Surface Water-Quality and Water-Quantity Data from Selected Urban Runoff-Monitoring Sites at the Rocky Mountain Arsenal, Commerce City, Colorado, Water Years 1988–2004

By John D. Gordon, Donald E. Schild, Joseph P. Capesius, and Cecil B. Slaughter

Prepared in cooperation with the
U.S. FISH AND WILDLIFE SERVICE

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Conversion Factors and Definitions

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^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)

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

$$°F=(1.8×°C)+32$$

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

$$°C=(°F–32)/1.8$$

Water Year in USGS reports dealing with surface-water supply is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends. For example, the year ending September 30, 1980, is called “water year 1980.”

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Abstract

The U.S. Geological Survey has monitored the quality and quantity of streamflow at the Rocky Mountain Arsenal (RMA) northeast of Denver, Colorado, since the early 1990s in cooperation with the U.S. Army. This report, prepared in cooperation with the U.S. Fish and Wildlife Service, documents existing surface-water-quality conditions on the RMA. All RMA water-quality data for the Irondale Gulch and First Creek Basins adjacent to and on the RMA were reviewed. Where applicable, water-quality data were compared to State standards established by the Colorado Department of Public Health and Environment. At both the Havana Interceptor below 56th Avenue gaging station and the Uvalda Interceptor below 56th Avenue gaging station, all of the dissolved-oxygen concentrations met the State standard requiring at least 5.0 milligrams per liter (mg/L) of dissolved oxygen for the protection of aquatic life. In contrast, the dissolved-oxygen concentrations at the Peoria Interceptor below 56th Avenue gage commonly were less than 5.0 mg/L. Excluding one suspect concentration of 1.6 mg/L, the dissolved-oxygen concentrations for the First Creek Basin ranged from 4.2 to 12.6 mg/L. Excluding the one suspect value, three dissolved-oxygen concentrations failed to meet the State standard of 5.0 mg/L at the First Creek below Buckley Road site. At the Peoria Interceptor below 56th Avenue site, all pH values were within the range specified by the State standard (6.50–8.99). Results of seven sampling events at the Havana Interceptor below 56th Avenue gaging station indicated a pH greater than or equal to 9 (pH values of 9 or greater exceed the upper limit of the standard). No sampling events indicated a pH less than 6.50. Results from one sampling event at the Uvalda Interceptor below 56th Avenue indicated pH values outside the range specified by the State standard. The concentrations obtained for chloride, magnesium, and sodium generally were below 200 mg/L at all three Irondale Gulch monitoring stations for the entire period of record, but there were a few sampling events at each of these sites where much higher concentrations for these analytes were obtained. The median concentrations for calcium, magnesium, and sodium generally were higher at the First Creek below Buckley Road site than in the three Irondale Gulch sites, while the 90th percentile and maximum concentrations for magnesium and sodium generally were higher at the three Irondale Gulch sites than at the First Creek below Buckley Road site. The urban runoff flowing onto the RMA had low concentrations and few, if any, detections for most organic contaminants. Part of the reason for low detections of organic contaminants may be in how the samples are collected. The existing surface-water sampling program was not designed specifically to target storm runoff and therefore does not characterize water quality for all hydrologic regimes, most notably storm runoff. As a result, the existing data may not adequately represent potential contaminant transport onto the RMA. In addition, during stormwater-runoff events, the sites examined for this report frequently are subject to sharp increases in discharge, and just as quickly the discharge rapidly recedes. These types of transient flow events make water-quality sampling difficult, and none of the sites have a safe place to sample the higher flows that occur in any given year. As a result, most of the surface-water-quality samples were collected after the flow had decreased substantially from the peak flow, which may have transported much of the chemical contaminant load through the system. Thus, little is known about the water quality during the critical initial stormwater-runoff period when contaminants are most likely to be mobilized and transported through the stormwater conveyances past the locations where gaging stations are located.

Introduction

The Rocky Mountain Arsenal (RMA) is becoming one of the largest urban wildlife refuges in the United States (U.S. Fish and Wildlife Service, 2005). The RMA is a former Army facility that is being restored to a native shortgrass prairie with a variety of aquatic habitats, including five small lakes and several wetlands. Several streams and drainages flow onto the RMA from the south and southeast; some ultimately drain into a series of lakes and wetlands in the southernmost sections of the RMA. The headwaters of these streams and drainages are undergoing rapid urban development. Several of the existing urban drainages are being extended farther upstream to collect additional urban runoff. The U.S. Geological Survey (USGS), in cooperation with the U.S. Army, has monitored the quality and quantity of streamflow in these streams and drainages since the early 1990s. It is expected that the increasing urban development south and east of the RMA will cause changes to the water quality and quantity, but the extent of these changes is not yet known. Increased runoff volumes and peak flows may cause increased erosion of the stream channels and banks. In addition, urban runoff typically has higher concentrations of anthropogenic contaminants, such as petroleum products, fertilizers, and pesticides (Hughes and others, 2000) that could become harmful for fish and waterfowl species on the RMA on either an episodic or chronic basis. This report, prepared in cooperation with the U.S. Fish and Wildlife Service, documents existing surface-water-quality conditions on the RMA and discusses in general terms the implications of these constituents to the ecological health of the new Rocky Mountain Arsenal National Wildlife Refuge.

Purpose and Scope

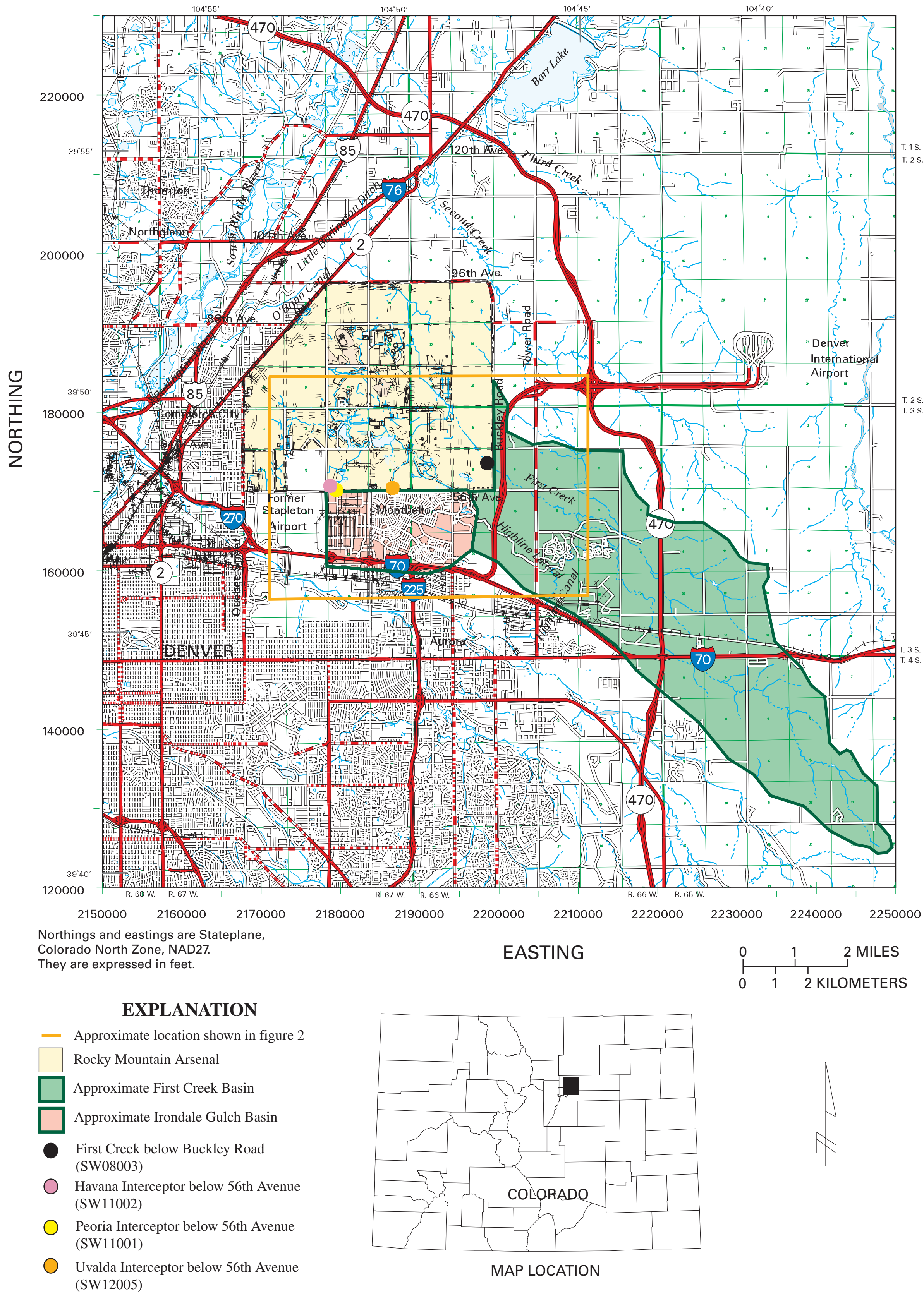
The purpose of this report is to provide a general characterization of the surface-water quality and quantity at urban-runoff sites for streams and stormwater conveyances that flow onto the RMA. Four urban runoff-monitoring sites located at the RMA were evaluated—the Irondale Gulch Basin sites of Havana Interceptor below 56th Avenue, Peoria Interceptor below 56th Avenue, Uvalda Interceptor below 56th Avenue, and the First Creek Basin site of First Creek below Buckley Road. These sites are in the southernmost sections of the RMA and were officially transferred in 2004 to the jurisdiction of the U.S. Fish and Wildlife Service (fig. 1). Water-quality characteristics that were measured include dissolved oxygen, pH, selected major ions (calcium [Ca], chloride [Cl], magnesium [Mg], potassium [K], sodium [Na], and sulfate [SO_4]), carbonate ion [CO_3^{-2}], bicarbonate ion [HCO_3^{-}], and specific conductance. All of the water-quality data presented in this report were collected between January 1988 and May 2004, whereas streamflow data presented in this report were collected between October 1992 and September 2003. Limitations of the existing (2005) sampling program are described, and methods to better monitor water quality from the urban interceptors also are discussed.

Hydrology

Two drainage basins provide nearly all of the surface water that flows onto the RMA: Irondale Gulch and First Creek. A drainage basin is defined as a part of the surface of the Earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water (Langbein and Iseri, 1960). Drainage basins are commonly referred to as basins (Nevada Department of Conservation and Natural Resources, 2005). The contributing drainage area for Irondale Gulch Basin encompasses approximately 7 mi^2 upstream from the RMA, whereas the upstream contributing area for First Creek Basin is much larger, encompassing approximately 36 mi^2 (fig. 1).

The Irondale Gulch Basin generally drains north and west toward the South Platte River. The area upstream from 56th Avenue (south), which is the southern boundary of the RMA, is mostly urban with a mix of light industrial, commercial, and residential land uses. The urban areas south of the RMA have existed since the 1970s, and the stormwater-drainage network consists primarily of manmade concrete-lined channels and culverts. At present (2005), the manmade drainage network is being extended farther upstream as areas east of the existing urban area become developed. New conveyance channels in this extended drainage network are being constructed as unlined earthen waterways with a wetland plant community across the wetted perimeter. These "wetland bottom" channels are anticipated to improve runoff water quality by reducing (trapping) suspended sediment and debris loads and by absorbing some dissolved water-quality constituents. Stormwater runoff in the Irondale Gulch Basin is managed according to the Irondale Gulch Stormwater Master Plan developed by the Urban Drainage and Flood Control District (2005) in conjunction with local governments (Denver, Commerce City, and Adams County) and the RMA. First Creek terminates at its confluence with the O'Brian Canal downstream from the RMA. The O'Brian Canal flows into Barr Lake. A review of USGS topographic maps of the area by the authors indicates the outflow from Barr Lake is distributed to numerous irrigation reservoirs through a network of canals. During low-flow conditions, very little First Creek streamflow reaches the O'Brian Canal. In times of extreme high flow in First Creek, a small amount of streamflow from First Creek may reach the South Platte River. A review of area maps by the authors indicates streamflow from the Irondale Gulch Basin seldom, if ever, reaches the South Platte River because the runoff from the Irondale Gulch Basin is distributed into a series of wetlands and reservoirs on the RMA (some of which predate the RMA), and stream channels downstream from the wetlands and reservoirs were extensively disrupted by historical anthropogenic activities in the area (as indicated by a review of historical aerial photographs and maps of the area by the authors). Ground-water recharge from precipitation and streamflow is a much more plausible mechanism for water from the First Creek and Irondale Gulch Basins to reach the South Platte River.

Three urban drainage channels or interceptors in Irondale Gulch flow onto the RMA. The three interceptors are named Havana Interceptor below 56th Avenue, Peoria Interceptor below 56th Avenue, and Uvalda Interceptor below 56th Avenue. Each interceptor is named after a nearby street and conveys intermittent stormwater runoff and a near-continuous urban-runoff-derived base flow onto the RMA. The Urban Drainage and Flood Control District map (fig. 2) shows most of the drainage features in the First Creek and Irondale Gulch Basins



Sources include Washington Group International, DPRA Incorporated, and U.S. Geological Survey.

Figure 1. Approximate location of First Creek and Irondale Gulch drainage basins upstream from Rocky Mountain Arsenal National Wildlife Refuge.

