Changes in Ground-Water Flow and Chemistry after Completion of Cattlemans Detention Basin, South Lake Tahoe, California— November 2001 to November 2003

Prepared in Cooperation with the
TAHOE ENGINEERING DIVISION, EL DORADO COUNTY DEPARTMENT OF TRANSPORTATION

Scientific Investigations Report 2005-5260

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

Cover: Photograph of Cattlemans detention basin on March 28, 2002 during spring snowmelt. Photograph was taken by J.L. Wood from the north side of the detention basin looking southwest toward outlet.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (Kg)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per foot (ft/ft)	1.0	meter per meter (m/m)

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

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

Altitude, as used in this report, refers to distance above the vertical datum.

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

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

Changes in Ground-Water Flow and Chemistry after Completion of Cattlemans Detention Basin, South Lake Tahoe, California— November 2001 to November 2003

By David E. Prudic, Jena M. Green, James L. Wood, and Katherine K. Henkelman

Abstract

A study of the Cattlemans detention basin in South Lake Tahoe, California began in November 2000 to evaluate the effectiveness of the detention basin in reducing sediment and nutrient loads from urban runoff to nearby Cold Creek. Detention basins commonly are used to minimize sediment and nutrient loads from urban runoff in the Lake Tahoe Basin, but the effects of these detention basins on changes in ground-water flow and chemistry are largely unknown. This report summarizes changes in ground-water flow and chemistry for two years after completion of Cattlemans detention basin in October 2001. The report includes a comparison of dissolved nutrient loads from ground-water discharge to Cold Creek below the detention basin with dissolved loads in Cold Creek.

Ground-water flow is through sand and gravel lenses within unconsolidated deposits in the vicinity of the detention basin. Ground water generally is less than 10 feet below land surface and is within meadow deposits consisting of gray silt and sand with lenses of sand and gravel. Ground-water levels rose during late winter and early spring and declined during the summer and fall. The general direction of ground-water flow remained persistent from east to west across the detention basin even when runoff into and precipitation on the detention basin caused an increase in ground-water levels during late winter and spring. A consistent downward gradient in water levels between paired wells on the west edge of the detention basin compared with generally upward gradients from the middle to the eastern edge of the detention basin indicates an abrupt thickening of the unconsolidated deposits beneath the western part of the detention basin. This downward flow into the unconsolidated deposits allows some of the ground water beneath the western part of the detention basin to flow underneath Cold Creek; however, a consistent gradient along the west side of the detention basin to a man-made meander on Cold Creek has focused ground-water discharge along the meander. The annual mean ground-water discharge along this meander was two to three orders of magnitude less than the annual mean discharge of Cold Creek during water years 2002 and 2003.

The chemical composition of ground water for a two-year period after completion of the detention basin did not change substantially from the chemical composition of ground water before completion of the detention basin. The principal dissolved cations remained sodium, iron, and calcium, and the principal dissolved anions were bicarbonate and chloride. Nitrogen concentrations in ground water from the meadow deposits also did not change substantially after completion of the detention basin. Ammonia remained the most common form of nitrogen and ranged from 0.001 to 15 mg/L. Nitrate plus nitrite concentrations were always less than 0.33 mg/L. The mean and median concentrations of dissolved phosphorus, orthophosphate, and organic carbon increased after completion, although the range in the concentrations did not substantially change.

Dissolved nitrogen, phosphorus, iron, and organic carbon loads from ground-water discharge along the meander below the detention basin were estimated by multiplying the range in annual ground-water discharge with annual mean concentrations in ground water immediately next to Cold Creek. Although dissolved nitrogen and phosphorus concentrations were 10 times greater in the ground water than dissolved concentrations in Cold Creek, the much greater discharge of Cold Creek compared with the discharge of ground water resulted in estimated loads from ground water of two orders magnitude less than the estimated annual loads in Cold Creek. Because dissolved iron concentrations in ground water were 250 times higher than in Cold Creek, the dissolved iron load from ground-water discharge is a larger fraction of the dissolved iron load in Cold Creek, which is consistent with the increase in measured dissolved iron concentrations in Cold Creek from above to below the detention basin.

Introduction

Detention basins commonly are used to minimize sediment and nutrient loads from urban runoff in the Lake Tahoe Basin (Fenske, 1990; Reuter and others, 1992b). Constructing wetlands in or adjacent to detention basins have shown improvements to the quality of runoff (Scherger and Davis, 1982; Martin, 1986; Reuter and others, 1992a; and Reuter and others, 1992b). However, degradation of water quality in ground water beneath the detention basins and associated wet-

lands has been documented (Church and Friesz, 1993; Granato and others, 1995).

Because effects of detention basins on changes in ground-water flow and chemistry are largely unknown in the Lake Tahoe Basin, a study was initiated in November 2000 to determine if nutrients that enter a detention basin are transported through ground water to nearby streams. The study is being done in cooperation with the Tahoe Engineering Division, El Dorado County Department of Transportation, and the California Tahoe Conservancy. The area selected for the study is the Cattlemans detention basin adjacent to Cold Creek, in South Lake Tahoe, California (fig. 1).

The study began nearly one year before completion of the detention basin. Data collection of ground water began in December 2000 and the detention basin was constructed in August and September 2001. The basin was not considered finished until after the planting of native vegetation was completed, which continued through October 2001. Thus, completion of the detention basin is considered herein as the end of October 2001. The basin was constructed as part of the Pioneer Trail III Erosion Control Project of the El Dorado County Department of Transportation.

Although the detention basin was completed at the end of October 2001, access during construction and landscaping of the detention basin with native vegetation resulted in a few wells next to the detention basin that were not accessible for sampling until the first week in November 2001. Because runoff into the newly constructed basin was limited to a few minor occurrences before the November sampling, the few samples that were collected in November 2001 were included in the analyses of ground-water quality before completion of the detention basin, whereas samples collected after November 2001 were used in the analyses of ground-water quality after completion of the detention basin. The analyses that compare water chemistry before and after completion of the detention basin are a comparison of samples collected between January 2001 and November 2001 with those collected between December 2001 and November 2003.

Purpose and Scope

The overall purpose of the study is to determine the effectiveness of the detention basin in reducing sediment and nutrient loads from urban runoff to nearby Cold Creek, a tributary to Trout Creek and Lake Tahoe (fig. 1). Nutrient and suspended-sediment loads to the lake are expected to decrease when urban runoff is directed into the detention basin rather than into Cold Creek, although a potential exists for nutrients to move through ground water from the detention basin to discharge points down gradient.

The overall scope of the project is to (1) estimate the quantity of urban runoff that enters and exits the detention basin along with estimates of total nutrient and suspended sediment loads, (2) estimate ground-water flow before and after completion of the detention basin, and (3) evaluate changes in nutrient and other dissolved-constituent loads that may enter Cold Creek from increased ground-water flow as the result of the detention basin. The overall project includes the collection of urban runoff, surface-water, and ground-water data approximately one year before completion of the detention basin and 3½ years after completion of the detention basin.

The purpose of this report is to present a preliminary evaluation of changes in ground-water flow and chemistry resulting from Cattlemans detention basin for a two-year period after its completion. An analysis of the direction of ground-water flow and chemistry before the detention basin is presented by Prudic and others (2005). The distribution of hydraulic conductivity of the shallow alluvial deposits is presented by Green and others (2004). The scope of data collection presented in this report include (1) measurements of ground-water levels in 30 wells from January 2001 to November 2003, and (2) a summary of analyses of dissolved major ions, trace elements, nutrients, and organic carbon in ground water from 13 wells and in Cold Creek above and below the detention basin.

