loading. The availability of a robust historical dataset of regional water quality makes Montrose Arroyo an ideal watershed for characterizing salinity and selenium loading with respect to land use over time. In response to the need to advance salinity and selenium science, the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, Colorado River Basin Salinity Control Forum, and Colorado River Water Conservation District, developed a study to characterize salinity and selenium loading and how salinity and selenium sources may relate to land-use change in Montrose Arroyo. This report characterizes changes in salinity and selenium loading to Montrose Arroyo from March 1992 to February 2010 and discusses how changes in loads may relate to land-use change. An analysis of the magnitude of land-use change between unirrigated desert, irrigated agricultural land, and urban land-use types, as well as changes in salinity and selenium loading in Montrose Arroyo and ways in which changes in loads may relate to land-use change are provided.

Montrose Arroyo is an approximately 8-square-mile watershed in Montrose County, Colorado. Montrose Arroyo is a tributary to Cedar Creek, which is a tributary to the Uncompahgre River. The primary land use in the study area is agriculture and unirrigated desert; however, residential and commercial development is increasing with population growth. Public lands managed by the U.S. Department of the Interior, Bureau of Land Management account for approximately 30 percent of Montrose Arroyo.

Over the period of 2 water years and respective irrigation seasons (2008-2010), 27 water-quality samples were collected and streamflow measurements were made at sites MA2 (control site) and MA4 (outflow site) from a 2001 study. Salinity and selenium loads were calculated from the streamflow and concentration data. For the loading analysis, samples for each site were separated into three study periods relative to an irrigation-lateral piping project and to a subsequent period of expanded urban land use: the pre-lateral-project period encompassed all data before April 1999, the post-lateral-project period was April 1999–October 2002, and the post-growth period was March 2008–February 2010. Salinity and selenium (concentrations and loads) and streamflow were compared by using parametric and nonparametric statistics between the pre-lateral-project period and the post-growth period and between the post-lateral-project period and the post-growth period.

No significant trends in streamflow, salinity (concentration and load), or selenium (concentration and load) were found at MA4 between all study periods. The trend analysis also indicated no significant trends in streamflow or salinity (both concentration and load) at MA2. Selenium concentration and load were significantly greater at MA2 between the pre-lateral-project and post-growth periods and between the post-lateral-project and post-growth periods. Land-use change between MA4 and MA2 may have contributed to the observed selenium trend, but the specific mechanisms causing selenium levels to increase are unknown.

By using a geographic information system (GIS) with imagery from 1993, 2002, and 2009, the change in land use was determined. Categories of land use from various data sources were consolidated into three major groups (irrigated agricultural, unirrigated desert, and urban land). All detailed land-use data were manually classified to fit into the three major land-use classes.

The most common land-use change from 1993 to 2009 in the Montrose Arroyo watershed was from irrigated agricultural land to urban land. The introduction of treated domestic water and septic systems to previously unirrigated land has the potential to mobilize salinity and selenium in the soils and potentially result in increased selenium and salinity loads. This land-use change type could become more common as development expands eastward and less and less irrigated agricultural land is available for development. Another land-use change of importance is the construction of ponds, most of which were developed during the construction of the golf course in Montrose Arroyo. Ponds that are unlined and perched above the water table have the potential to seep.

A final exercise in the analysis of land-use change was a GIS comparison of growth projections in the City of Montrose 2008 comprehensive plan with acreage of non-Federal land outside the plan area. The GIS estimated projections for Montrose Arroyo are that approximately 786 acres of previously irrigated agricultural land will be converted to urban land and 689 acres of unirrigated desert will be converted to urban land. Outside of and primarily to the east of the area identified as potential land-use change in the 2008 Comprehensive Plan is approximately 3,954 acres of non-Federal land, of which 2,815 acres is unirrigated desert. New development on previously unirrigated land in shale areas would likely increase the potential to mobilize new selenium and salinity to Montrose Arroyo and the Lower Gunnison River Basin.

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