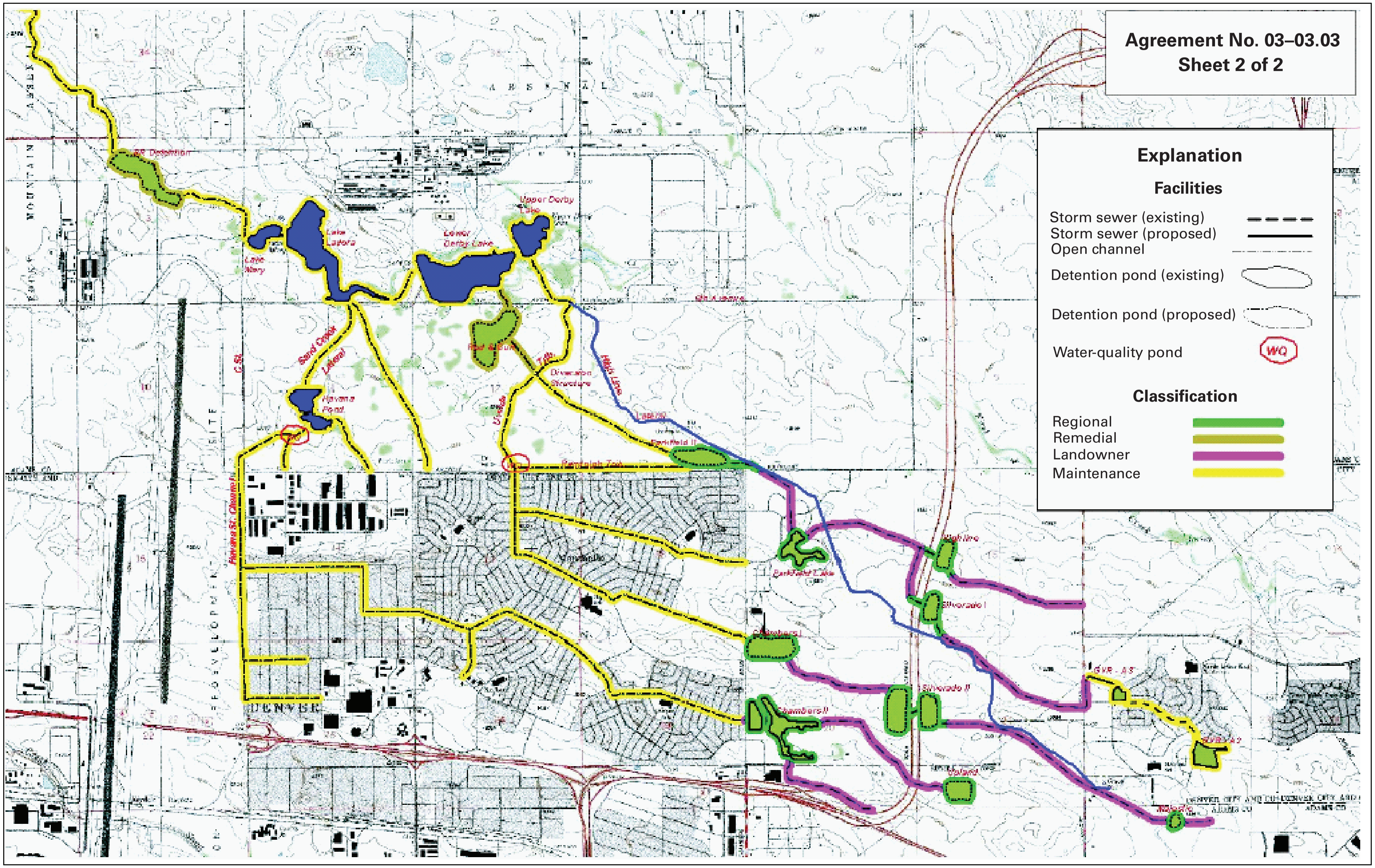


Figure 2. Drainage features in the First Creek and Irondale Gulch Basins, including new drainage channels and detention ponds planned for the Irondale Gulch Basin near the Rocky Mountain Arsenal National Wildlife Refuge (Urban Drainage and Flood Control District map, courtesy of U.S. Fish and Wildlife Service, 2004), Commerce City, Colorado.

and most of the new drainage channels and detention ponds that will be constructed in the Irondale Gulch Basin as urban development proceeds. Havana Interceptor has its highest flow during the summer with peaks regularly exceeding 20 cubic feet per second (ft^3/s) in response to storms, but the stream essentially dries up during the winter (fig. 3). The Havana Interceptor carries the largest flows during runoff events because it has the largest contributing drainage area of the three Irondale Gulch interceptors. Of the three Irondale Gulch interceptors, Peoria Interceptor has the lowest base flow (about 0.01 ft^3/s), the smallest drainage area, and consequently, the smallest peaks in response to runoff events (fig. 4). Uvalda Interceptor has a moderate base flow (about 0.4 ft^3/s) and carries moderate-sized flows from the upstream urban area during runoff (fig. 5). The contributing area and channelized parts of the Uvalda Interceptor Basin are scheduled for expansion over the next few years to accommodate increased urban development.

After entering the RMA, runoff in Havana and Peoria Interceptors flows into Havana Pond (fig. 2), which is a flood-control pond. Stormwater runoff provides most of the inflow to Havana Pond. The water level of Havana Pond increases rapidly during stormwater runoff, and Havana Pond loses much of its water to infiltration within a few days of a stormwater-runoff event (fig. 6). A stormwater-runoff event is a period of stormwater runoff occurring in response to precipitation. Occasionally, water in Havana Pond is released into the Sand Creek Lateral, an unlined irrigation ditch, and flows into Lake Ladora or infrequently over a designed spillway that also discharges into the Sand Creek Lateral. Uvalda Interceptor flows for about 1 mi on the RMA in an unlined earthen channel to a junction box where flows can be diverted into two downstream lakes, Lower and Upper Derby Lakes.

Streamflow data were stored in the USGS National Water Information System (NWIS) database and in the Rocky Mountain Arsenal Environmental Database (RMAED). Based on a compilation of data obtained from the USGS NWIS database (*http://waterdata.usgs.gov/nwis*), between 1992 and 2004, the combined mean annual runoff volume from the three Irondale Gulch interceptors onto the RMA was 1,761 acre-ft.

The second major basin to cross the RMA is First Creek. First Creek is a natural stream and generally flows west and north toward the South Platte River. Flow in First Creek is intermittent and does not occur during much of the summer except following periods of heavy precipitation (fig. 7). Base flow returns to First Creek usually in the fall or early winter of each year and stops in the late spring or early summer as transpiration of riparian plants increases. In the past, the Highline Lateral had a major influence on the flow of the First Creek Basin with respect to the RMA. Although Highline Canal water does not originate from the First Creek Basin, it enters the RMA in the First Creek Basin. Before 2004, the Highline Lateral was used to deliver an annual water-right volume of 387 acre-ft to reservoirs, ponds, and wetlands at the RMA. Because of the high seepage losses associated with delivery of water to the RMA through the Highline Lateral, the Denver Water Board negotiated a new method of delivering water with the RMA beginning in 2004. In most years, water will be delivered in ways that do not involve using the Highline

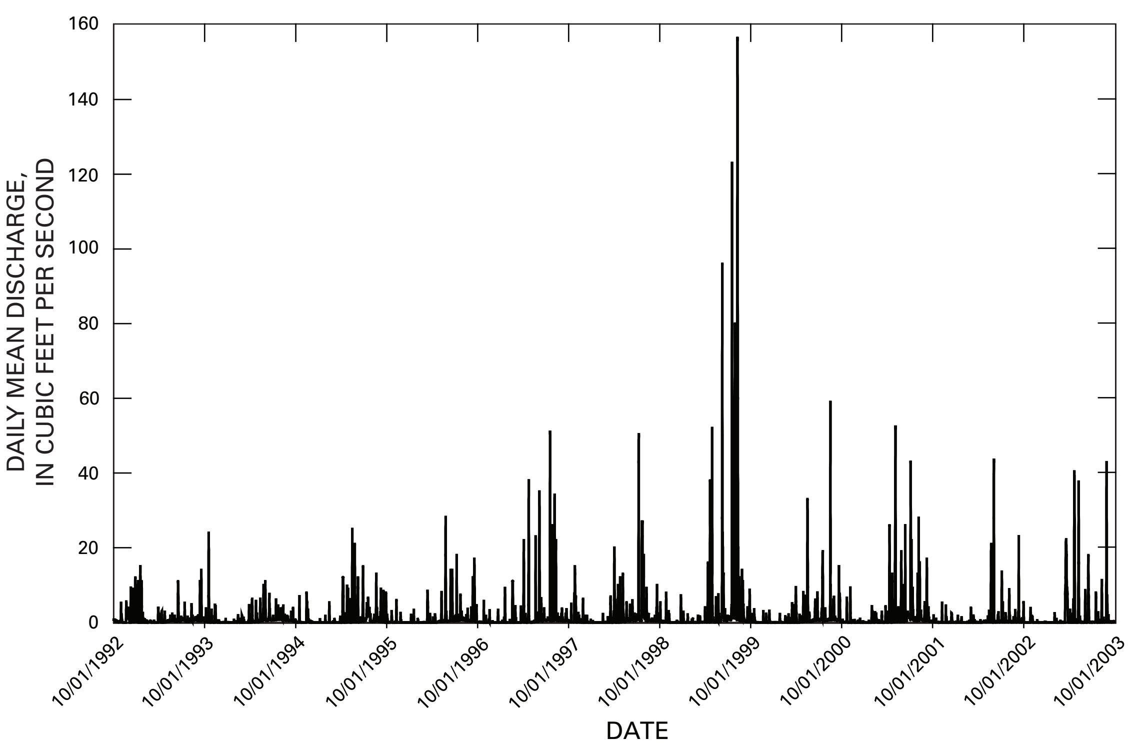


Figure 3. Daily mean discharge at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1993–2003.

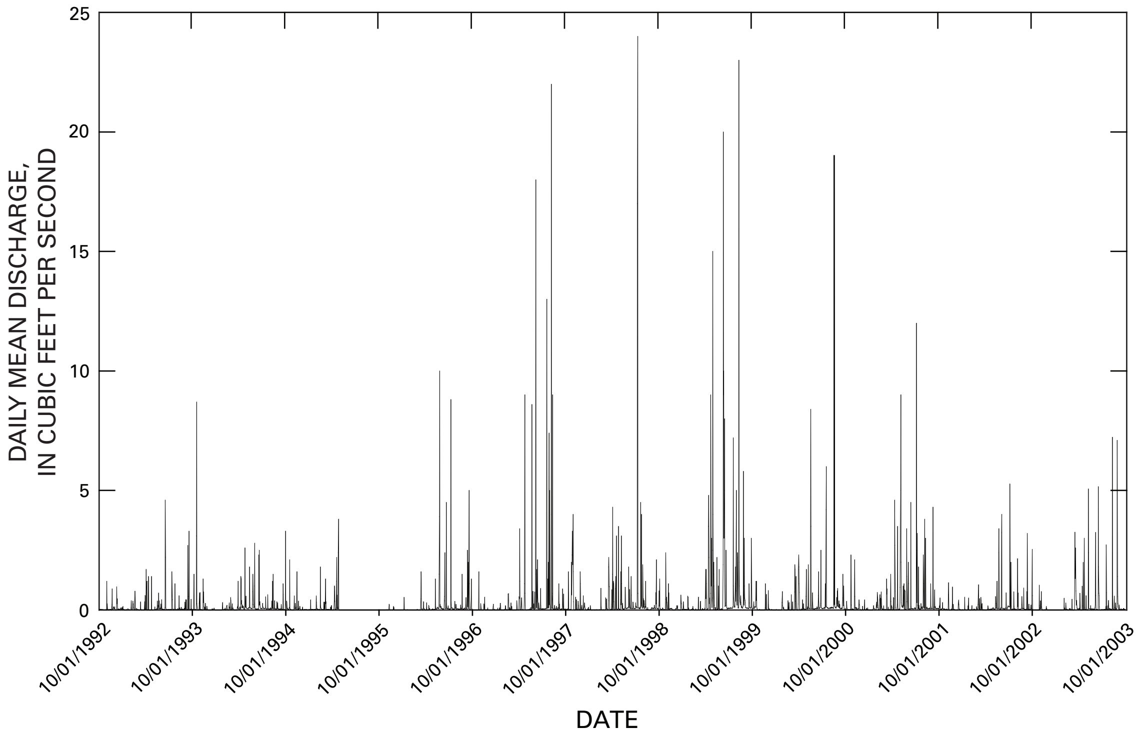


Figure 4. Daily mean discharge at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1993–2003.

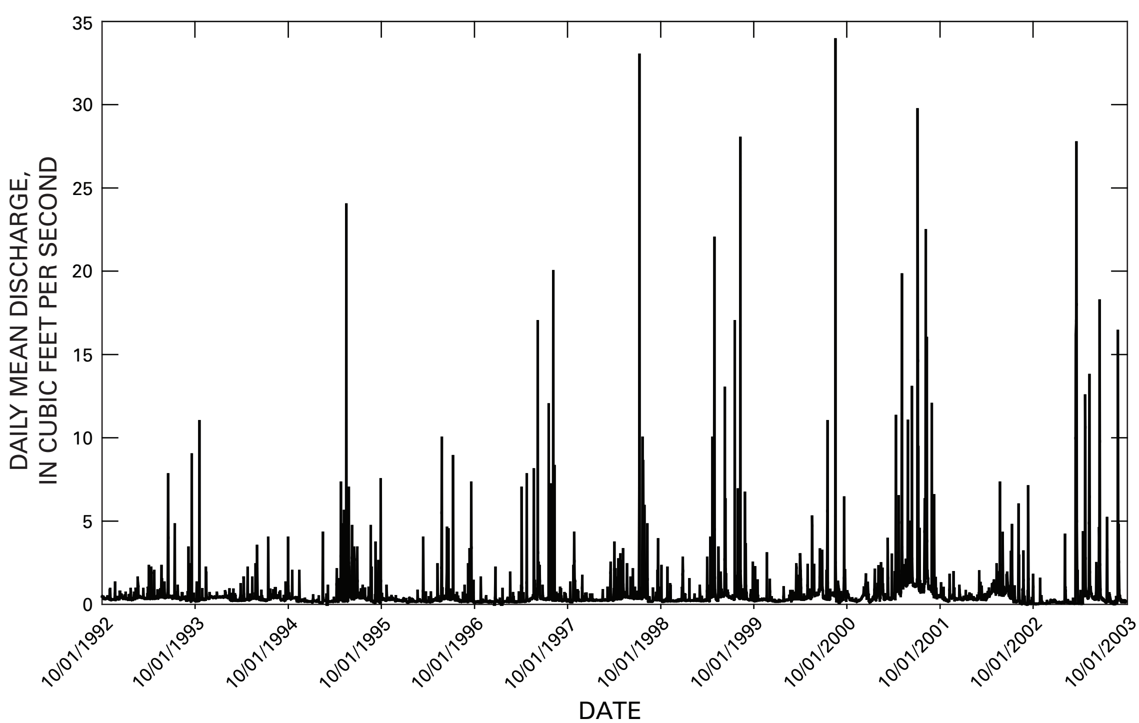


Figure 5. Daily mean discharge at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1993–2003.

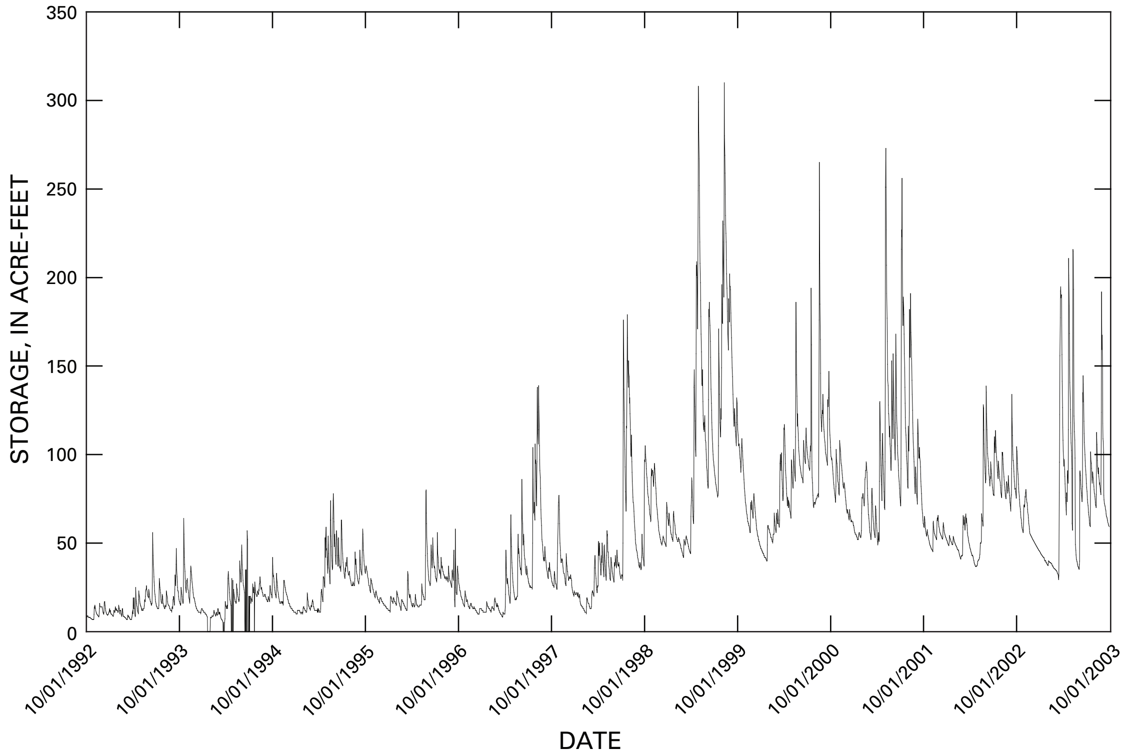


Figure 6. Havana Pond storage, Commerce City, Colorado, water years 1993–2003.