Acknowledgments

David Friestad from the Tahoe Engineering Division, El Dorado County Department of Transportation designed the overall Pioneer Trail III Erosion Control Project of which Cattlemans basin is a part. Clayton Chappell and Janel Gifford from the Tahoe Engineering Division, El Dorado County Department of Transportation and Kimberly Carr from the California Tahoe Conservancy were instrumental in developing the work plan and securing funding for this study. Finally, Clayton Chappell, Troy Alexander, Eric Prouty, and Jennifer Quickel (Tahoe Engineering Division, El Dorado County Department of Transportation) assisted with data collection.

Description of Cold Creek and Cattlemans Detention Basin

The headwater area of Cold Creek is in the mountains south of Lake Tahoe and the creek flows northwest until it joins with Trout Creek about 3.6 mi from Lake Tahoe (fig. 1). Cold Creek is the largest watershed feeding the Trout Creek drainage basin, which is the second largest drainage tributary to Lake Tahoe. The drainage area of Cold Creek is 12.8 mi^2 (Rowe and Allander, 2000, p. 8). The drainage upstream of the detention basin and Pioneer Trail is largely undeveloped (less than 5 percent of the drainage area is developed; Prudic and others, 2005). The creek drains an area that is composed primarily of granodiorite and in places is covered by glacial till (Bonham and Burnett, 1976). Cold Creek enters a large meadow where Pioneer Trail crosses the creek about 0.6 mi above its confluence with Trout Creek.

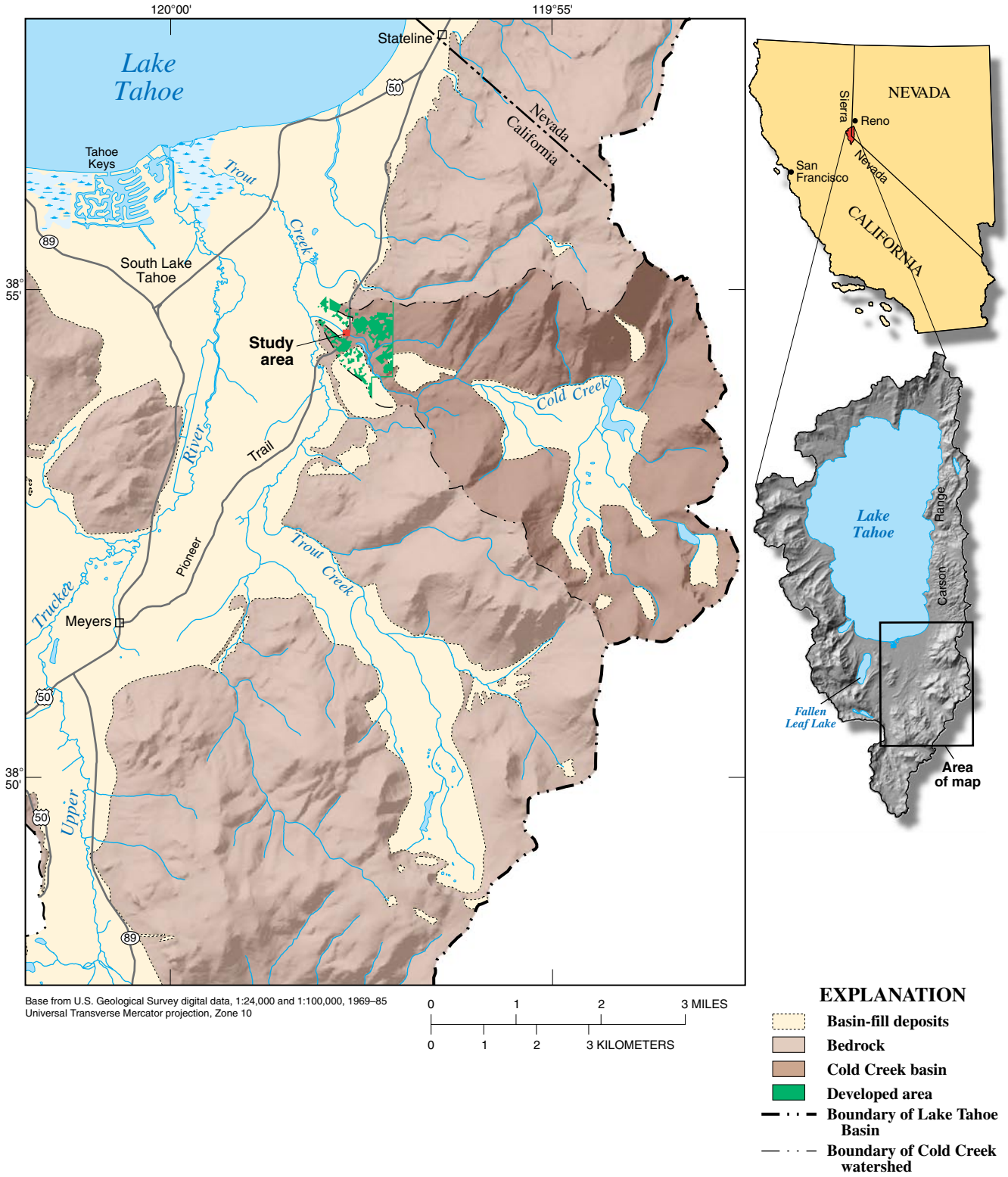


Figure 1. Location of Lake Tahoe and study area adjacent to Cold Creek, South Lake Tahoe, California (modified from Prudic and others, 2005).

Cattlemans detention basin is located at the end of Cattlemans Court and is bordered by Pioneer Trail to the east and Cold Creek to the north and west (fig. 2). Construction began in August 2001 and the basin was largely completed at the end of October 2001. The channel of Cold Creek downstream from Pioneer Trail depicted in figure 2 was reconstructed in 1994 into its present form (Kimberly Carr, California Tahoe Conservancy, South Lake Tahoe, Calif., oral commun., 2003). The reconstructed channel is wider and deeper than the natural channel and has a much greater sinuosity. The excavation of the channel below the water table and the creation of meanders that cross the direction of ground-water flow in the meadow increased ground-water exchange with the stream as compared to the exchange with the natural channel (Prudic and others, 2005).

Cattlemans detention basin is designed to capture urban runoff from part of adjacent neighborhoods and Pioneer Trail. Runoff flowed in ditches adjacent to Pioneer Trail to Cold Creek or across a flat area at the end of Cattlemans Court before completion of the detention basin (Prudic and others, 2005). The unlined basin was constructed to hold a total volume of 22,000 ft^3 without surface discharge (Jennifer Quickel, Tahoe Engineering Division, El Dorado County Department of Transportation, South Lake Tahoe, Calif., written commun., 2003). A spillway was constructed of concrete and large boulders on the west side of the detention basin. Overflow from the detention basin is routed through the spillway and apron into the meadow just south of Cold Creek (fig. 2). The capacity of the basin when the basin begins to spill (at the maximum elevation of 6,276 ft) is 28,500 ft^3 (Jennifer Quickel, Tahoe Engineering Division, El Dorado County Department of Transportation, South Lake, Tahoe, Calif., written commun., 2003). Flow into the meadow is retained behind bundled straw (referred to as a biolog) to prevent overflow from the detention basin directly reaching Cold Creek (fig. 2).

Methods

Ground Water

A series of monitoring wells were installed before completion of the detention basin because of a concern for transport of nutrients through ground water from the detention basin to Cold Creek (fig. 2). The drilling and construction of the wells are described by Prudic and others (2005). Briefly, wells were either augered with a trailer mounted rig or by hand. Nominal 2-in. diameter polyvinyl chloride (PVC) casing with a 1-ft long screen was placed 2 to 3 ft below the water table. Deeper wells, also with 1-ft screen lengths, were installed to depths 5 ft below the adjacent shallow wells for the purpose of estimating vertical ground-water gradients in the alluvial deposits. In this report, a shallow well adjacent to the deeper well is designated by an S following the well name (for example; well cc3S) and the deeper well is designated by a D following the well name (for example; well cc3D). The shallow wells generally were completed in a gray silt and sand with lenses of sand and gravel, whereas the deeper wells generally were completed in a brown sand and gravel with lenses of silt and sand. Information on well construction and depth to water for each well is available in the U.S. Geological Survey's (USGS) National Water Information System (NWIS) database and summarized in Green and others (2004).

Measurements of depth to water in the wells were made routinely after the wells were drilled. Depth to water was measured using either an electric tape calibrated to a steel tape or a steel tape. Water depths generally were 3 ft or less below land surface in wells next to Cold Creek and depths were more than 9 ft below land surface at wells cc3S and cc3D during summer and late fall. Water-level elevations were determined by subtracting the depth to water in each well from the elevations of the top or the measuring point of each well. The elevation of the top of each well, or measuring point, was surveyed using a Nikon Total Station (model DTM-A5LG) referenced to the elevation reported for a benchmark set by the Tahoe Engineering Division, El Dorado County Department of Transportation at the north end of Cattlemans Court. The altitude of the benchmark is 6,282.85 ft above NAVD 1988. Depth to water in monitoring wells for water years 2001-2003 (October 1, 2000–September 30, 2003) were published in Garcia and others (2002), Berris and others (2003); and Stockton and others (2004). All water-level information is available in the USGS NWIS database.

Pressure transducers having a pressure range from 0 to 5 lb/in^2 (Global Water, Inc. model numbers WL14X and replaced with WL15 in October 2003) were installed in several wells (cc3S, cc3D, cc6S, cc6D, cc8S, cc8D, cc13S, cc13D, and cc14). Water-level data from the pressure transducers were recorded every hour and the data were retrieved using a laptop computer. Data from the pressure transducers were checked with periodic measurements of depth to water using an electric or steel tape. The purpose of the pressure transducers was to measure changes in water levels during inaccessible periods (when deep snow covered the ground) and to assess daily variations in water levels. Pressure transducers initially were installed in wells cc8S and cc8D but were moved to wells cc6S and cc6D after completion of the detention basin because of concerns that the water level in the pond could rise and cover wells cc8S and cc8D.

Cold Creek

A streamflow gage was established on the upstream side of the culvert that allows Cold Creek to flow beneath Pioneer Trail (fig. 2; surface-water level recorder near well cc1 is USGS stream gage number 10336778 and named Cold Creek at Pioneer Trail, South Lake Tahoe, Calif.). The staff plate, metal housing, and control plate across the bottom of the culvert had been installed during reconstruction of Cold Creek

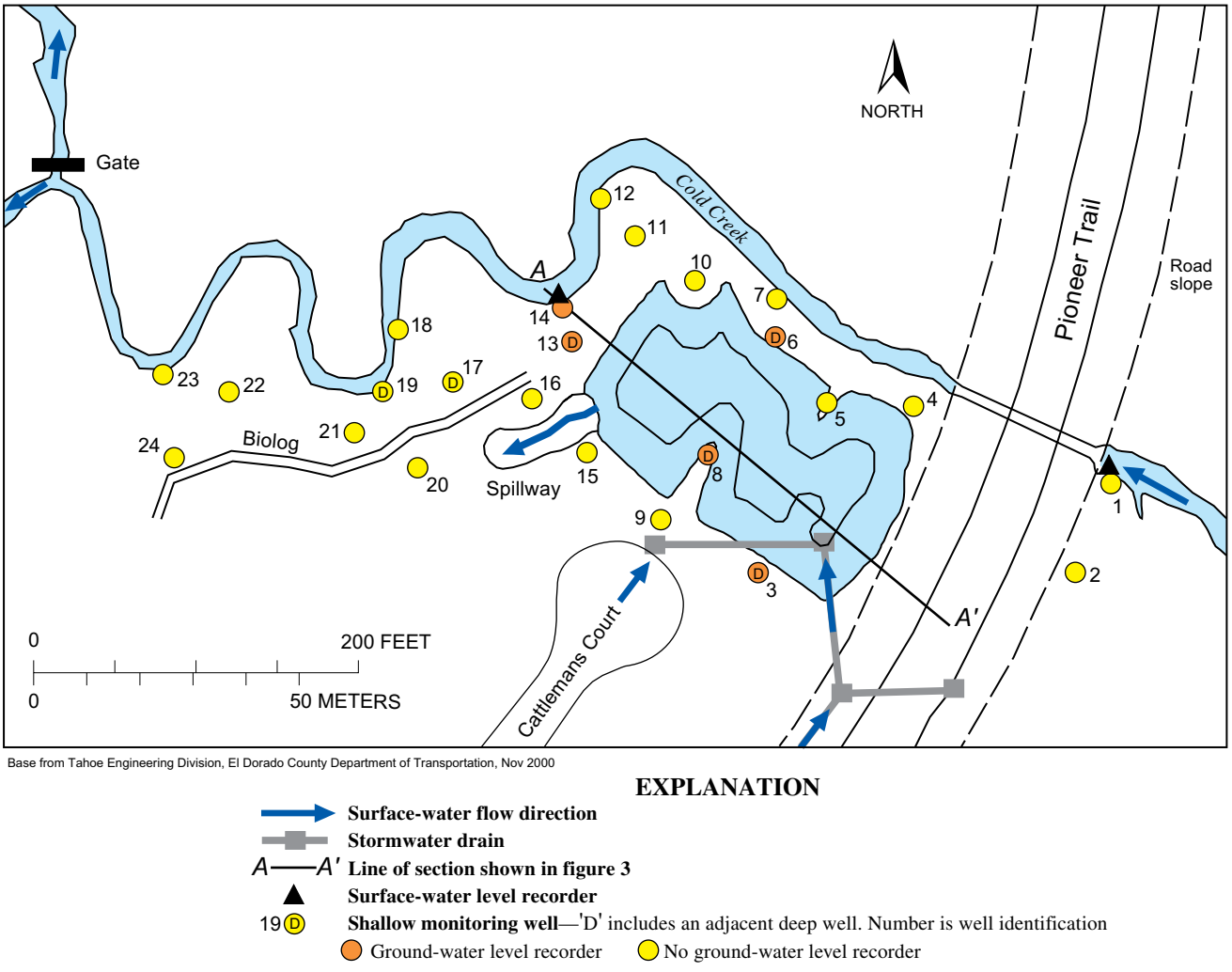


Figure 2. Location of wells, storm drains, and Cold Creek in relation to Cattlemans detention basin at the end of Cattlemans Court, South Lake Tahoe, California.

Well identifications have been abbreviated by omitting the "cc" part of the name. Location of study area is shown in figure 1.

through the meadow in 1994. A pressure transducer (Global Water, Inc. model WL-15) having a pressure range from 0 to 1 lb/in^2 was used to monitor stream stage every 15 minutes. This transducer failed twice during the study. The first time was in November 2001 and the second time was in October 2003. Shifts in data were determined by comparing pressure transducer readings with the outside staff gage. Daily mean discharges for the period June 26, 2001 through September 30, 2003 were published in Stockton and others (2004, p. 338-340). Stream discharge also is available in the USGS NWIS database.