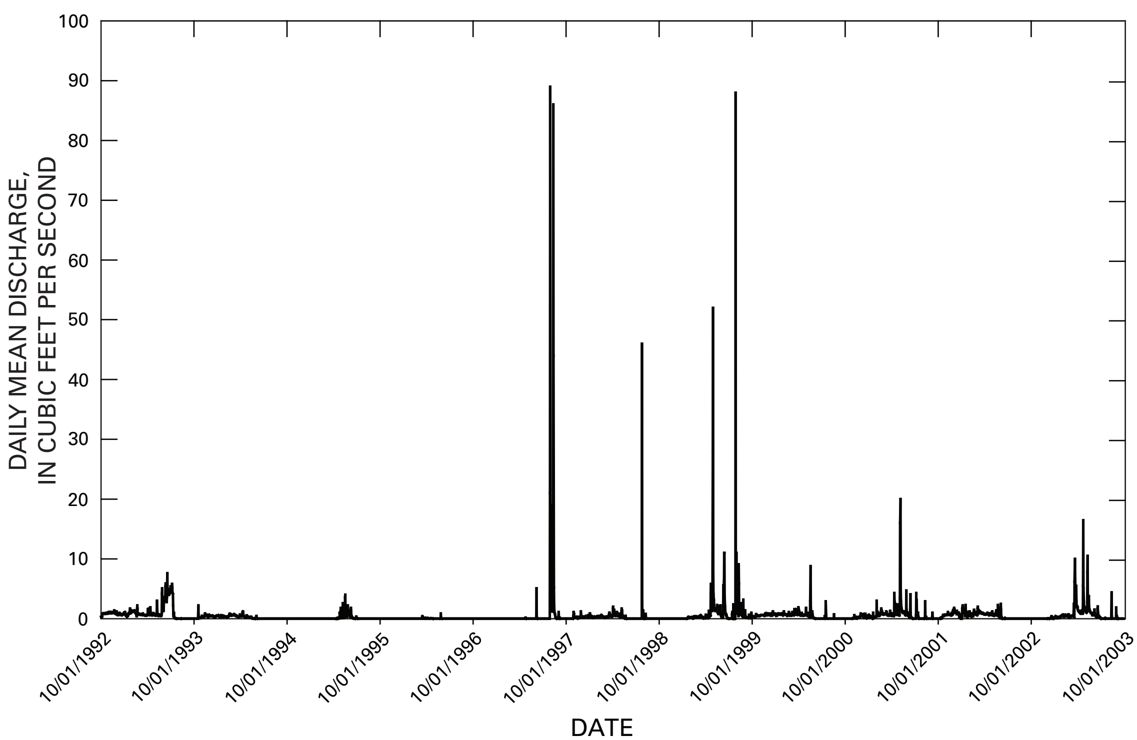


Figure 7. Daily mean discharge at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1993–2003.

Lateral. Alternative water sources were being investigated as described in the RMA Surface-Water Management Plan, Water Year 2004 (Tetra Tech Foster Wheeler Incorporated, written commun., 2004).

The First Creek Basin is part of a master-planned drainage system for which surface runoff is managed according to the First Creek Stormwater Master Plan developed by the Urban Drainage and Flood Control District in cooperation with local governments (Aurora, Denver, Commerce City, and Adams County) and the RMA. Details of the existing master plan can be found in various reports listed on the Urban Drainage and Flood Control Master Plan Web site (*http:////www.udfcd.org/master.htm*, accessed October 25, 2004). The hydrology of the First Creek Basin is changing. Flood-detention and flood-retention ponds have been built along First Creek upstream from Tower Road in conjunction with the Green Valley Ranch Golf Club, and future flood-detention and flood-retention ponds will be built elsewhere in the basin, consistent with the First Creek Stormwater Master Plan. Flood-retention basins are storage basins or other structural measures designed to attentuate runoff hydrographs and be of benefit during any flow regime. Flood-detention basins temporarily store flow and can be part of the same basins or structural measures designed for flood-retention purposes (Fox, 2003). Parts of the First Creek Basin have been urbanized with residential and light commercial developments, and runoff likely will increase in the future from increases in both the runoff from impervious areas and increased irrigation in the basin. Increased urban development results in higher amounts of both impervious and irrigated areas in the upstream watersheds. The increased impervious areas include parking lots, roofs, roads, driveways, and sidewalks, and the increased irrigated areas include parks, golf courses, lawns, and other irrigated landscaping. Increased impervious land covers in the drainages upstream from First Creek below Buckley Road are likely to cause increased peak flows, and increased lawn irrigation is expected ultimately to increase the base flows. Figure 8 depicts some of the open land in First Creek Basin where development is anticipated to occur within a few years. In the foreground are flood-detention ponds in the Green Valley Ranch Golf Club along First Creek. Although the First Creek Basin is more than five times as large as the Irondale Gulch Basin, the mean annual runoff volume onto the RMA from the First Creek Basin from October 1992 through September 2003 was only 656 acre-ft per year—about one-third of the mean annual runoff volume from the Irondale Gulch interceptors onto the RMA for this same period. This is due, in part, to the complete absence of stormwater detention or retention ponds in the Montbello residential and commercial districts located immediately south of the RMA in the Irondale Gulch Basin (figs. 1 and 2). In addition, the stormwater conveyance channels throughout Montbello are concrete-lined waterways that minimize transit losses, thereby increasing stormwater discharge onto the RMA.

Figure 8. Aerial view of flood-detention ponds in a golf course along First Creek, near Commerce City, Colorado, 2003.

Methods of Investigation

Continuous streamflow data were collected at four USGS gaging stations beginning October 1, 1992: Havana Interceptor below 56th Avenue (USGS 06720285, RMAED SW11002), Peoria Interceptor below 56th Avenue (06720280, RMAED SW11001), Uvalda Interceptor below 56th Avenue (USGS 06720255, RMAED SW12005), and First Creek below Buckley Road (USGS 06720460, RMAED SW08003). The location of each of these gaging stations is shown in figure 1. Water-quality samples were collected at these four gaging stations on a periodic basis beginning in 1988. All USGS streamflow data were collected according to methods described by Rantz and others (volumes 1 and 2, 1982); all of the streamflow data were stored in both the NWIS database and RMAED, while the water-quality data were stored only in the RMAED. Samples were collected following procedures that are outlined in the Surface-Water Monitoring Program Sampling and Analysis Plan, July 2001, and in accordance with the Program Management Contractor Chemical Quality Assurance Plan (Foster Wheeler Environmental Corporation, written commun., 2002). The surface-water sampling plan has changed over the years to reflect changes in the RMA program. The suite of analytes for each water-quality sample also has changed over the years. The present (2005) analyte suite is outlined in the Surface-Water Sampling and Analysis Plan (Foster Wheeler Environmental Corporation, written commun., 2001). Appendix 1 contains a list of all analytes that have been collected as part of the surface-water program and the abbreviations used for them at the RMA. The constituents addressed in this report also are in Appendix 1.

Water-Quality Analysis

All of the water-quality data for the three Irondale Gulch Basin sites and the one First Creek Basin site were reviewed. Where applicable, water-quality data were compared to standards established by the Colorado Department of Public Health and Environment for the Upper South Platte River Basin, segment 16C, which includes all tributaries to the South Platte River between Chatfield Reservoir and Big Dry Creek. The applicable use designations are Warm Water Class 2, Recreation Class 1, and Agricultural. A detailed review of the water-quality data reveals few detections of the contaminants targeted by the analytical suite in the surface water at the RMA, with only a few samples exceeding applicable State standards. Even though a large suite of organic contaminants was included in the sampling program (Appendix 1), the urban runoff flowing onto the RMA had low concentrations and few, if any, detections for most organic contaminants. Because there were virtually no organic contaminants with concentrations above their method reporting limits, the water-quality data evaluated in this report were limited to dissolved oxygen, pH, specific conductance, certain major ions (calcium, chloride, magnesium, potassium, sodium, and sulfate), and carbonate ion and bicarbonate ion.

Analysis of Irondale Gulch Water-Quality Data

Water-Quality Field Measurements

Water-quality field measurements provide information about the properties of the water in the field environment, which helps with interpreting water-quality analyses. Field measurements of dissolved oxygen, pH, specific conductance, and water temperature are collected for all water-quality samples. Water temperature is not discussed as a separate entity, as it is heavily dependent on air temperature at the time of measurement for the predominantly shallow flows measured at the Irondale Gulch sites.

Dissolved Oxygen

Dissolved oxygen is essential to the respiration of aquatic organisms, and its concentration in streams is a major determinant of the species composition of biota in the water and underlying sediments. Moreover, the dissolved oxygen in streams has a profound effect on the biochemical reactions that occur in water and sediments, which in turn affect numerous aspects of water quality, including the solubility of many toxic elements and esthetic qualities of odor and taste (Smith and others, 1993). In the absence of substances that cause its depletion, dissolved-oxygen concentration in streams approximates the saturation level for oxygen in water that is in contact with the atmosphere (Smith and others, 1993). Dissolved-oxygen concentration decreases with increasing water temperature, from about 14 milligrams per liter (mg/L) at freezing to about 7 mg/L at 86°F (30°C) (Smith and others, 1993). For this reason, in ecologically healthy streams, the dissolved-oxygen concentration depends primarily on temperature, which varies with season and climate (Smith and others, 1993).

Major sources of substances that cause depletion of dissolved oxygen in streams are discharges from municipal and industrial wastewater-treatment facilities; leaks and overflows from sewage lines and septic tanks; stormwater runoff from agricultural and urban land; and decaying vegetation, including aquatic plants from the stream itself and detrital terrestrial vegetation (Smith and others, 1993). Photosynthesis by aquatic vegetation is a major source of dissolved oxygen in streams. The aeration that takes place as the stream flows over rocks, riffles, and waterfalls adds dissolved oxygen (Smith and others, 1993). When aquatic vegetation is abundant, photosynthesis during daylight hours followed by nighttime respiration results in a substantial diurnal fluctuation in the concentration of dissolved oxygen. According to the State standard for the protection of aquatic life, the dissolved-oxygen concentration must be 5.0 mg/L or greater for the streams in the Irondale Gulch and First Creek Basins.

At the Havana Interceptor below 56th Avenue gaging station, all of the dissolved-oxygen measurements met the State standard requiring at least 5.0 mg/L of dissolved oxygen for the protection of aquatic life (fig. 9). In contrast, the dissolved-oxygen results at the Peoria Interceptor below 56th Avenue gage (fig. 10) commonly were less than 5.0 mg/L. The Uvalda Interceptor below 56th Avenue dissolved-oxygen concentrations were similar to those detected at the Havana Interceptor, with none of the concentrations falling below the State standard (fig. 11). Few trees line the Havana and Uvalda Interceptors in the reaches immediately upstream from the gaging stations, but the Peoria Interceptor has an abundance of trees along its banks in the reach upstream from the gaging station. At the Peoria site, large amounts of leaf debris tend to collect in the channel immediately upstream from the gaging station. One possible explanation for the more frequent occurrences of low dissolved-oxygen levels at the Peoria gaging station compared to the two other interceptors is the leaf matter from nearby cottonwood trees that collects on a seasonal basis and may decompose in the pool of water upstream from the gaging station, which would help consume the dissolved oxygen at this gaging station. The elevated (≥14 mg/L) dissolved-oxygen concentrations shown in figures 9–11 may have been influenced by a combination of abundant aquatic vegetation and low-flow conditions when many of the dissolved-oxygen measurements were made. It is not unusual for streams with a combination of extreme low-flow conditions and abundant aquatic vegetation to reach supersaturated levels of dissolved oxygen on a diel basis (Fondriest Environmental Products, *http://www.fondriest.com/technotes/dosaturation.htm*, accessed February 2, 2005). Another possible cause of dissolved-oxygen readings greater than 100-percent air saturation arises from the fact that equilibration (or equalization) of the oxygen content of water with the air above it is seldom rapid except in fast-flowing streams (Fondriest Environmental Products, *http://www.fondriest.com/technotes/dosaturation.htm*, accessed February 2, 2005).

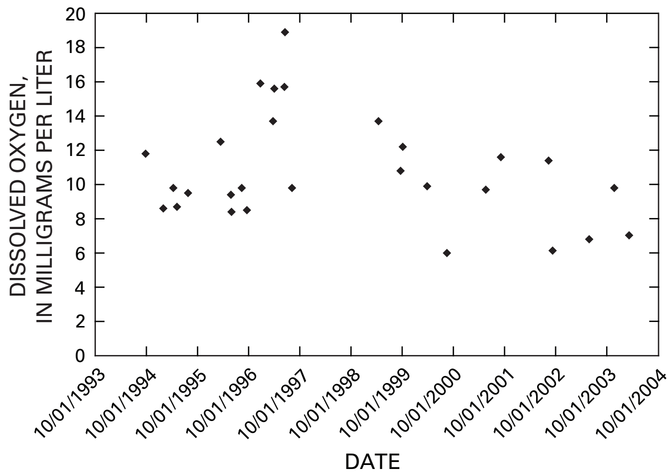


Figure 9. Dissolved-oxygen concentration at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

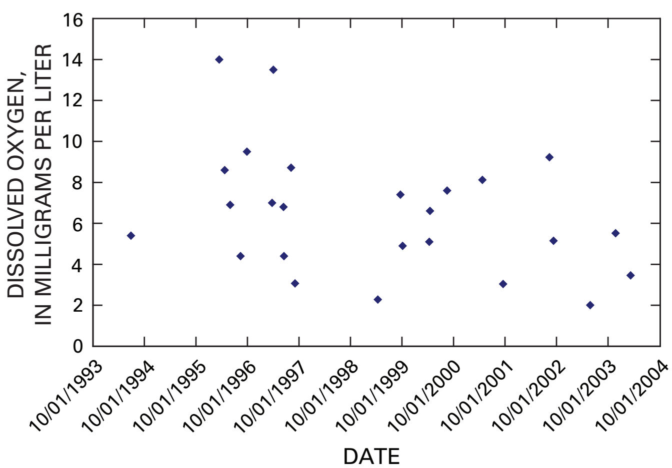


Figure 10. Dissolved-oxygen concentration at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

pH

pH is a measurement of the hydrogen-ion activity (H^+) in a solution, based on a negative logarithmic scale. pH is a unitless value usually between 0 and 14 derived from the ratio of H^+ to hydroxyl (OH^-) ion activities at a given temperature (Wilde and Radtke, 1999) indicating whether a solution is acidic (pH < 7), neutral (pH = 7), or basic/alkaline (pH > 7) (Wikipedia Encyclopedia, 2005). The pH of surface water can vary widely for numerous reasons. The Washington State University Department of Ecology published a report titled "A Citizen's Guide to Understanding and Monitoring Lakes and Streams" (Michaud, 1991), which succinctly summarizes the reasons pH variation occurs and how increased nutrient loading from anthropogenic sources affects pH:

Geology of the watershed and the original source of the water determine the initial pH of the water. The greatest natural cause for change in pH in a stream is the seasonal and daily variation in photosynthesis. Photosynthesis uses up hydrogen molecules, which causes the concentration of hydrogen ions to decrease and therefore the pH to increase. Respiration and decomposition processes lower the pH. For this reason, pH is higher during daylight hours and during the growing season, when photosynthesis is at its peak.