A second pressure transducer (Global Water, Inc. WL-14X) having a pressure range from 0 to 5 lb/in^2 was placed in Cold Creek below the detention basin adjacent to well cc14 (fig. 2) in June 2000. The transducer was installed to compare stream stage or elevation in relation to the ground-water elevation in well cc14. The pressure transducer was replaced with a newer model (WL-15) in November 2003.

Water-Quality Sampling Procedures

Wells from which water-quality samples were obtained for chemical and nutrient analyses were pumped using a portable battery-operated peristaltic pump using C-flex tubing and following procedures outlined in Gibs and Wilde (1999). The C-flex tubing was rinsed with de-ionized water following each sampling. About 1 gal was pumped from the wells every 10 minutes. At least 3 well-bore volumes were pumped from each well before sampling. Volumes ranged from about 0.25 to 0.5 gal for the shallow wells in the meadow area and near Cold Creek to 2 gal for the deeper wells. The discharge from the pump was monitored for pH, specific conductance, dissolved oxygen, and water temperature only in wells where major-ion and trace-element samples were collected. Two wells (wells cc17S and cc21) recovered slowly after water was removed from the casing. These wells were allowed to recover before removing more water from the casing and the process was repeated until 3 well-bore volumes were removed.

Measurements of temperature, specific conductance, and pH were made in a flow-through cell at the time the wells were sampled. Dissolved oxygen also was measured from unfiltered water in the flow cell for wells that were sampled for major ions and organic carbon. For wells sampled for major ions, alkalinity concentrations were measured in the field using the incremental acid titration method (Rounds and Wilde, 2001). All ground-water samples collected for analyses including alkalinity and bicarbonate were filtered through a 0.45-micron (µm) filter.

All wells were sampled for dissolved nutrients during the spring, summer, and fall of each year from November 2001 to November 2003 by passing the water through a 0.45-µm filter. During this same period, 13 to 15 wells also were sampled for dissolved organic carbon and major ions. In addition to major ions, trace elements were analyzed for samples collected from November 2001 to October 2002. After October 2002, only bromide, iron, and manganese were analyzed as most of the other trace elements were at or below laboratory reporting limits.

Water from Cold Creek was sampled next to well cc1 (upstream of the stream gage at Pioneer Trail) and next to well cc14 (fig. 2). Samples generally were collected by placing C-flex tubing from a portable battery-operated peristaltic pump about mid-depth in the stream near the bank, and pumping water through a flow-through chamber (Webb and others, 1999). Water was pumped from Cold Creek until pH, temperature, and specific conductance measured in the flow-through chamber stabilized (generally 1 to 2 gal) at which time the chamber was removed. A capsule filter (0.45 µm) was placed on the end of the tubing and samples were collected for analysis. The water was filtered to directly compare water in Cold Creek with ground water in the wells. Filtered samples were analyzed for nutrients, organic carbon, and major ions and occasionally for trace elements. Dissolved oxygen also was measured by placing the probe directly into Cold Creek at the time of sampling using the amperometric method (Radtke and others, 1998). Alkalinity and bicarbonate concentrations were determined from a filtered sample using the incremental acid titration method (Rounds and Wilde, 2001).

Nutrient analyses of all samples included Kjeldahl nitrogen (ammonia and organic nitrogen), ammonia, nitrate plus nitrite, phosphorus, orthophosphate, and iron. All nutrient samples were placed in ice and chilled to 4°C or less and remained chilled until analyzed (Wilde and others, 1999). Water samples collected for organic carbon (either filtered or unfiltered) were collected into baked glass bottles and preserved with 4.5N sulfuric acid. Samples for filtered and unfiltered iron were acidified with nitric acid to a pH of 2.0 or less. Filtered water samples collected for anions were untreated and filtered water samples for cations and trace elements were acidified with nitric acid to a pH of 2.0 or less. One unfiltered and untreated water sample was used for laboratory determination of specific conductance and pH.

Analyses of Water Samples

Samples collected by the USGS were sent to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado for major-ion, trace-element, and organic carbon chemical analyses or to the University of California, Davis and the Tahoe Research Group Laboratories for nutrient analyses of filtered and unfiltered samples. Samples for Kjeldahl nitrogen and iron were sent to the University of California, Davis in Davis, California, whereas samples for ammonia, nitrate and nitrite, phosphorus, and orthophosphate were sent to the Tahoe Research Group Laboratory in Tahoe City, California. Analytical results from all samples are stored in the USGS NWIS database. Water-quality data collected for this project (both surface water and ground water) were published in Garcia and others (2002), Berris and others (2003), Stockton and others (2004).

Quality of the water-quality data was documented by collecting a field blank during most sampling trips and by collecting duplicate samples at some sites. Also, the University of California, Davis and the Tahoe Research Group Laboratories ran duplicate analyses of at least one nutrient per sample as a laboratory Quality Assurance (QA) procedure. The sample analyses completed by the USGS NWQL have been quality assured by standard laboratory procedures and are documented at *http://wwwnwql.cr.usgs.gov/USGS/USGS_tech.html*. The results of all quality assurance combined indicated that no contamination or analytical problems affected the concentrations reported for constituents in water samples.

Ground Water

Principal Aquifer

The principal aquifer in the meadow and beneath the detention basin consists of sand and gravel lenses within unconsolidated deposits. The uppermost 5 to 8 ft of the unconsolidated deposits generally are a gray silt and sand with lenses of sand and gravel and generally are low in dissolved oxygen (Prudic and others, 2005). They are herein referred to as meadow deposits. Beneath the gray silt and sand is a brown sand and gravel with lenses of silt and sand. Hydraulic conductivity estimated from slug tests of 27 wells ranged from 0.5 to 70 ft/d and the mean was 18 ft/d (Green and others, 2004). Estimates of hydraulic conductivity were similar in both units; however, the deeper deposits generally have higher dissolved oxygen and lower dissolved organic carbon concentrations.

The composition of unconsolidated deposits beneath a depth of 15 ft is unknown. The unconsolidated deposits were estimated to be about 80 ft thick just west of the detention basin (Prudic and others, 2005). The meadow extends just east of Pioneer Trail where unconsolidated deposits abut against granodiorite exposed at land surface. The area above Pioneer Trail is mapped as bedrock (fig. 1). Granodiorite was encountered at a depth of about 6 ft at well 2 and may be bedrock. A narrow zone of unconsolidated deposits continues next to the channel of Cold Creek into the bedrock area. A detailed description of the unconsolidated deposits and depth to bedrock is presented in Prudic and others (2005).

The detention basin was constructed at the base of the upland area adjacent to the upgradient (east) edge of a large meadow. The basin is an area in which 4 to 5 ft of fill had been placed over the meadow during the construction of houses to the south of Cold Creek (Prudic and others, 2005). Construction of the detention basin removed much of the fill in the area of the basin such that much of the basin floor was excavated into the meadow deposits (fig. 3). The water table beneath the area of the detention basin commonly occurs in the gray silt and sand of the meadow deposits; consequently, lateral ground-water flow from the area of the detention basin to Cold Creek primarily occurs through the meadow deposits.

Seasonal Trends in Water Levels

Generally, the ground-water levels rose throughout the study area from the fall to early spring and declined from late spring through the summer of each year (fig. 4), except in wells east of Pioneer Trail (cc1 and cc2). Ground-water levels generally were highest in late winter and spring and lowest in late summer and early fall. Seasonal changes in water levels were least for wells next to Cold Creek and were greatest in wells adjacent to the detention basin. The observed trends in water levels are consistent with ground-water inflow from the upland areas to the east and south, seepage to and from Cold Creek, and recharge from infiltration of runoff and precipitation (rain and snowmelt) within the detention basin and in the meadow area surrounding the detention basin.