Although pH may be constantly changing, the amount of change remains fairly small. Natural waters are complex, containing many chemical "shock absorbers" that prevent major changes in pH. Small or localized changes in pH are quickly modified by various chemical reactions so little or no change may be measured. This ability to resist change in pH is called buffering capacity. Not only does the buffering capacity control would-be localized changes in pH, it controls the overall range of pH change under natural conditions. The pH scale may go from 0 to 14, but the pH of natural waters hovers between 6.5 and 8.5.

The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (such as phosphorus, nitrogen, and carbon) and heavy metals (such as lead, cadmium, and copper). For example, in addition to determining how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use it. Heavy metals tend to be more toxic at lower pH because they are more soluble and more bioavailable.

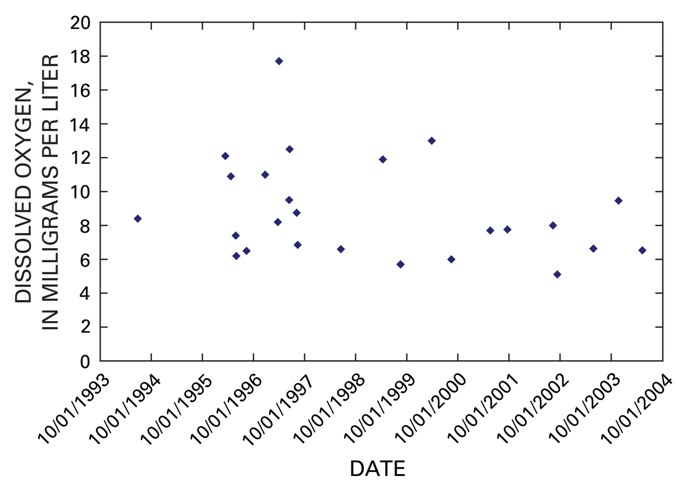


Figure 11. Dissolved-oxygen concentration at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

During periods of low flow in the urban watersheds upstream from the RMA, the streamflow is composed mainly of treated water, which tends to have elevated (>7.0) pH values while at the same time is highly buffered. Sampling events consist of base flow and stormwater runoff; irrigation return-flow-dominated streamflow and urban-runoff-dominated streamflow are both represented in the mix of sampling events. The State water-quality standard for pH applicable to the Irondale Gulch and First Creek Basins requires the pH to be between 6.50 and 8.99 for the protection of aquatic life. Generally, pH for the surface-water gaging stations in the Irondale Gulch Basin has remained within the range specified by the State standard. Values of pH in the Irondale Gulch Basin generally have ranged from 7.0 to 8.5, which is typical for natural runoff for this area. Elevated pH above the State standard also could occur in samples collected during periods of active photosynthesis by algae and aquatic vegetation due to the removal of carbon dioxide from the water by these plants. There were seven sampling events at the Havana Interceptor below the 56th Avenue gaging station (fig. 12) with pH values greater than or equal to 9, and no sampling events where the pH was less than 6.50. At the Peoria Interceptor below 56th Avenue site (fig. 13), all pH values were between 6.50 and 8.99; there was one sampling event at the Uvalda Interceptor below 56th Avenue site that was outside the range specified by the standard (fig. 14).

Specific Conductance

Electrical conductance is a measure of the capacity of water (or other media) to conduct an electrical current. Electrical conductivity of water is a function of the types and quantities of dissolved substances in water, but there is no universal linear relation between total dissolved substances and electrical conductivity (Wilde and Radtke, 1999).

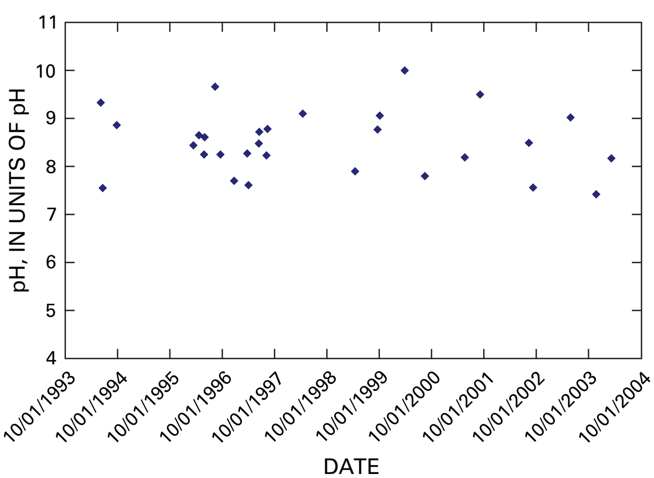


Figure 12. Values for pH at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

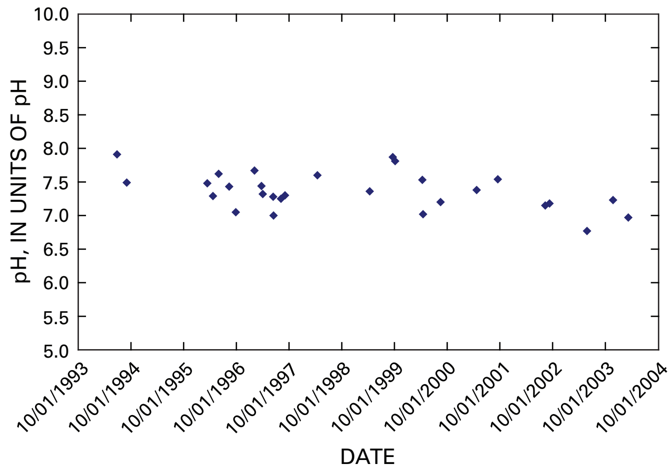


Figure 13. Values for pH at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

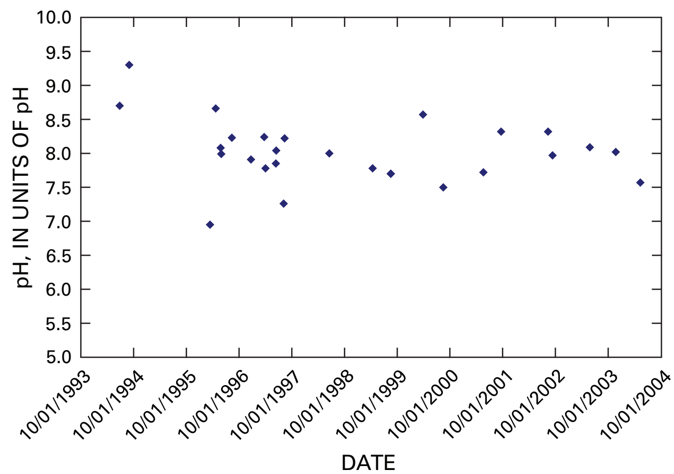


Figure 14. Values for pH at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

Michaud (1991) provides a detailed summary of the factors controlling electrical conductivity, which include the geology of the watershed, other sources of ions, and various types of wastewater runoff, nutrients, and pesticides. In this same 1991 publication, Michaud also provides a good summary of the particular risks to the aquatic health of an ecosystem posed by runoff from roads:

> Runoff from roads including road salt has a particularly episodic nature with pulsed inputs when it rains or during more prolonged snowmelt periods. It may “shock” organisms with intermittent extreme concentrations of contaminants which seem low when averaged over a week or month.

The USGS reports electrical conductivity in microsiemens per centimeter at 25 degrees Celsius (µS/cm) and refers to the physical property as "specific electrical conductance" or specific conductance. There are no applicable standards for specific conductance at the RMA. For the three urban interceptors entering the RMA at 56th Avenue, there is a strong negative exponential relation between discharge and specific conductance (figs. 15–17). At each site, the highest measurements of specific conductance occur at low flows, as high flows typically dilute the concentrations of dissolved solids.

Specific conductance ranged from 40 to 1,750 µS/cm at the three Irondale Gulch sites, not including snowmelt-runoff samples collected on November 24, 2003. The analysis of the specific-conductance data shows that all three urban interceptors (figs. 15–17) had a particularly high measure of specific conductance on November 24, 2003. The specific-conductance measurements on that date far exceed all previous specific-conductance measurements at all three sites, ranging from 3,520 µS/cm at the Peoria site to 6,330 µS/cm at the Uvalda site. These high measurements of specific

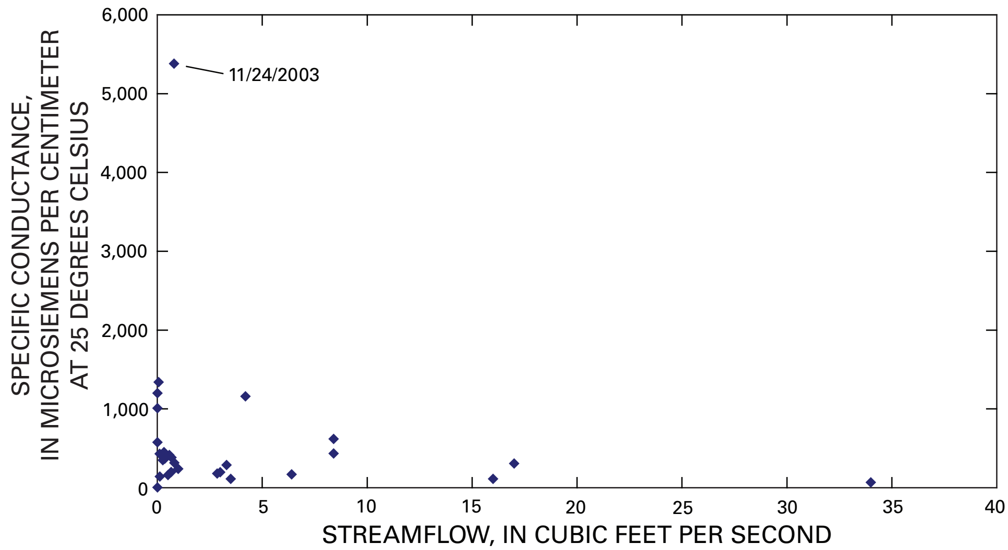


Figure 15. Variation of specific conductance with streamflow at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

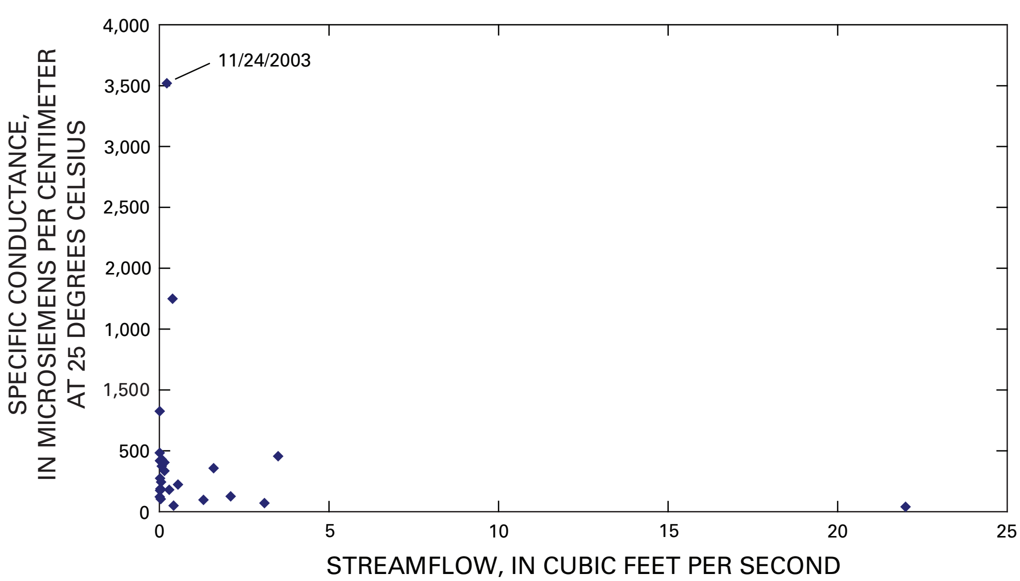


Figure 16. Variation of specific conductance with streamflow at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

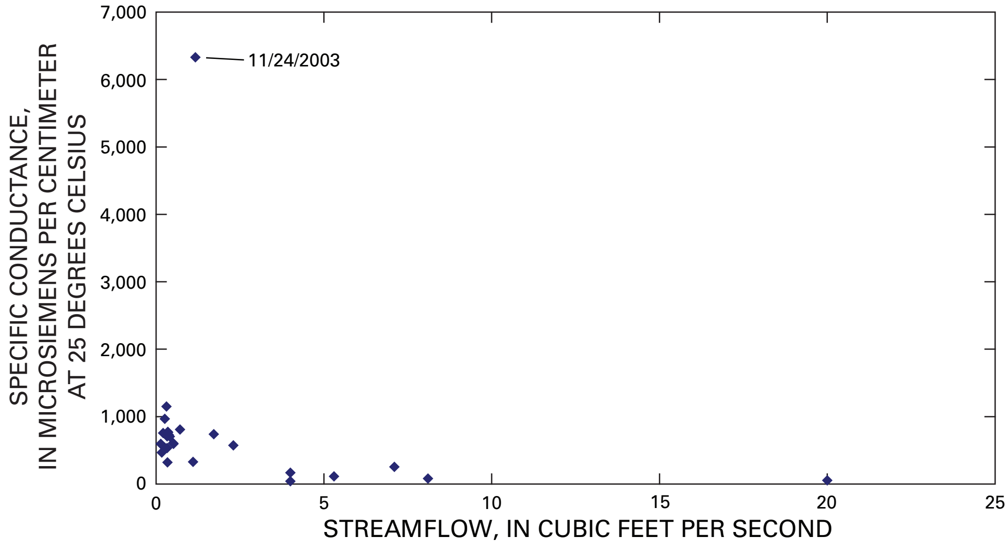


Figure 17. Variation of specific conductance with streamflow at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1994–2004.

conductance indicated a large concentration of dissolved solids in the stream on that particular day. Further examination of the chemical analysis data provides a potential explanation for the cause of these high values.

Chemical Analysis

The analyte suite for analysis of surface water at the RMA has changed over the years. The present (2005) analytical suite is outlined in the Surface Water Sampling and Analysis Plan (Foster Wheeler Environmental Corporation, written commun., 2001). Most of the organic constituents that were analyzed had concentrations that were less than the method reporting limits. The urban runoff flowing onto the RMA had low concentrations, if any detections, for most organic contaminants. Part of the reason for low detections of organic contaminants may be related to when the samples were collected. The existing surface-water sampling program was not designed specifically to target storm runoff and therefore does not characterize water quality for all hydrologic regimes, most notably storm runoff. As a result, the existing data may not adequately represent potential contaminant transport onto the RMA. In addition, the urban-runoff sites experience sharp rises in water stage; an evaluation of the hydrographs from these sites indicates it is not uncommon during intense storms for the stage to rise approximately 1 ft every 15 minutes. These types of transient runoff events make water-quality sampling difficult, and none of the sites have a safe place to sample the highest flows that occur in any given year. As a result, most of the surface-water-quality samples were collected after the flow had decreased substantially from the peak flow, which may have transported much of the chemical contaminant load through the stream. Thus, the quality of the streamflow during the initial stormwater-runoff period is not well characterized. In addition, brief periods of high concentrations of contaminants harmful to the health of the aquatic ecosystem could occur but go undetected with the existing twice-per-year sampling regime for surface-water quality. Given the increasing urban development and extension of existing concrete-lined runoff channels, which have little attenuation of stormwater and contaminants, ongoing and expanded monitoring would allow for timely responses to the degradation of water quality, help to better identify future sources of contaminants, and help mitigate any adverse effects that the changing hydrology may have on refuge wildlife and habitat. Appendixes 2, 3, and 4 list all of the analytical results for the Havana, Peoria, and Uvalda Interceptor sites in the Irondale Gulch Basin, respectively (values preceded by "LT" in Appendixes 2–4 were less than the analytical method reporting limit). Appendix 5 contains a list of codes used to identify each analytical laboratory used to analyze water-quality samples and the full laboratory name corresponding to each laboratory code. Appendix 6 contains a list of all analytical flag codes and their descriptions. Appendix 7 contains a list of all data qualifier codes and their descriptions. For most of the chemical analyses, only major ions were detected. The detections of elevated concentrations of certain major ions are useful in determining sources of certain contaminants entering the RMA such as deicer fluids applied to road surfaces upstream from the gages.