The greatest water-level change before completion of the detention basin was recorded in well cc3S, which rose 2.3 ft between January 30 and March 21, 2001 (fig. 5). The greatest rise after completion of the detention basin was observed in well cc6S when the water level rose 3.2 ft between November 5 and November 7, 2002. The rise most likely was caused by a rapid filling of the detention basin from urban runoff. Runoff into the detention basin commonly resulted in a rapid rise in ground-water levels in wells adjacent to the detention basin followed by a gradual decline.

The water level in well cc14 generally followed the same trend as that in well cc13S from late summer to early spring, although the magnitude of the water-level change was much less (fig. 5). Inflow into the detention basin after September 2001 produced rapid changes in the ground-water levels at wells cc13S and cc14 and in the stage of Cold Creek. However, snowmelt runoff from the drainage area upstream of Pioneer Trail caused the water level in well cc14 to peak later than water levels in wells adjacent to the detention basin (fig. 5). Unfortunately, the pressure transducer in Cold Creek near well cc14 was affected by turbulence during periods of high flow because of flow around logs that had been embedded into the bank during reconstruction of the channel in 1994 (Prudic and others, 1995, p. 4). Consequently, water levels measured in Cold Creek near well cc14 during periods of high flow could not be used to compare with the water level in well cc14. The water level measured from the pressure transducer in Cold Creek at Pioneer Trail was transposed to the elevation of the pressure transducer near well cc14 during the spring of 2003. The measured water level in well cc14 followed the same trend as that in Cold Creek using the transposed data from the pressure transducer above Pioneer Trail (fig. 5).

During the spring, the water table in the unconsolidated deposits on the eastern side of the detention basin generally rose above the basin bottom and remained above the basin bottom until late spring (elevation of the basin floor near the inlet and outlet structures are shown in fig. 5). Ground-water

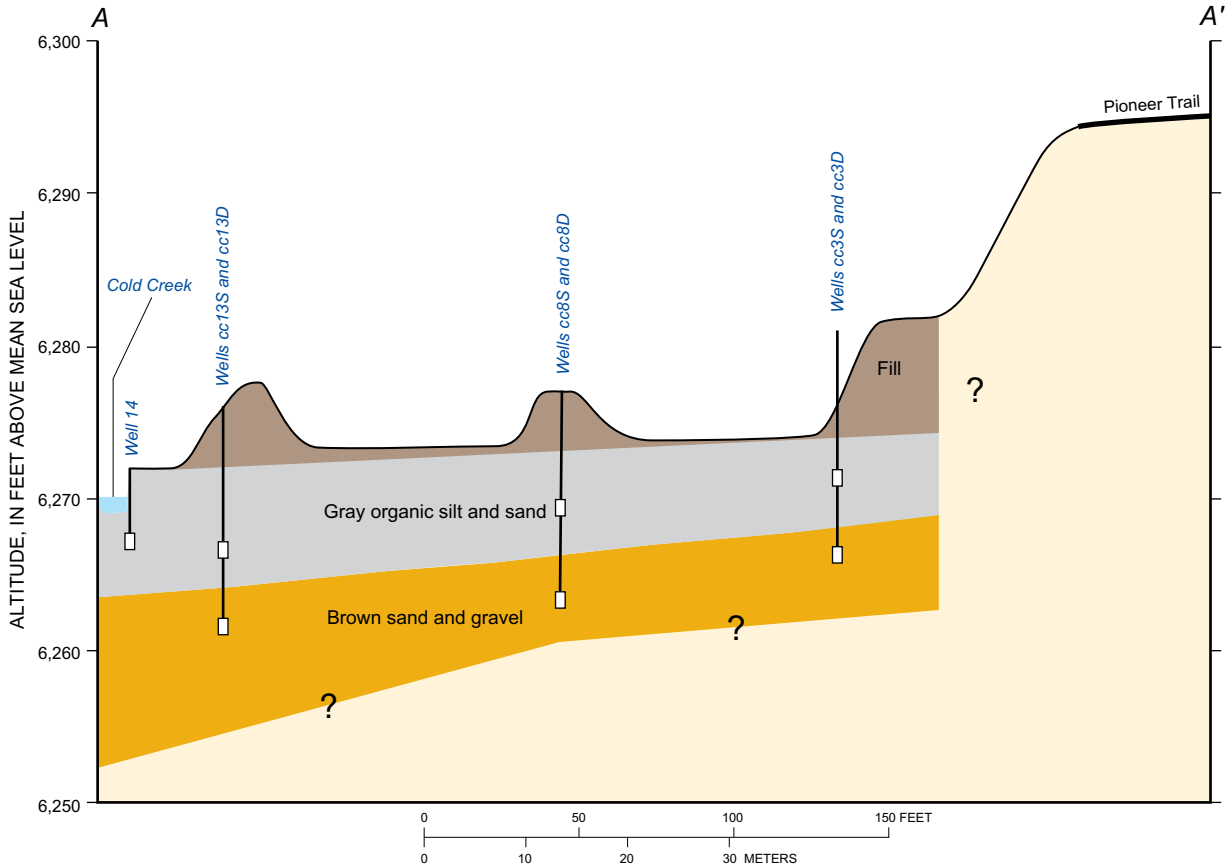


Figure 3. Distribution of unconsolidated deposits beneath Cattlemans detention basin. Location of section is shown in figure 2. Wells cc3S and cc3D are projected onto section.

seeps were common along the east side of the pond in April and May, which suggests that the water level of the pond in the basin was partly maintained by ground water for several weeks after runoff from snowmelt ceased.

Changes in Direction of Flow

Ground-water levels in the meadow deposits on May 9, 2001, before completion of the detention basin, generally decreased from east to west following the land surface of the meadow (fig. 6A). Because ground-water flow is from higher to lower water levels, ground-water flow generally was from east to west. The slightly higher water levels at wells cc1 and cc2 east of Pioneer Trail than those west of Pioneer Trail suggest that ground water east of Pioneer Trail contributes flow to the meadow deposits. Although the ground-water level was higher in the spring and lowest in late summer and early fall (fig. 6B), the general pattern of higher ground-water levels east of Pioneer Trail and lower ground-water levels west of the detention basin remained persistent after completion of the detention basin (fig. 6B–F).

Runoff into and precipitation on the detention basin caused an increase in ground-water levels along the western side of the basin during the spring of 2002 and 2003 (fig. 4E). However, ground-water levels generally returned to those measured in the fall of 2001 (fig. 4E). The observed trends in ground-water levels within the meadow deposits are consistent with ground-water inflow from areas to the east and south of the detention basin, ground-water discharge to Cold Creek, and evapotranspiration in the spring and summer within the detention basin and adjacent meadow.

Not all the shallow ground water beneath the detention basin discharges into Cold Creek. Differences in ground-water levels between paired shallow and deeper wells show consistent patterns before and after completion of the detention basin (fig. 7). The differences in the patterns between the paired shallow and deeper wells are likely caused by variations in the thickness or transmissivity (hydraulic conductivity multiplied by thickness) of unconsolidated deposits beneath the detention basin. The unconsolidated deposits become thicker beneath the detention basin because bedrock is near land surface east of the detention basin (at well cc2) and is 80 ft below land surface about 100 ft west of the detention basin (Prudic and others, 2005, p. 15).