Stiff diagrams show major-ion composition in milliequivalents per liter in a manner that facilitates rapid comparison of different sampling events because of distinctive graphical shapes (Freeze and Cherry, 1979). Stiff diagrams for select sampling events for the three Irondale Gulch sites (Havana Interceptor below 56th Avenue, Peoria Interceptor below 56th Avenue, and Uvalda Interceptor below 56th Avenue) are depicted in figures 18–20. Stiff diagrams were constructed for sampling events when the cation/anion balance was within 5 percent. The fact that snowmelt-runoff samples collected on

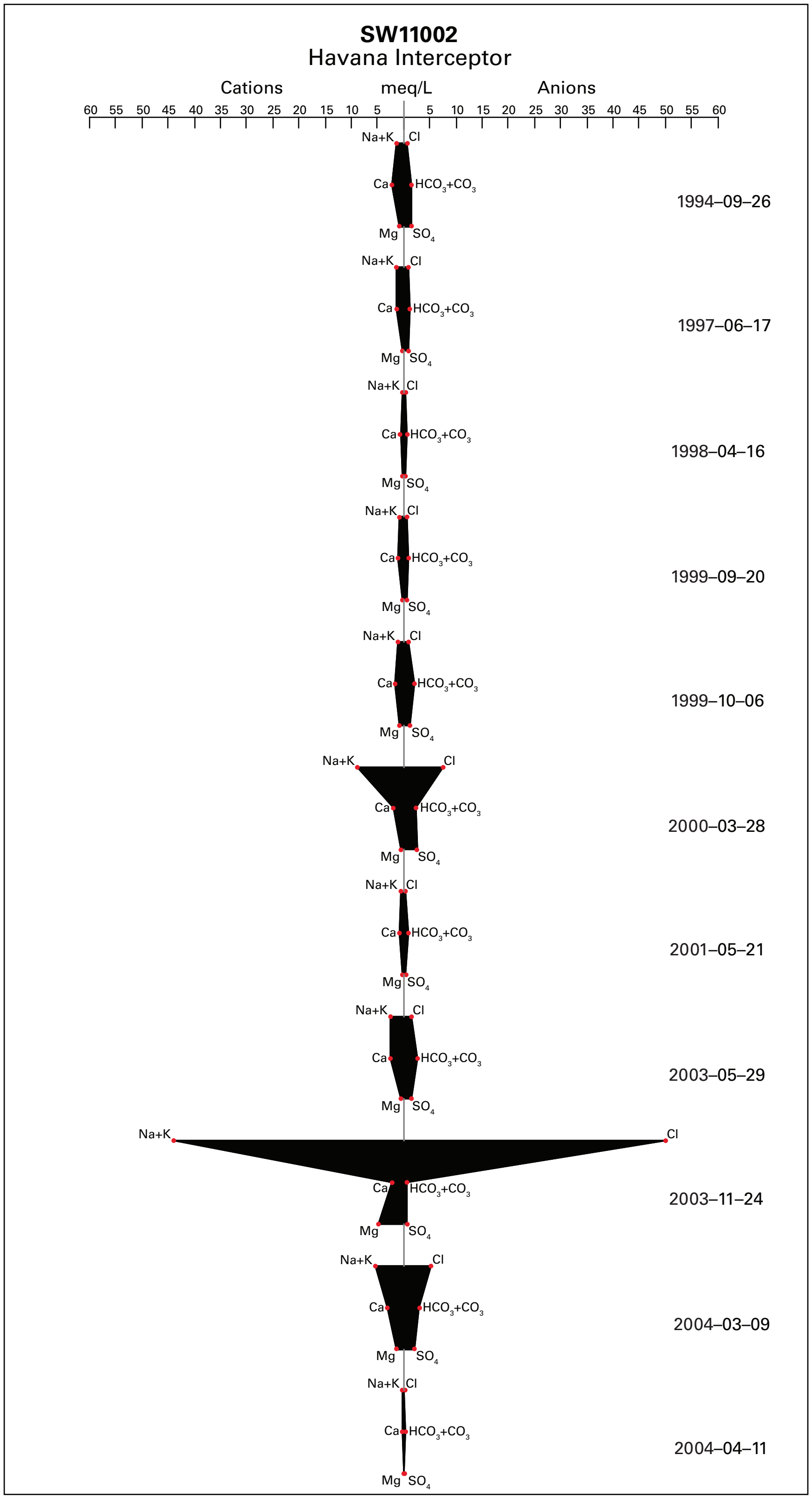


Figure 18. Concentrations of selected cations and anions in milliequivalents per liter for various sampling events at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, 1994–2004.

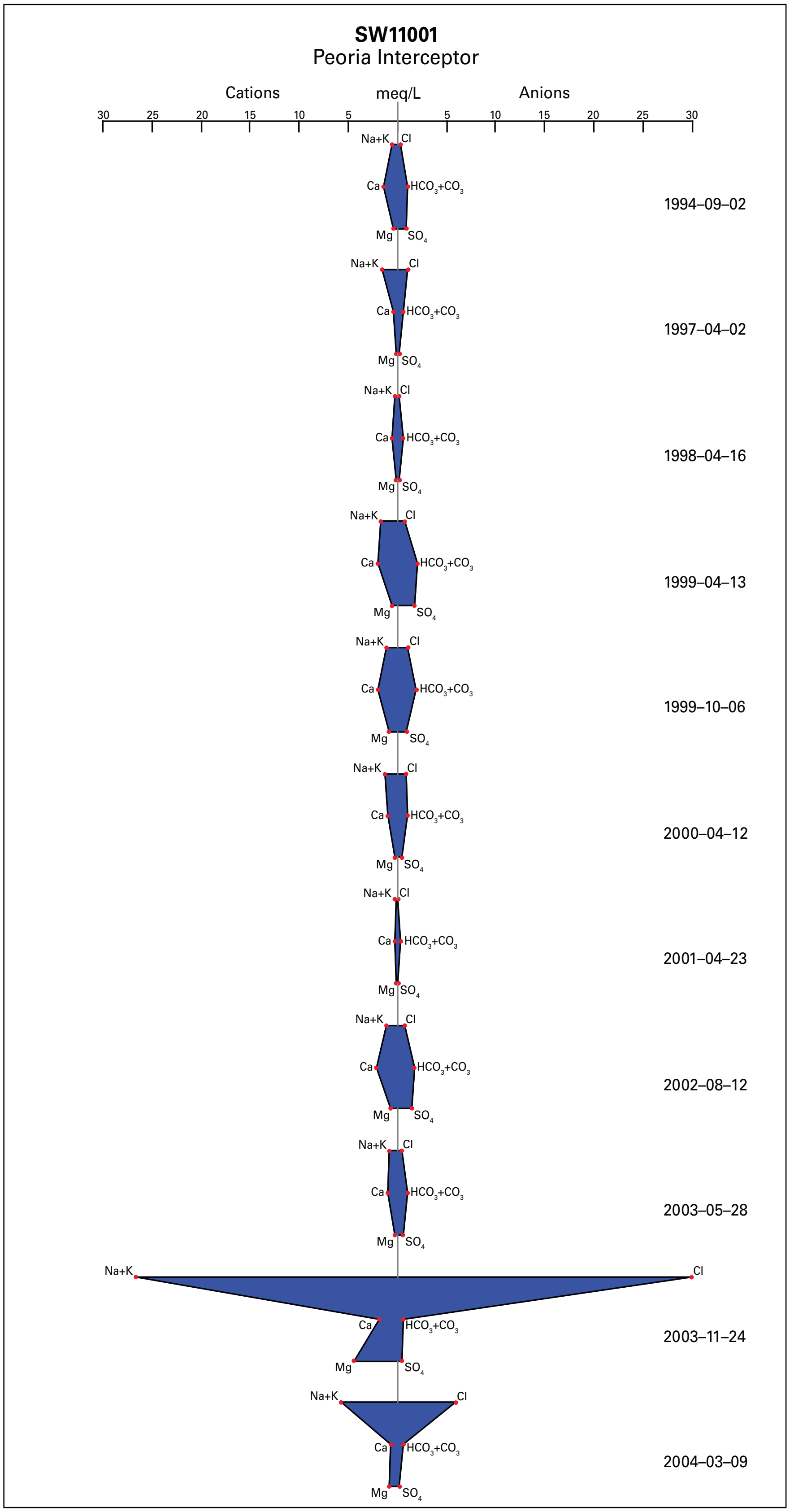


Figure 19. Concentrations of selected cations and anions in milliequivalents per liter for various sampling events at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, 1994–2004.

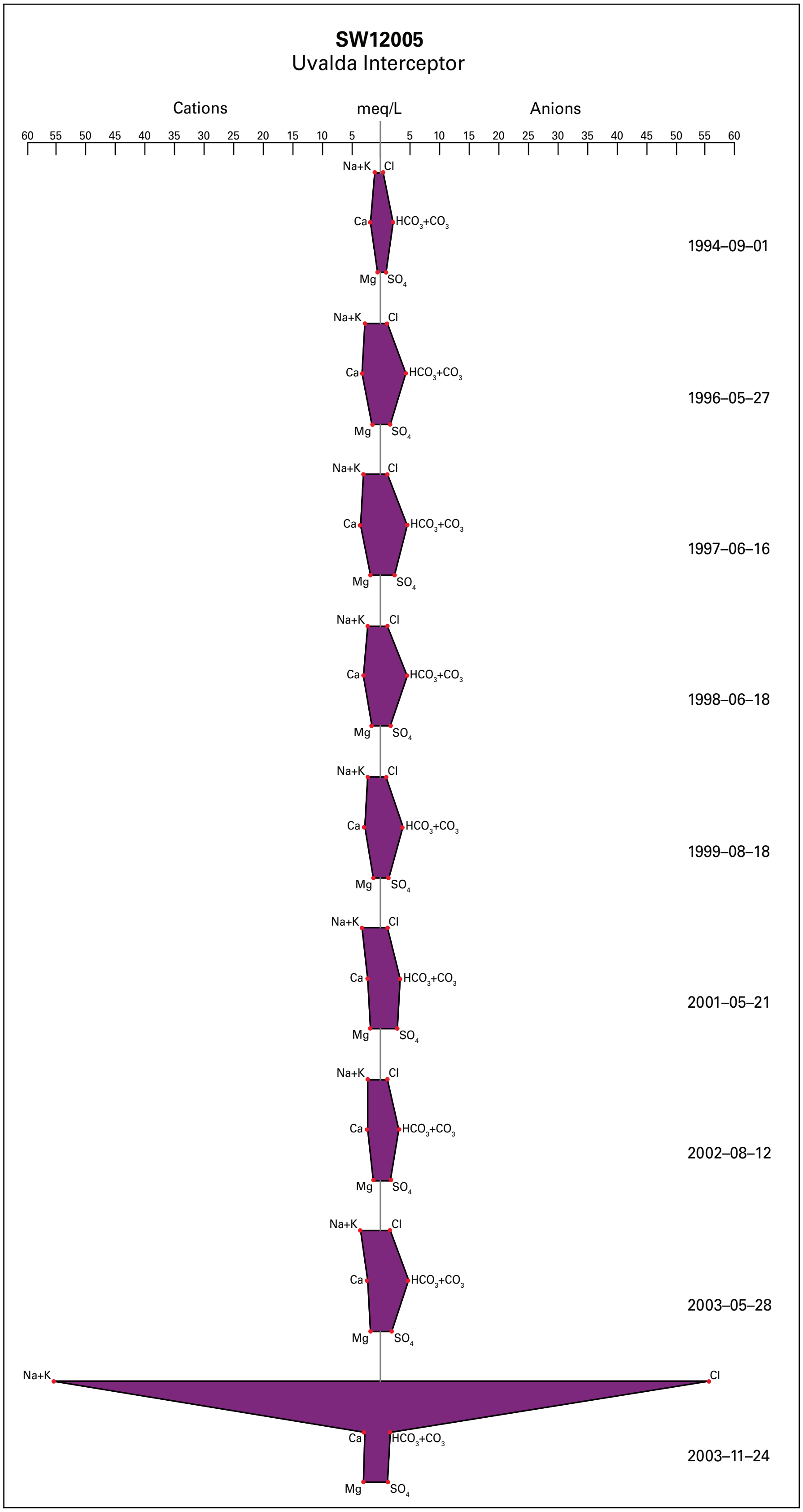


Figure 20. Concentrations of selected cations and anions in milliequivalents per liter for various sampling events at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, 1994–2003.

March 28, 2000, November 24, 2003, and March 9, 2004, at the Havana Interceptor below 56th Avenue gaging station had higher concentrations of sodium, chloride, and magnesium than nonsnowmelt-runoff samples is readily apparent from the Stiff diagrams for this site (fig. 18). Major-ion concentrations at the Peoria and Uvalda Interceptors following snowmelt-runoff samples also were elevated, resulting in larger Stiff diagrams for snowmelt runoff compared to the Stiff diagrams for nonsnowmelt-runoff sampling events (figs. 19 and 20). Differences in major-ion composition from base flow or stormwater runoff were not readily apparent at the Irondale Gulch sites. Further analysis of the data is needed to investigate the possibility that subtle differences in major-ion composition from stormwater runoff and base flow may exist in the historical data from these sites.

Summary statistics for major-ion data for the Irondale Gulch sites are provided in tables 1–3. The total number of samples collected for each constituent between 1988 and 2004 varied extensively, depending upon sampling plans and requirements, and ranged from as few as 6 samples to as many as 76. The concentrations obtained for chloride, magnesium, and sodium generally were below 200 mg/L at all three Irondale Gulch monitoring stations for the entire period of record (figs. 21–23), but there were a few sampling events at each of these sites where much higher concentrations for these analytes were measured. For example, the water-quality sample collected on November 24, 2003, at all three urban stormwater interceptors had unusually high concentrations of chloride and sodium. An analysis of the major-ion data shows that the concentrations of chloride and sodium also were unusually high as compared to historical samples collected at each of the three urban interceptors. Further analysis reveals that the ratios of chloride ions to sodium and magnesium are similar to those of sodium chloride and magnesium chloride. Both of these chemicals are used as road deicers throughout the urban area south of the RMA. In addition, an

Table 1. Selected statistics for water-quality samples collected at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

[All units in milligrams per liter except pH, in units of pH, and specific conductance, in microsiemens per centimeter at 25 degrees Celsius; N, number of samples; Interquartile range, the range of the central 50 percent of the data]

Analyte	N	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Interquartile range
Calcium	72	3.54	6.38	12.3	21.8	38.3	45.0	80.9	26.1
Magnesium	68	0.413	1.12	2.29	4.20	6.86	10.4	60.2	4.57
Sodium	72	2.75	4.84	8.74	21.5	38.6	118	986	29.8
Potassium	69	0.620	1.55	2.55	3.66	4.99	13.3	36.6	2.44
Ammonium	8	0.015	0.029	0.038	0.353	0.993	1.45	2.43	0.954
Chloride	55	2.30	4.94	8.79	26.0	50.7	192	1,770	41.9
Nitrate + nitrite	32	0.005	0.026	0.063	0.255	0.925	1.37	2.30	0.862
Sulfate	50	3.10	6.51	14.5	32.0	65.3	92.4	120	50.8
pH	30	7.42	7.56	7.97	8.46	8.84	9.35	10.00	0.873
Specific conductance	30	53.0	112	185	359	448	1,160	5,380	263

Table 2. Selected statistics for water-quality samples collected at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

[All units in milligrams per liter except pH, in units of pH, and specific conductance, in microsiemens per centimeter at 25 degrees Celsius; N, number of samples; Interquartile range, the range of the central 50 percent of the data]

Analyte	N	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Interquartile range
Calcium	75	2.73	5.44	9.02	18.3	33.6	40.5	66.9	24.5
Magnesium	75	0.278	0.647	1.56	3.31	8.01	9.87	53.8	6.45
Sodium	75	1.30	2.46	8.83	16.8	27.0	101	591	18.1
Potassium	76	0.620	1.50	2.93	3.76	4.72	6.23	35.3	1.80
Ammonium	11	0.103	0.118	0.196	0.690	1.51	1.66	2.18	1.31
Chloride	58	0.500	2.45	5.64	17.5	34.5	210	1,060	28.9
Nitrate + nitrite	34	0.010	0.113	0.202	0.380	0.993	1.70	2.44	0.79
Sulfate	54	1.58	4.66	9.49	21.0	36.8	59.8	85.0	27.3
pH	29	6.77	7.02	7.18	7.32	7.53	7.70	7.91	0.350
Specific conductance	27	40.0	62.6	124	274	419	620	3,520	295

Table 3. Selected statistics for water-quality samples collected at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

[All units in milligrams per liter except pH, in units of pH, and specific conductance, in microsiemens per centimeter at 25 degrees Celsius; N, number of samples; Interquartile range, the range of the central 50 percent of the data]

Analyte	N	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Interquartile range
Calcium	70	3.14	14.2	32.3	54.1	67.2	80.2	140	34.9
Magnesium	68	0.394	3.38	7.86	17.8	22.0	30.0	40.0	14.1
Sodium	70	2.76	15.1	35.8	57.8	76.4	102	1,250	40.6
Potassium	67	0.850	2.35	2.95	4.01	5.08	6.09	43.9	2.13
Ammonium	6	0.015	0.039	0.069	0.107	0.713	1.66	2.41	0.644
Chloride	52	1.62	8.85	27.0	37.0	43.0	84.0	1,970	16.0
Nitrate + nitrite	28	0.095	0.176	0.587	1.35	3.68	5.00	12.0	3.09
Sulfate	47	1.25	13.8	35.6	79.0	100	118	270	64.4
pH	27	6.95	7.54	7.75	8.00	8.24	8.61	9.30	0.485
Specific conductance	27	42.0	101	326	597	748	872	6,330	423

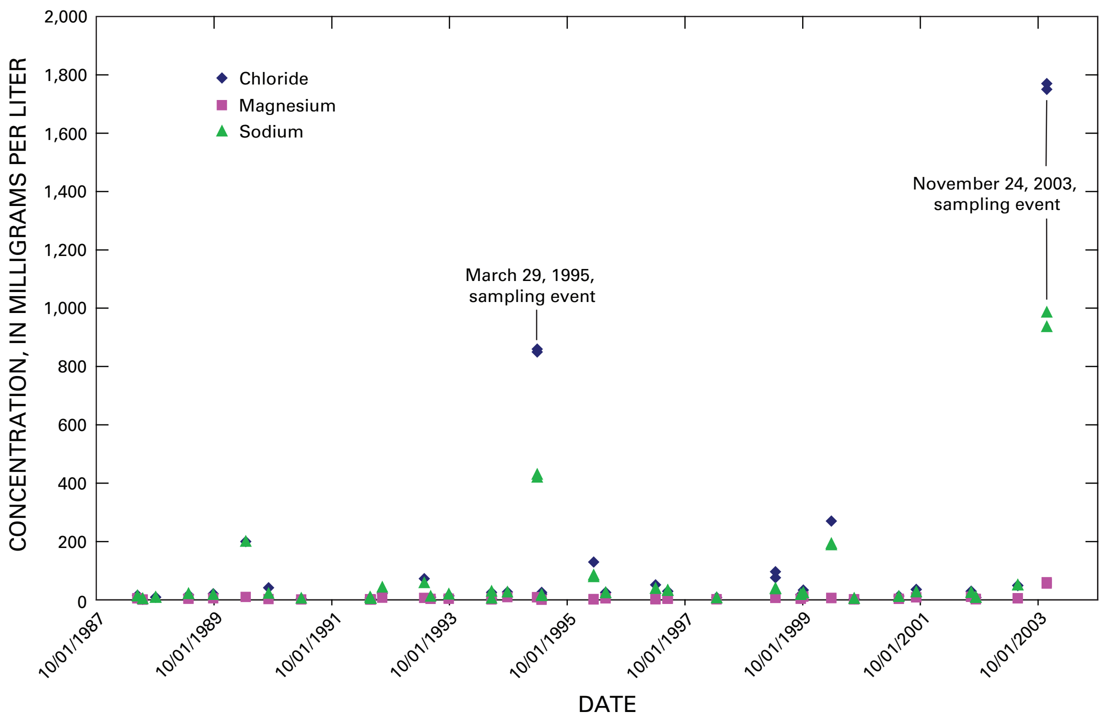


Figure 21. Chloride, magnesium, and sodium concentrations at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

examination of climatological data reported by the National Weather Service at the Denver International Airport (National Weather Service, *http://www.crh.noaa.gov/den/cli/climo.php*, accessed October 25, 2004) indicated that only 0.03 inch of precipitation occurred on November 22, 2003, and the high temperatures for November 23 and 24, 2003, did not exceed 29°F. Given the cold temperatures during this period, it seems plausible that large amounts of road deicers were applied to the streets in the Irondale Gulch Basin upstream from the RMA relative to the small amount of precipitation that occurred, resulting in little dilution of salts in runoff. This may explain the large concentrations of these ions in the runoff that was sampled on November 24, 2003, and the relatively high specific-conductance values recorded on this date. An examination of the historical water-quality record shows that large concentrations of sodium and chloride also were detected in samples collected on March 29, 1995, at the Havana and Peoria Interceptors and on March 30, 1995, at the Uvalda

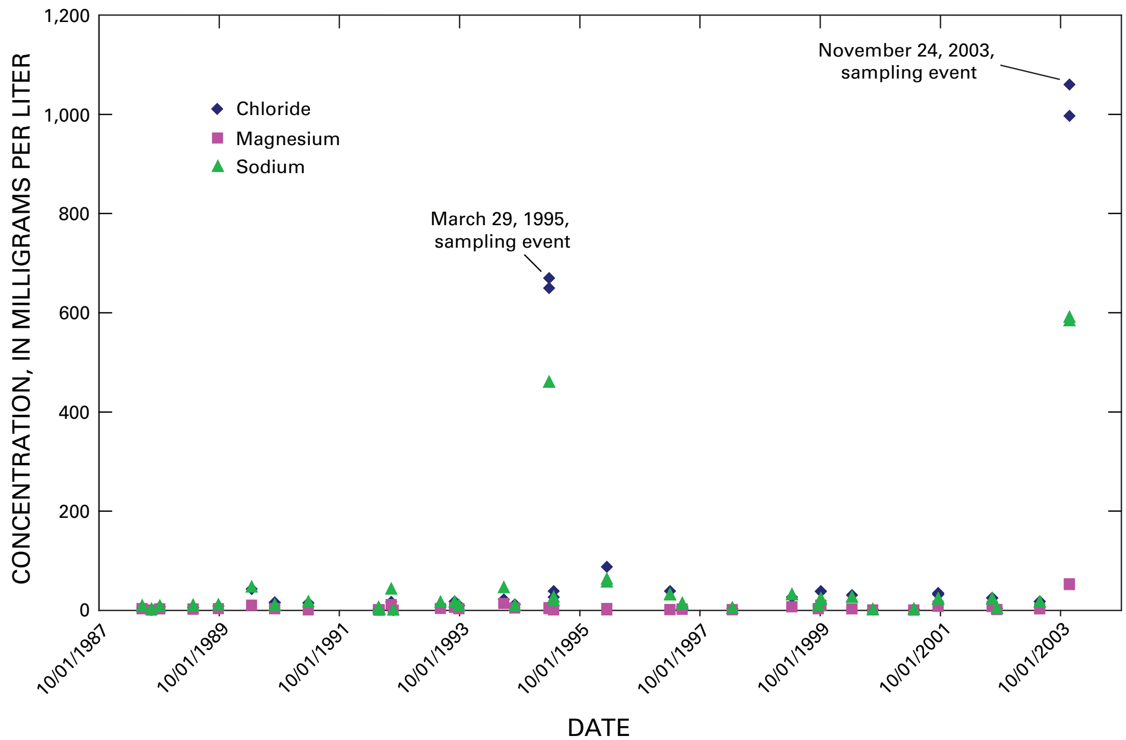


Figure 22. Chloride, magnesium, and sodium concentrations at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

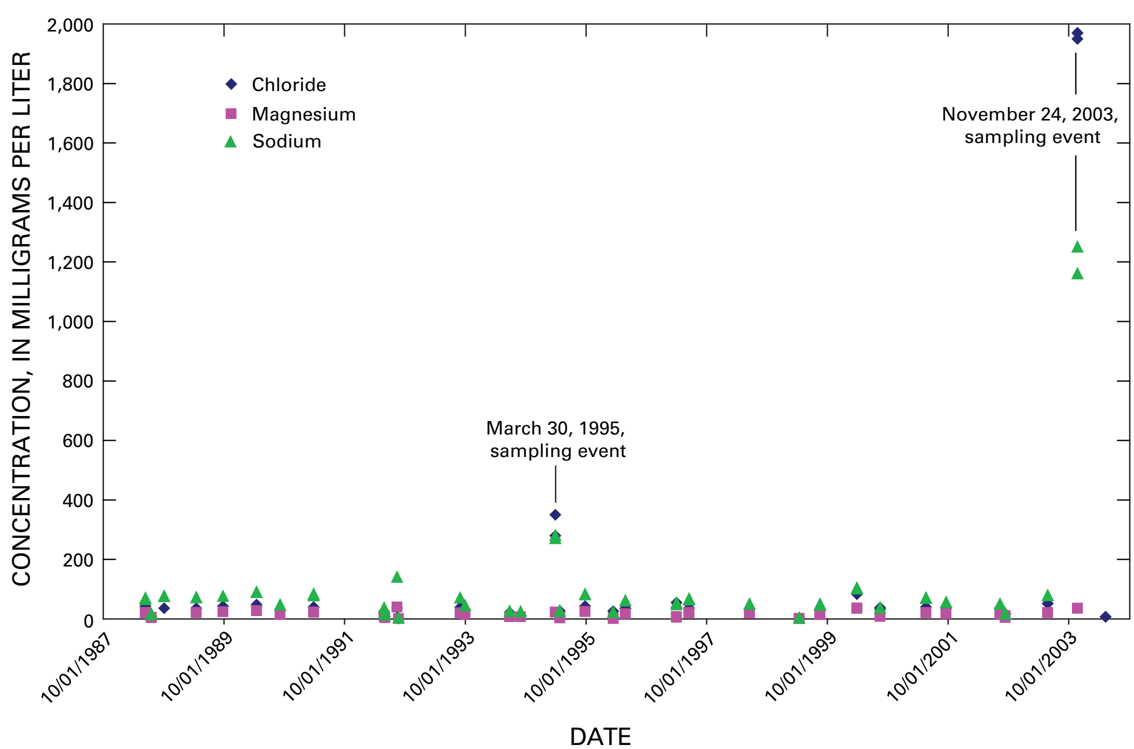


Figure 23. Chloride, magnesium, and sodium concentrations at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

Interceptor. On March 29, 1995, 0.12 inch of precipitation was recorded and temperatures were below freezing during the entire day, making it likely that relatively large amounts of road deicers were applied with little precipitation to dilute runoff concentrations of the salts that compose the deicers. No precipitation was recorded on March 30, 1995, and the official high temperature was 40°F.

Sulfate concentrations measured at the Irondale Gulch sites were generally well below 250 mg/L. Although there is no applicable State sulfate standard for the protection of aquatic life for this portion of Irondale Gulch, a State standard of 250 mg/L would apply if any of the Irondale Gulch streams were designated as domestic water supplies. The State does not have any kind of sulfate standard in place at any of the Irondale Gulch sites (Havana, Peoria, and Uvalda Interceptors). Sulfate concentrations at the Irondale Gulch sites are shown in figures 24–26.

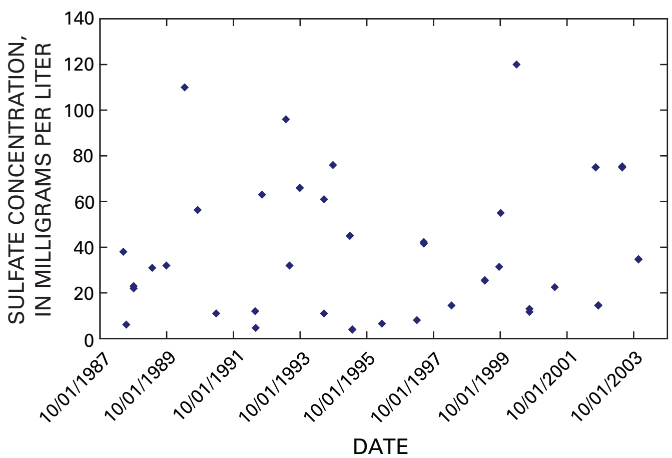


Figure 24. Sulfate concentration at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

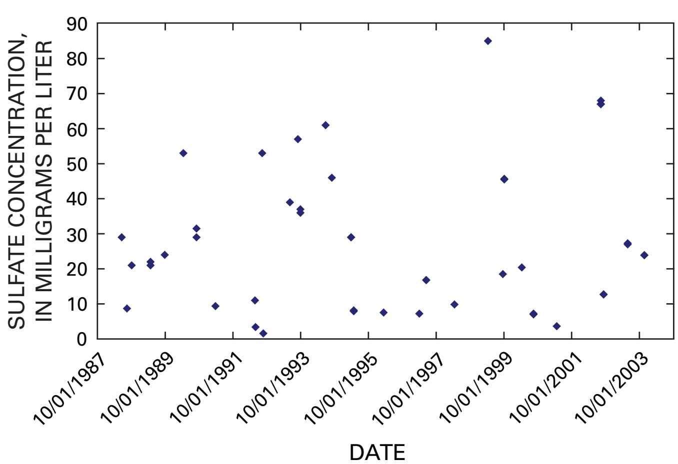


Figure 25. Sulfate concentration at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

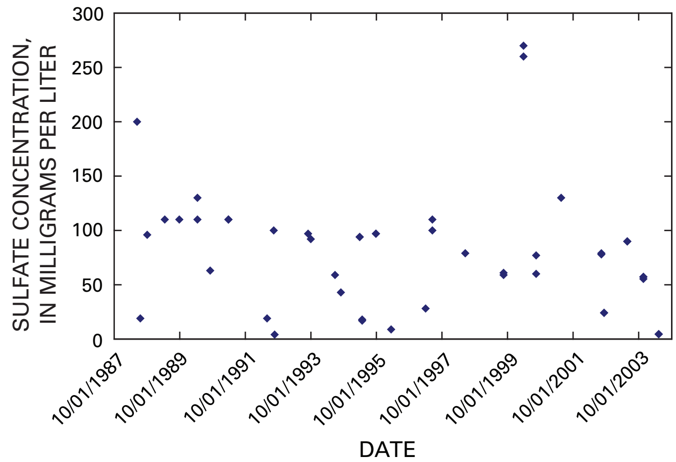


Figure 26. Sulfate concentration at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado, water years 1988–2004.