At wells cc3S and cc8S (figs. 7A), the gradient between the shallow and deeper wells was upward (a negative value in figure 7A) before completion of the detention basin, and

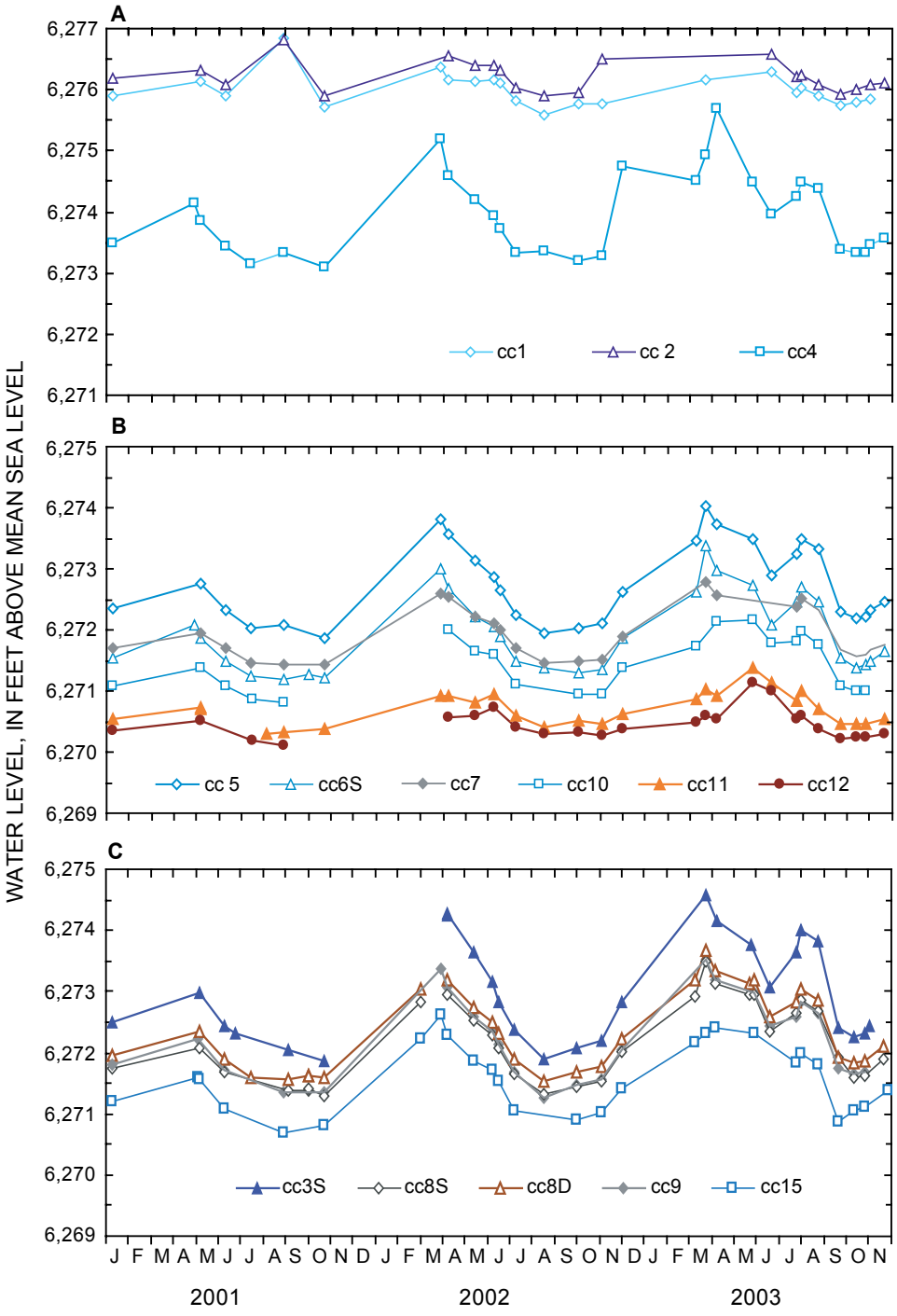


Figure 4. Trends in ground-water levels from January 2001 through November 2003 (A) along eastern side, (B) along northern side, (C) along southern side, and (D) along western side of Cattlemans detention basin, and (E) in meadow distant from detention basin.

Locations of wells are shown in figure 2.

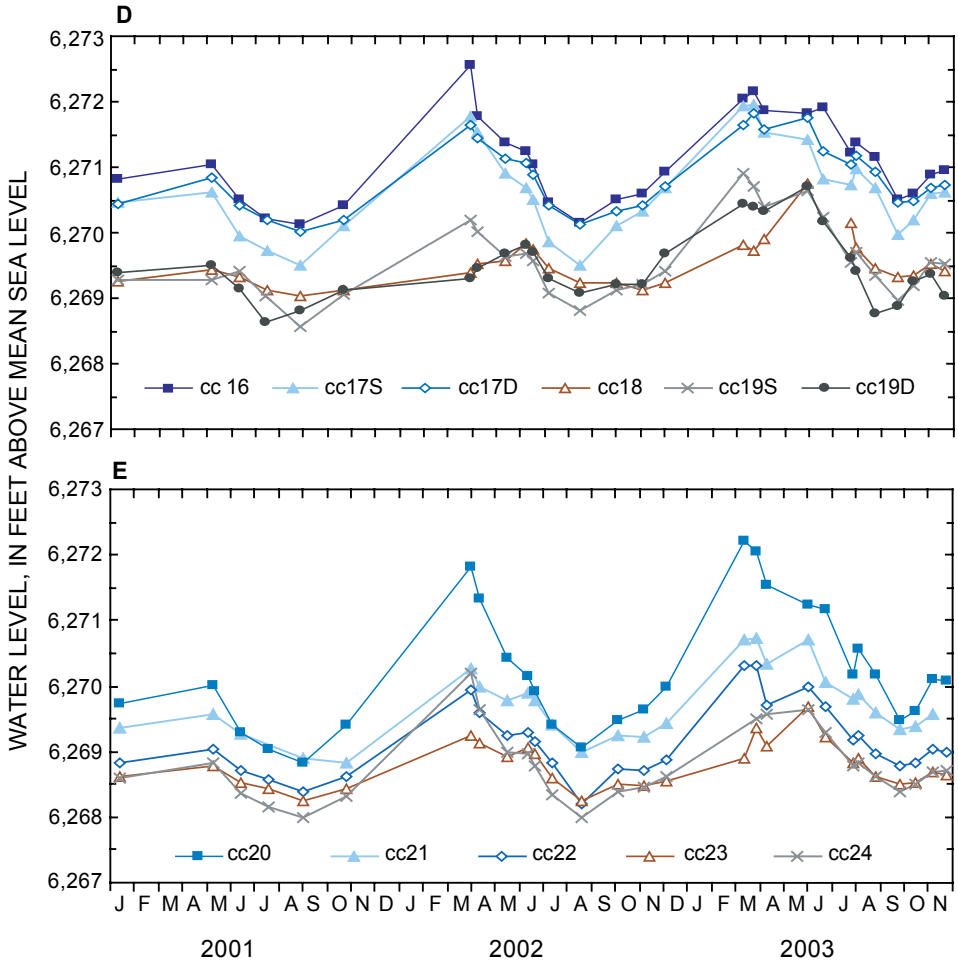


Figure 4. Trends in ground-water levels from January 2001 through November 2003 (A) along eastern side,(B) along northern side, (C) along southern side, and (D) along western side of Cattlemans detention basin, and (E) in meadow distant from detention basin—Continued.

Locations of wells are shown in figure 2.

remained generally upward except during periods when there was rapid filling of the detention basin. Large increases in the upward gradient occurred at well pair cc3S and cc3D (large negative gradients) during the fall whenever the water table was near or below the screen in well cc3S and there was rapid filling of the basin from urban runoff. This, combined with a lower hydraulic conductivity in the vicinity of well cc3S compared with well cc3D, resulted in a ground-water level rise in well cc3D that preceded a rise in well cc3S.

At well pair cc6S and cc6D, the vertical hydraulic gradient was always low (less than 0.02 ft/ft), which suggests that ground-water flow mostly was lateral. The hydraulic gradient at this well pair was slightly upward before completion of the detention basin but after completion, the gradient reversed to downward (a positive gradient in fig. 7A) whenever the basin filled with water. The vertical gradient at well pair cc13S and cc13D differed markedly from the other paired wells in that the gradient was consistently downward. The consistent downward gradient at well pair cc13S and cc13D indicates an abrupt thickening of the unconsolidated deposits between wells cc8S and cc13S. Continued thickening of the unconsolidated deposits further downstream probably causes ground water beneath the detention basin to gradually flow deeper into the deposits.

More important to the effectiveness of the detention basin is the change in the horizontal water-level gradients in the shallow wells between the basin and next to Cold Creek (fig. 7B). The detention basin is nearest Cold Creek near wells cc6S and cc13S. Changes in the horizontal water-level gradients between wells cc6S and cc7, wells cc10 and cc12, and wells cc13S and cc14 are indications of the change in shallow ground-water flow from the detention basin to Cold Creek. The ground-water level in well cc7 generally was higher than that in well cc6S before completion of the deten-

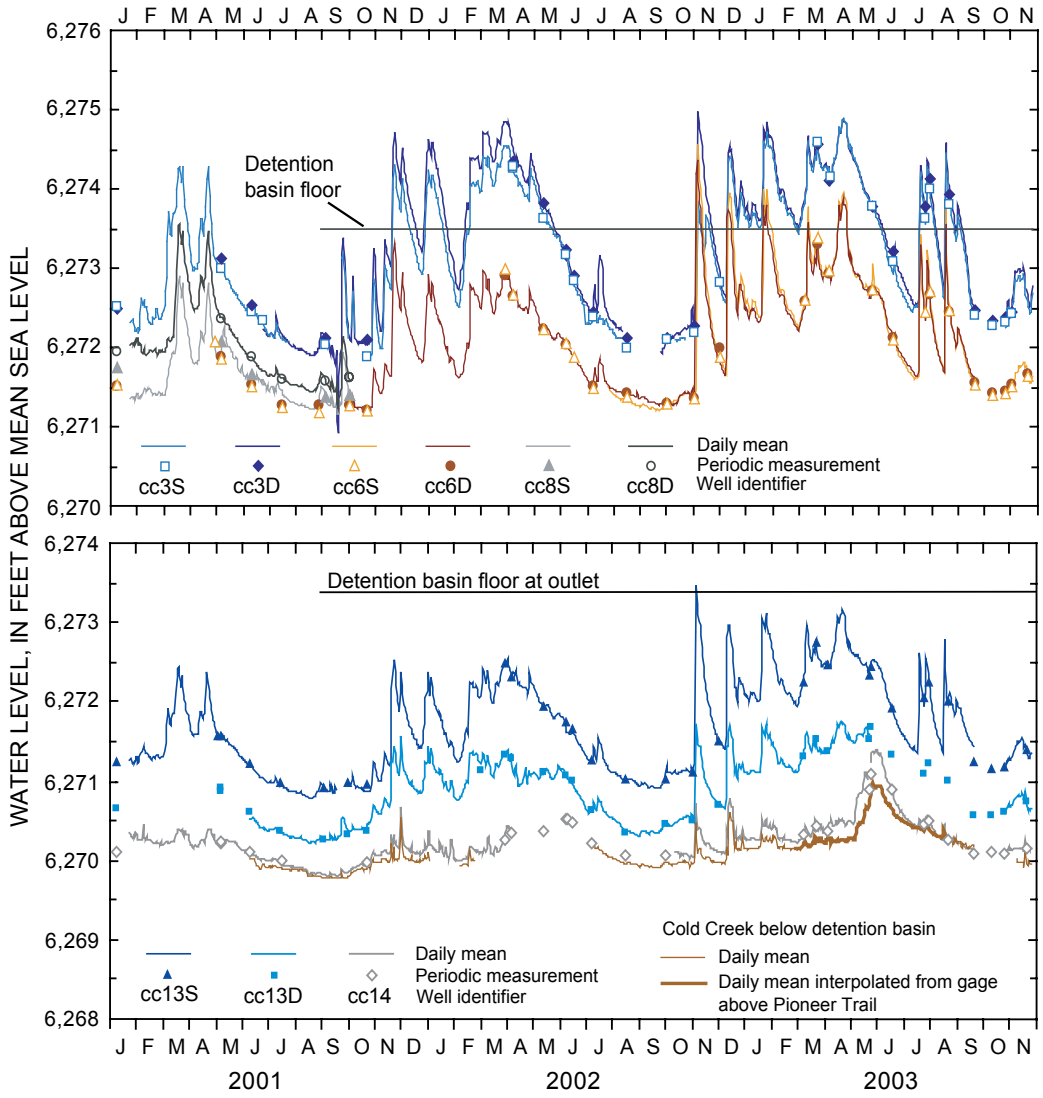


Figure 5. Daily mean water levels in wells with recording pressure transducers near Cattlemans detention basin from January 2001 through November 2003.

Locations of wells are shown in figure 2.

tion basin, suggesting that water in Cold Creek was seeping into the meadow deposits along the left bank (viewed looking downstream; see fig. 6A). Thus, the horizontal gradient from wells cc6S and cc6D to well cc7 was slightly negative prior to November 2001 (fig. 7B). The water level in well cc7 was not measured in April 2001 when the water level in wells cc6S and cc6D were higher than those on May 9, 2001, and the gradient could have changed from negative to positive during that period. After completion of the detention basin, the gradient between wells cc6S and cc7 was toward Cold Creek (positive values in fig. 7B) during periods when there was water in the basin. This suggests that ground water discharged to Cold Creek near well cc7 whenever there was water in the detention basin.

The horizontal water-level gradient between wells cc10 and cc12, and wells cc13S and cc14 was always toward the creek even before completion of the detention basin (fig. 7B). The gradient between wells cc13S and cc14 was generally 3 times greater than that between wells cc10 and cc12. The lower gradient between wells cc10 and cc12 may be caused by a greater distance between the wells, although the higher gradient between wells cc13S and cc14 likely is the result of the meander that was built during reconstruction of Cold Creek, which focused ground-water flow to the area immediately around well cc14 (fig. 6).

Water-level gradients from periodic measurements of wells cc13S and cc14 were supplemented with daily averaged gradients from hourly pressure transducer data (fig. 7B). Daily gradients from January to November 2001 ranged from