Analysis of First Creek Water-Quality Data

The water quality of First Creek is different from that of the Irondale Gulch. As mentioned previously, First Creek is being maintained more as a natural stream as the area becomes urbanized, compared to the Irondale Gulch Basin, which was developed when it was common to extensively modify stream channels by straightening and lining them with concrete or putting them below ground in culverts. First Creek Basin has an approximately 36-mi^2 contributing drainage area upstream from the RMA. The amount of urban land use in First Creek Basin has substantially increased since 1999, and several flood-detention ponds have been built upstream from the RMA. Between the urbanized area of First Creek Basin and the RMA, the stream still has several miles of natural channel, which supports a dense growth of cattails and riparian cottonwood trees. This vegetation helps to suppress flow velocities, which reduces the amount of suspended solids carried in the stream. In addition, the sandy soils of First Creek Basin limit large volumes of runoff to periods of high-intensity thunderstorms or several days of moderate precipitation. As a result, the water quality of runoff remains generally good, and most of the results of the chemical analyses (other than those for major ions) typically have yielded concentrations less than the method reporting limit.

Water-Quality Field Measurements

Water-quality field measurements at the First Creek below Buckley Road site (fig. 1) included dissolved oxygen, pH, specific conductance, and temperature. Water temperature is not discussed as a separate entity because at this site, water temperature commonly is a function of air temperature.

Dissolved Oxygen

At the First Creek below Buckley Road site, dissolved-oxygen concentrations have ranged from 4.2 to 12.6 mg/L with the exception of one suspect concentration of 1.6 mg/L (fig. 27). For the entire sampling period, only three dissolved-oxygen concentrations (excluding the previously mentioned 1.6-mg/L concentration) did not meet the State standard of 5.0 mg/L for the protection of aquatic life at the First Creek below Buckley Road site. As urban development proceeds in the First Creek Basin, the amount of disturbed land and bare soil areas in the basin likely will increase for several years to come. Bare soil areas are subject to erosion despite best-management practices designed to limit sediment transport. If soils are washed into receiving waters due to development activities, natural aquatic bacteria could decompose the organic matter in the soil, depleting dissolved-oxygen concentrations (Michaud, 1991). Increasing amounts of nutrients from lawn fertilizers and other sources also could wash into the First Creek Basin while urban development proceeds, resulting in more dissolved-oxygen concentrations below the State standard. The dissolved-oxygen measurements above 10 mg/L were measured during March and April, when water temperatures typically are low and First Creek predominantly experiences low-flow conditions. During the early spring, oxygen-consuming organic-matter decay is minimal, while aquatic plant respiration is increasing as spring begins and the hours of sunlight increase each day.

pH

At the First Creek below Buckley Road site, measurements of pH ranged from 7.31 to 8.35, within the range of 6.50 to 8.99 specified by the State standard for the protection of aquatic life, and there was no seasonality to the measurements (fig. 28). The values of pH for First Creek were generally similar to values from nearby urban-runoff sites in the Irondale Gulch Basin, with the exception that none of the values at the First Creek below Buckley Road site exceeded the State standard of 9, which happened occasionally at the Irondale Gulch sites.

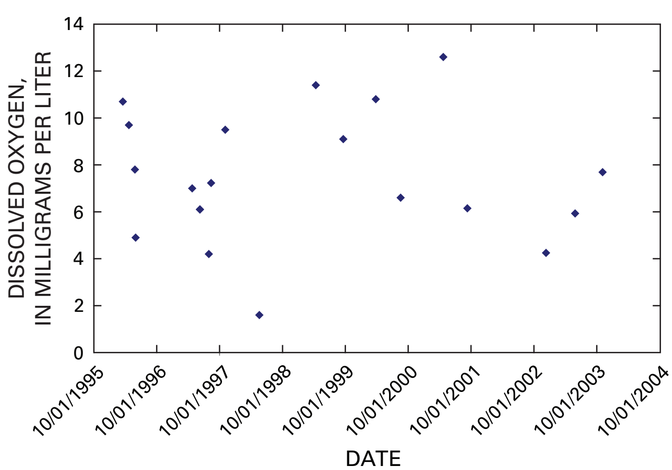


Figure 27. Dissolved-oxygen concentration at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1996–2004.

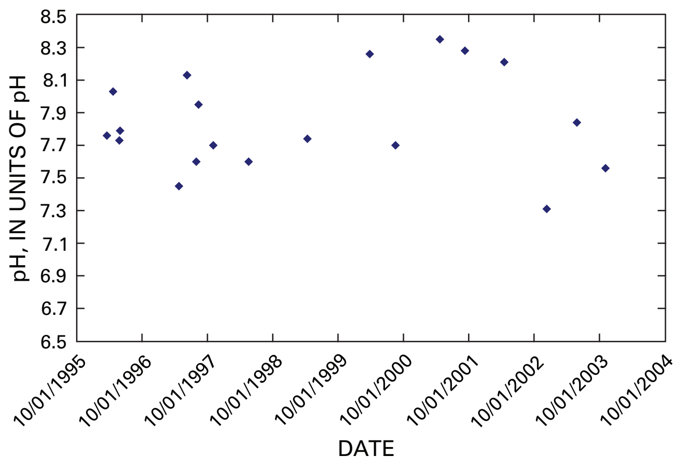


Figure 28. Values for pH at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1996–2004.

Specific Conductance

The range in specific conductance measured at First Creek below Buckley Road seems reasonable for natural streams in eastern Colorado. Specific conductance ranged from 257 to 1,380 μS/cm (fig. 29). No applicable State standard exists for specific conductance. In general, specific conductance typically is higher during the winter and spring base flow than during summer runoff—an expected pattern, given that dissolved solids are usually more concentrated in ground water than in surface runoff. Unlike the urban stormwater interceptors of the Irondale Gulch Basin, none of the samples collected at First Creek below Buckley Road had large specific-conductance values.

Chemical Analysis

The same analytical suite was used for all First Creek below Buckley Road samples as was used at all of the Irondale Gulch Basin sites (Appendix 1). In general, only major ions were measured in concentrations above the analytical method reporting limits. Similar to the results from the Irondale Gulch sites, most of the organic constituents that were analyzed at the First Creek below Buckley Road site had concentrations that were less than the detection limits. Unlike the Irondale Gulch gaging stations that receive runoff from a heavily urbanized basin, the First Creek below Buckley Road gaging station receives runoff from a basin that still has a large percentage of undeveloped land. With only a small fraction of the road surface in the Irondale Gulch Basin, it is not surprising that the runoff from the First Creek Basin does not have a noticeable snowmelt-runoff signature, and that the Stiff diagrams

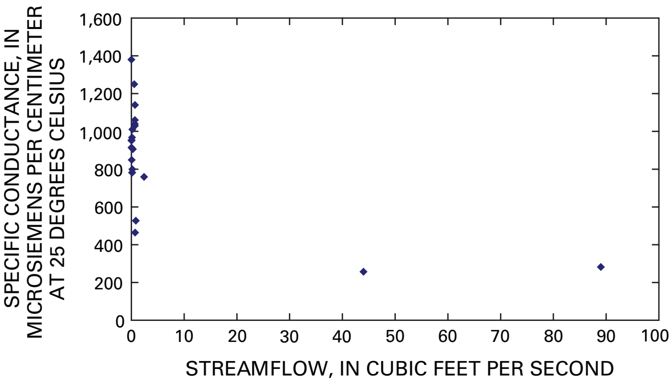


Figure 29. Variation of specific conductance with streamflow at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1996–2004.

for all types of sampling events generally are quite similar. Appendix 8 contains all of the analytical results obtained at the First Creek below Buckley Road site. Stiff diagrams were constructed for sampling events if the cation/anion balance was within 5 percent (fig. 30).

Summary statistics for major-ion data for the First Creek below Buckley Road site are provided in table 4. The total number of samples from the First Creek below Buckley Road site collected for each constituent between water years 1989 and 2004 varied extensively, depending upon sampling plans and requirements, and ranged from 8 to 59. The median concentrations for calcium, magnesium, and sodium generally are higher at the First Creek below Buckley Road site (table 4) than in the three Irondale Gulch Basin sites (tables 1–3), whereas the 90th percentile and maximum concentrations for magnesium and sodium generally are higher at the three Irondale Gulch Basin sites than at the First Creek below Buckley Road site.

Some general trends in water quality were observed at the First Creek below Buckley Road site. The first trend observed is that concentrations of magnesium, sodium, and chloride apparently are increasing over time (fig. 31). Discharge could be an important factor in the concentrations of these analytes, and further evaluation in the form of a flow-adjusted trend analysis would help corroborate this finding. Concentrations of the three analytes (chloride, sodium, and magnesium) seem to be strongly correlated, and this correlation could be related to discharge as well. Increases in concentration are consistent with the increasing urbanization of the basin, which tends to result in more water being applied to the soils. Increased irrigation can help mobilize naturally occurring chloride, sodium, and magnesium. As in the Irondale Gulch Basin, increased urban development also typically results in an increased use of road deicers, primarily sodium chloride and magnesium chloride. These deicers are easily dissolved into the urban runoff, which then flows onto the RMA. A second trend at this site is observed in the sulfate concentrations, and this trend probably is related to increased urban land use in First Creek Basin. Sulfate concentrations in First Creek appear to be increasing over time. A more detailed evaluation using flow-adjusted concentrations would help describe this trend but is beyond the scope of this report. Nonetheless, this apparent upward trend in sulfate concentration is corroborated by the fact that four samples with the highest sulfate concentrations (above 200 mg/L) all have occurred since 2000 (fig. 32).

Sulfate naturally occurs in the soils of the semiarid and arid areas of the United States; the salt compounds of magnesium sulfate (epsom salt), sodium sulfate (glauber salt), and calcium sulfate (gypsum) are found in the saline soils throughout Colorado. Irrigation water commonly contains salts picked up as water moves across the landscape (Colorado State University, 2004). Although First Creek Basin has no irrigated agriculture, it does have substantial areas that are undergoing urban development. With urbanization comes the increased use of water for golf courses, lawns, and other landscaping. For example, an 18-hole golf course is bisected by First Creek. Incorporated into the design of the golf course are several flood-detention and flood-retention ponds. Also, the sandy soils in First Creek Basin allow for a relatively rapid infiltration of irrigation water from lawns and golf courses, which likely helps to mobilize sulfate and other cations and anions present in the salt compounds that have accumulated in the soils over time.

Streamflow Trends in First Creek

Given the intermittent nature of streamflow in First Creek (fig. 7), the sandy soils of the basin upstream from the RMA, and the increasing urbanization of the basin, it is expected that there will be discernible changes to the basin hydrology within a few years. It is probable that the surface-water quantity will increase and the water quality will change as the basin upstream from the RMA becomes increasingly urbanized. First Creek Basin has a comprehensive flood-control design to ensure that the postdevelopment floods on First Creek are comparable in size to predevelopment floods. The flood control is accomplished by developing flood-detention and flood-retention ponds throughout First Creek Basin. Although these flood-control structures keep the magnitude of the postdevelopment floods about the same as predevelopment, the duration of elevated flow likely will increase, resulting in larger flood volumes. However, few large flows have occurred since urban development has increased in First Creek Basin, and little data can be presented to prove this point given the drought of the past 4 years. In addition to the change in the nature of floods due to urban development, the increase in lawn irrigation likely has increased the base flow in First Creek. Some changes in base flow are being observed. Typically, at the First Creek near Buckley Road gaging station, base flow occurs during the fall or early winter and continues through the spring or early summer, when riparian plants begin to transpire, thus reducing streamflow to zero. One way to quantify the base-flow period is to count the number of consecutive days of flow during this base-flow period and compare this number to the amount of precipitation. Precipitation data collected at the nearby weather station maintained at the site of the former Denver Stapleton Airport were used for this analysis.

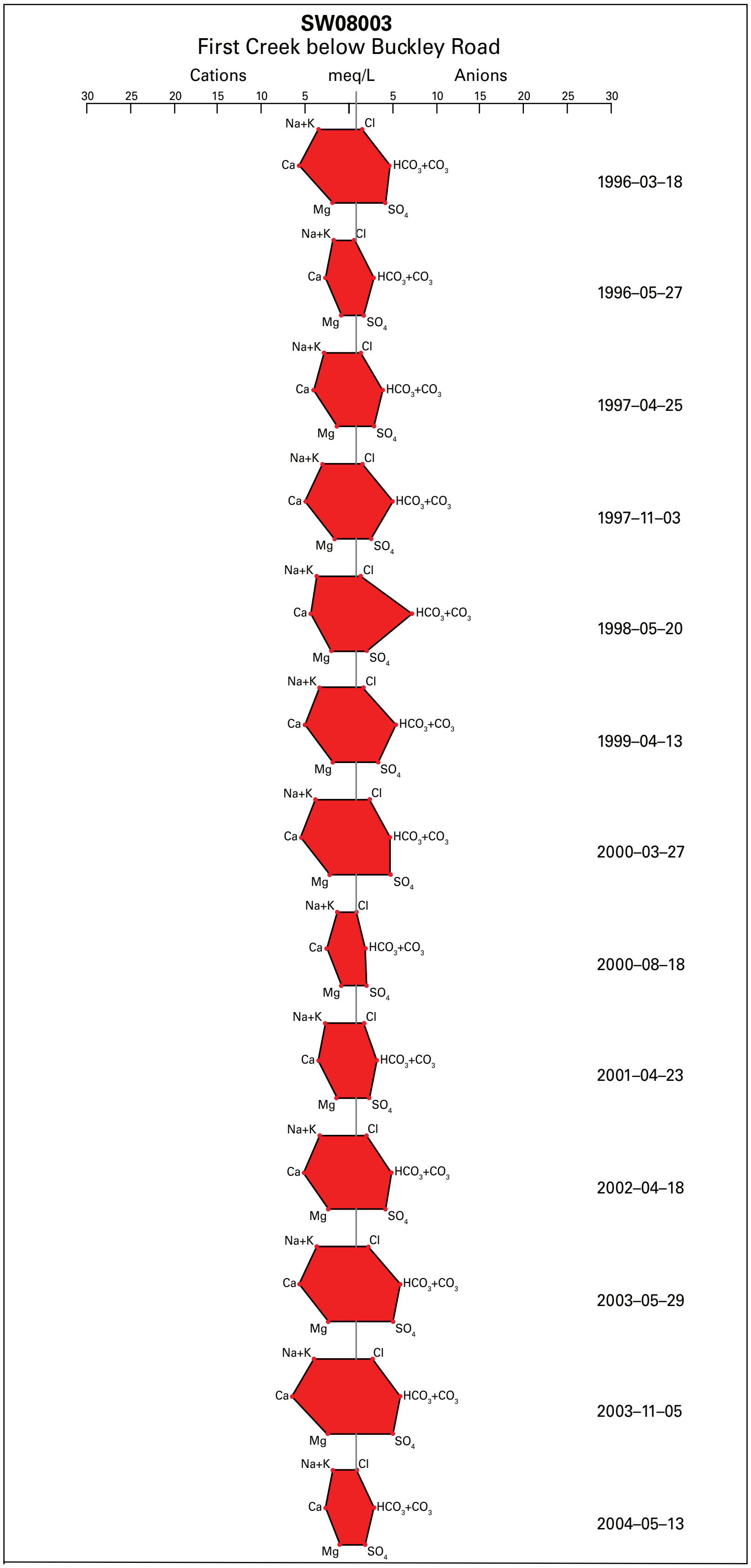


Figure 30. Concentrations of selected cations and anions in milliequivalents per liter for various sampling events at the First Creek below Buckley Road gaging station, Commerce City, Colorado, 1996–2004.

Table 4. Selected statistics for water-quality samples collected at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1989–2004.

[All units in milligrams per liter except pH, in units of pH, and specific conductance, in microsiemens per centimeter at 25 degrees Celsius; N, number of samples; Interquartile range, the range of the central 50 percent of the data]

Analyte	N	Minimum	10th percentile	25th percentile	Median	75th percentile	90th percentile	Maximum	Interquartile range
Calcium	59	30.2	48.5	68.4	85.4	111	120	141	42.2
Magnesium	57	6.21	10.7	16.0	20.2	25.7	28.7	33.1	9.70
Sodium	59	13.1	28.8	45.9	63.4	77.9	83.5	86.8	32.0
Potassium	55	2.70	3.79	4.60	5.91	9.32	12.0	18.2	4.73
Ammonium	8	0.015	0.015	0.015	0.015	0.038	0.041	0.042	0.023
Chloride	47	7.48	22.0	32.5	50.0	68.0	84.8	96.6	35.5
Nitrate + nitrite	22	0.010	0.014	0.102	0.210	0.362	0.483	1.34	0.260
Sulfate	43	31.0	67.8	94.4	140	200	239	280	106
pH	22	7.31	7.56	7.70	7.82	8.13	8.28	8.53	0.430
Specific conductance	22	257	470	765	910	1,020	1,130	1,380	255

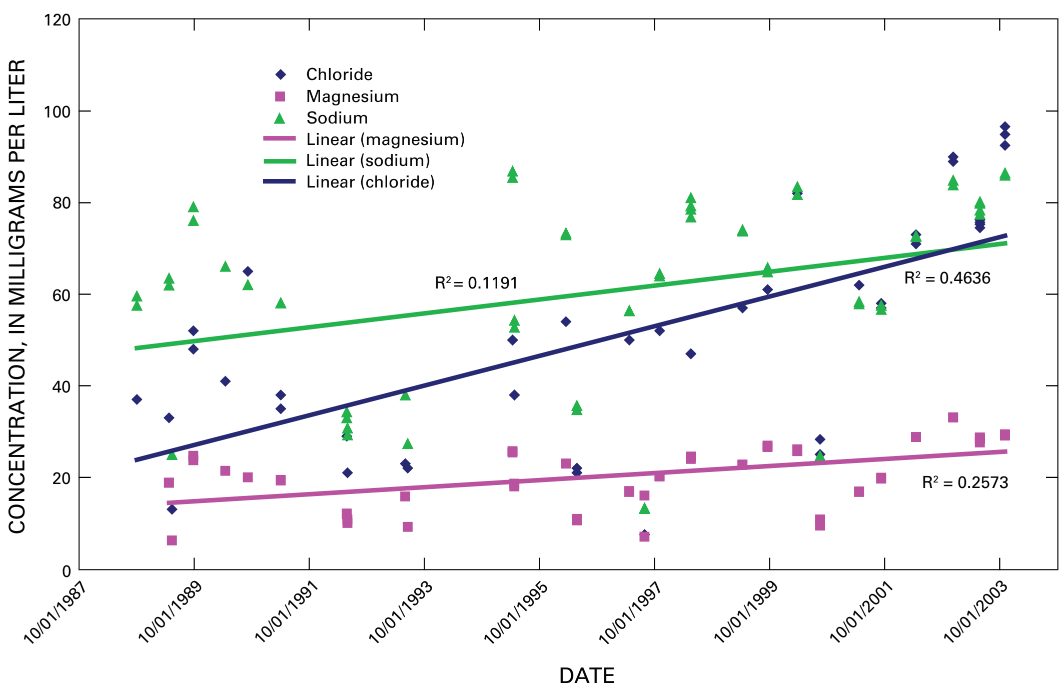


Figure 31. Chloride, magnesium, and sodium concentration at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1988–2004. The solid lines represent linear regression (least-squares) fit lines for each analyte.

Stapleton weather station data from 1998 through 2004 were obtained from the National Weather Service Cooperative Observer's Monthly Precipitation for Northeast Colorado (*http://www.crh.noaa.gov/den/coop/cooppcpn.html*, accessed February 3, 2005). Precipitation data from the Stapleton weather station for all years before 1998 were obtained from annual climatological data summaries published by the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration, 1993–97). The comparison of base flow to precipitation shows an apparent inverse relation between precipitation and days of base flow for First Creek (fig. 33). One plausible explanation is that as precipitation decreases, the amount of lawn irrigation increases. This lawn irrigation on the sandy soils in First Creek Basin likely recharges the ground water, which ultimately feeds the base flow of First Creek. This explanation is supported by the observed increase in sulfate in the streamflow of First Creek. This apparent trend of increased sulfate concentration and longer periods of continuous base flow is expected to continue for many years as more of First Creek Basin is converted from nonirrigated vegetation to irrigated lawns and landscapes.

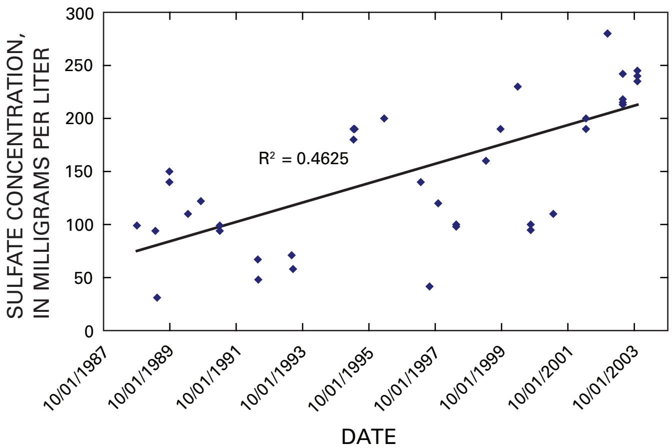


Figure 32. Sulfate concentration at the First Creek below Buckley Road gaging station, Commerce City, Colorado, water years 1988–2004. The solid line represents a linear regression (least-squares) fit to the data.

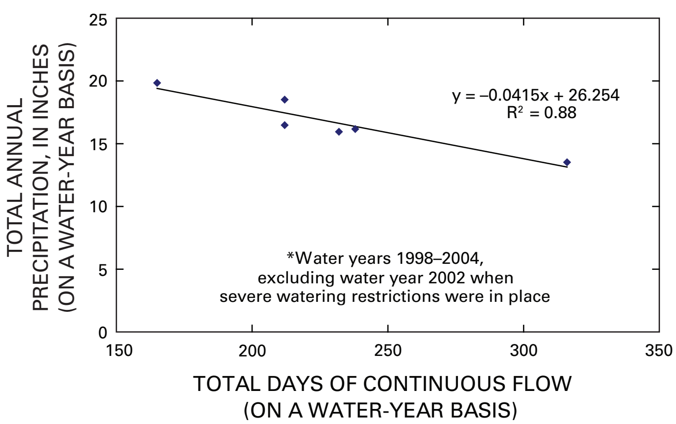


Figure 33. Days of continuous streamflow at the First Creek below Buckley Road gaging station in relation to annual precipitation totals from former Denver Stapleton Airport*, Colorado, water years 1998–2004.

Summary and Conclusions

The Rocky Mountain Arsenal (RMA) is positioned to become one of the premier urban wildlife refuges in the U.S. Fish and Wildlife Service National Wildlife Refuge System. Rapid urban development to the north, east, and south of the RMA may have various effects on its vital aquatic habitats. Since the early 1990s, the U.S. Geological Survey, in cooperation with the U.S. Army, has monitored the quality and quantity of water flowing onto the RMA. This report, prepared in cooperation with the U.S. Fish and Wildlife Service, documents existing surface-water-quality conditions on the RMA. All RMA water-quality data for the Irondale Gulch and First Creek Basins adjacent to and on the RMA were reviewed.

At the Havana Interceptor below 56th Avenue gaging station, all of the dissolved-oxygen results met the applicable State standard requiring a minimum of 5.0 milligrams per liter (mg/L) of dissolved oxygen for the protection of aquatic life. In contrast, the dissolved-oxygen results at the Peoria Interceptor below 56th Avenue gage commonly were less than 5.0 mg/L. Dissolved-oxygen concentrations at the Uvalda Interceptor below 56th Avenue were similar to those observed at the Havana Interceptor, with none of the concentrations less than the State standard. At the First Creek below Buckley Road site, dissolved-oxygen concentrations have ranged from 4.2 to 12.6 mg/L, with the exception of one suspect concentration of 1.6 mg/L. For the entire sampling period, only three dissolved-oxygen concentrations (excluding the previously mentioned 1.6-mg/L concentration) did not meet the State standard of 5.0 mg/L at the First Creek below Buckley Road site.

The State water-quality standard for pH applicable to the Irondale Gulch and First Creek Basins requires the pH to be between 6.50 and 8.99 for the protection of aquatic life. Generally, pH for the surface-water gaging stations in the Irondale Gulch Basin has remained within the range specified by the State standard. Values of pH in the Irondale Gulch Basin generally have ranged from 7.0 to 8.5, which is typical for natural runoff for this area. There were seven sampling events at the Havana Interceptor below 56th Avenue gaging station with pH values greater than or equal to 9, and no sampling events where the pH was less than 6.50. At the Peoria Interceptor below 56th Avenue site, all pH values were between 6.50 and 8.99; there was one sampling event at the Uvalda Interceptor below 56th Avenue site that was outside the range specified by the standard. At the First Creek below Buckley Road site, measurements of pH ranged from 7.31 to 8.35 and were generally similar to values from nearby urban-runoff sites in the Irondale Gulch Basin.

Specific conductance ranged from 40 to 1,750 microsiemens per centimeter at 25 degrees Celsius (µS/cm) at the three Irondale Gulch sites, not including snowmelt-runoff samples collected on November 24, 2003. All three Irondale Gulch sites had particularly high measurements of specific conductance on November 24, 2003, ranging from 3,520 µS/cm at the Peoria site to 6,330 µS/cm at the Uvalda site. The specific-conductance measurements on that date far exceeded all previous specific-conductance measurements at these three sites, indicating a large concentration of dissolved solids in the stream on that particular day. For the entire period of record for all of the samples analyzed at the First Creek below Buckley Road site, specific conductance ranged from 257 to 1,380 µS/cm.

Snowmelt-runoff samples collected on March 28, 2000, November 24, 2003, and March 9, 2004, at the Havana Interceptor below 56th Avenue gaging station had higher concentrations of sodium, chloride, and magnesium than nonsnowmelt-runoff samples for this site. Major-ion concentrations at the Peoria and Uvalda Interceptors following snowmelt-runoff sampling also were elevated. Differences in major-ion composition from base flow or stormwater runoff were not readily apparent at the Irondale Gulch sites.

At the Irondale Gulch sites, the concentrations obtained for chloride, magnesium, and sodium generally were below 200 mg/L at all three Irondale Gulch monitoring stations for the entire period of record (1988–2004), but there were a few sampling events at each of these sites where much higher concentrations for these analytes were measured. For example, the water-quality sample collected on November 24, 2003, at all three urban stormwater interceptors had unusually high concentrations of chloride and sodium. An analysis of the major-ion data shows that the concentrations of chloride and sodium also were unusually high as compared to historical samples collected at each of the three urban interceptors. Large concentrations of sodium and chloride also were detected in samples collected on March 29, 1995, at the Havana and Peoria Interceptors and on March 30, 1995, at the Uvalda Interceptor. On March 29, 1995, 0.12 inch of precipitation was recorded and temperatures were below freezing during the entire day, making it likely that relatively large amounts of road deicers were applied with little precipitation to dilute runoff concentrations of the salts that compose the deicers.

The urban runoff flowing onto the RMA had low concentrations and few, if any, detections for most organic contaminants. Part of the reason for low detections of organic contaminants may be related to when the samples were collected. The existing surface-water sampling program was not designed specifically to target storm runoff and therefore does not characterize water quality for all hydrologic regimes, most notably storm runoff. As a result, the existing data may not adequately represent potential contaminant transport onto the RMA. In addition, the urban-runoff sites are subject to sharp rises in water stage; an evaluation of the hydrographs from these sites indicates it is not uncommon during intense storms for the stage to rise approximately 1 foot every 15 minutes. These types of transient runoff events make water-quality sampling difficult, and none of the sites have a safe place to sample the highest flows that occur in any given year. As a result, most of the surface-water-quality samples were collected after the flow had decreased substantially from the peak flow, which may have transported much of the chemical contaminant load through the stream. Thus, the quality of the streamflow during the initial stormwater-runoff period in the First Creek and Irondale Gulch Basins is not well characterized. In addition, brief periods of high concentrations of contaminants harmful to the health of the aquatic ecosystem could occur but go undetected with the existing twice-per-year sampling regime for surface-water quality.

Overall, the small number of water-quality samples collected each year shows that the quality of water flowing onto the refuge is generally good and that changes in runoff hydrology have not yet been observed. However, given the increasing urban development and extension of existing concrete-lined runoff channels, which have little attenuation of stormwater and contaminants, ongoing and expanded monitoring would allow for timely responses to a degradation of water quality, help to better identify future sources of contaminants, and help mitigate any adverse effects that the changing hydrology may have on refuge wildlife and habitat.

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Appendixes

1. List of analytes that have been collected as part of the surface-water program and the abbreviations used for them at the Rocky Mountain Arsenal (2 pages). *(Available in **Excel** and **pdf** format)*

2. Analytical results for all water-quality samples collected at the Havana Interceptor below 56th Avenue gaging station, Commerce City, Colorado (115 pages). *(Available in **Excel** and **pdf** format)*

3. Analytical results for all water-quality samples collected at the Peoria Interceptor below 56th Avenue gaging station, Commerce City, Colorado (118 pages). *(Available in **Excel** and **pdf** format)*

4. Analytical results for all water-quality samples collected at the Uvalda Interceptor below 56th Avenue gaging station, Commerce City, Colorado (109 pages). *(Available in **Excel** and **pdf** format)*

5. List of laboratory codes and the complete names of each analytical laboratory used by the Rocky Mountain Arsenal (3 pages). *(Available in **Excel** and **pdf** format)*

6. List of analytical flag codes and descriptions for the Rocky Mountain Arsenal (1 page). *(Available in **Excel** and **pdf** format)*

7. Data qualifier codes and their descriptions (1 page). *(Available in **Excel** and **pdf** format)*

8. Analytical results for all water-quality samples collected at the First Creek below Buckley Road gaging station, Commerce City, Colorado (90 pages). *(Available in **Excel** and **pdf** format)*