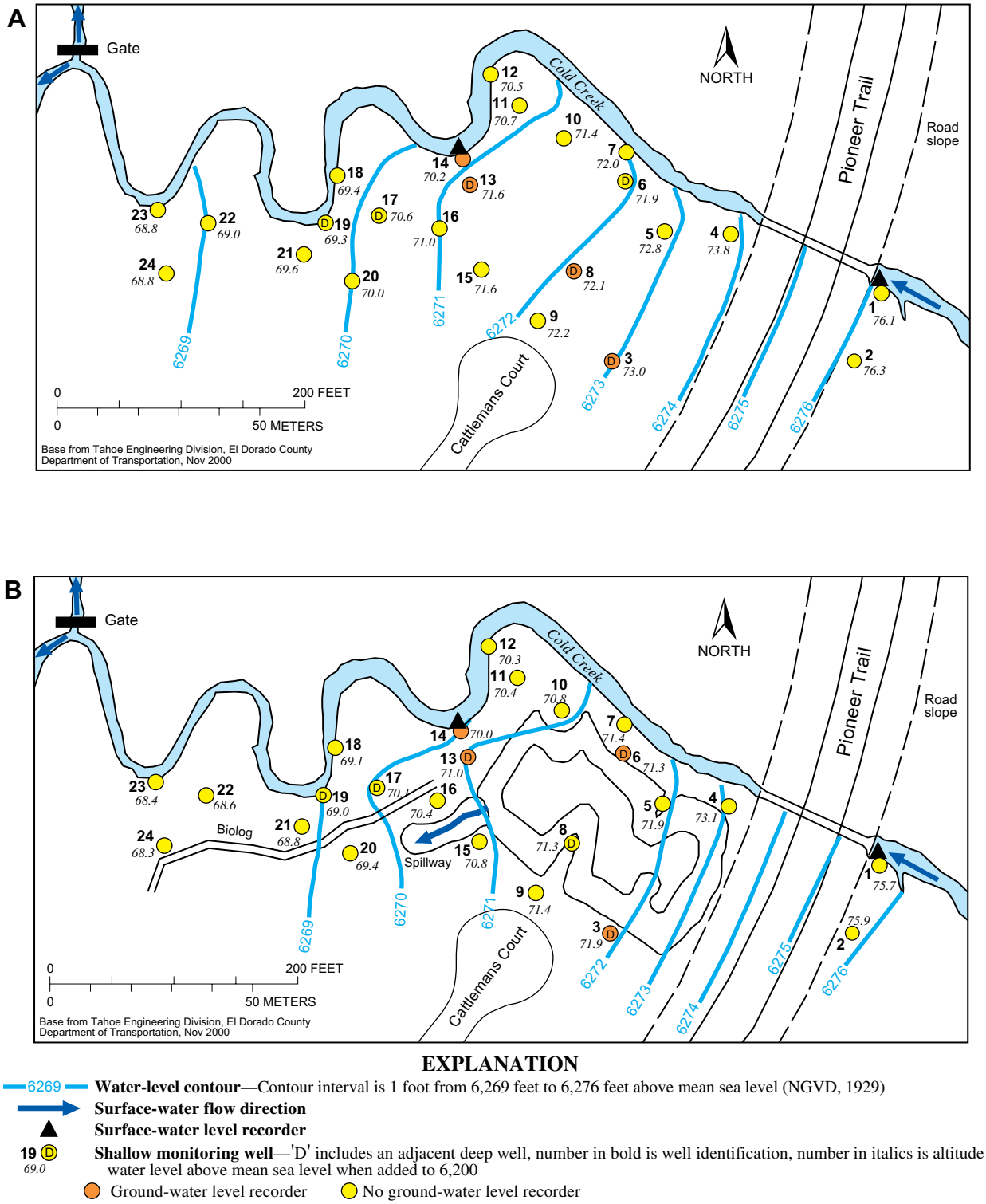
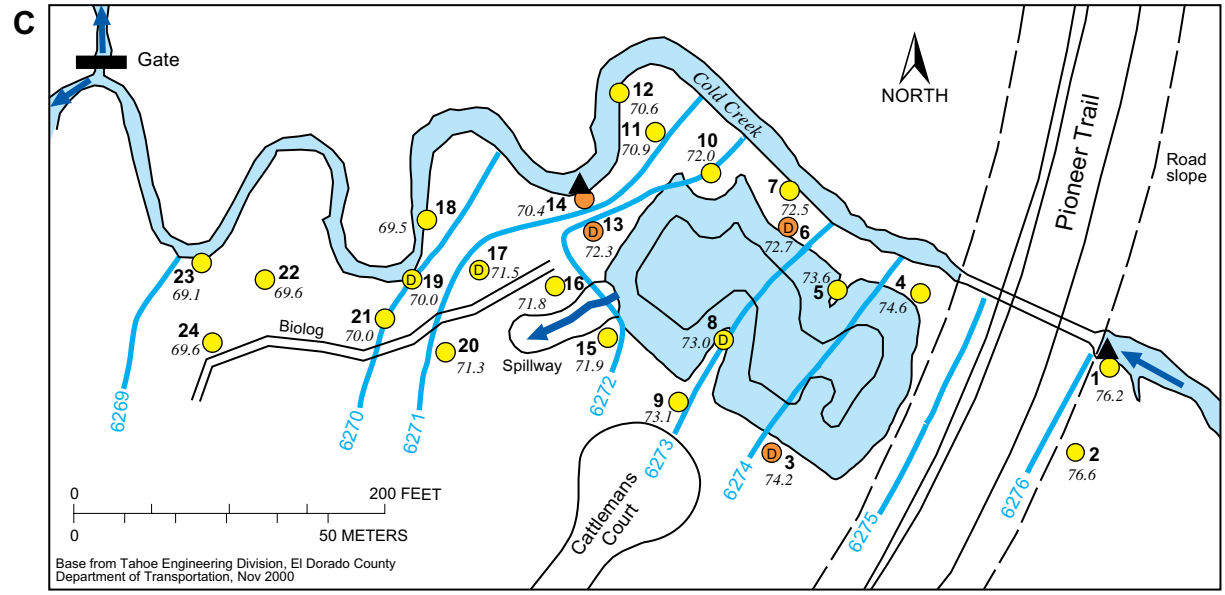
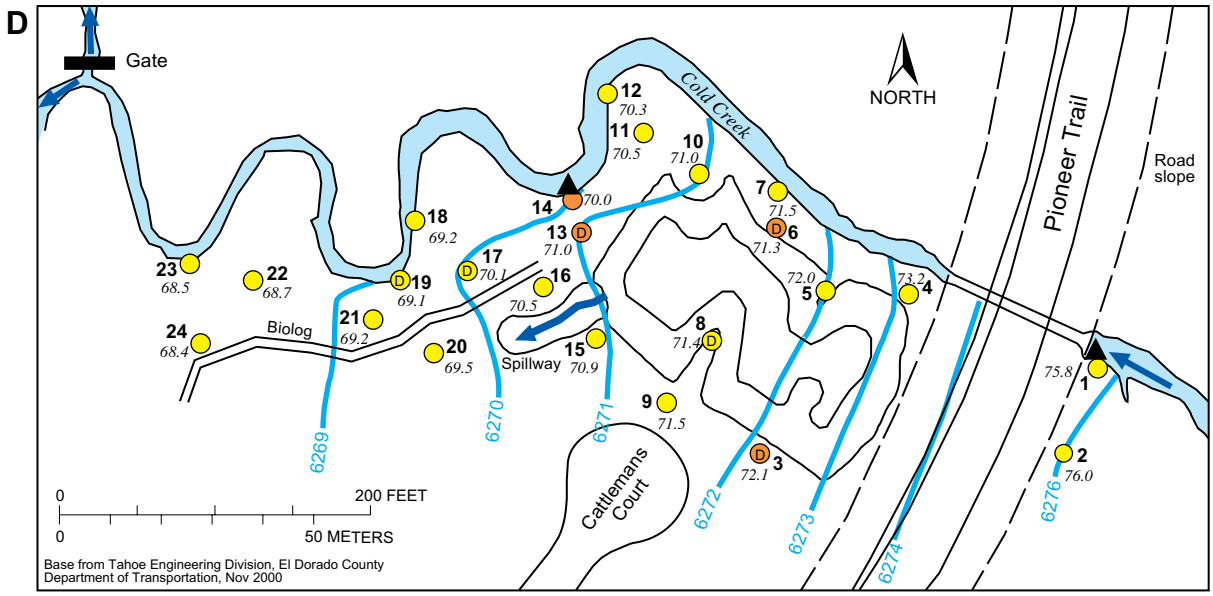


Figure 6. Contours of ground-water levels at Cattlemans detention basin for selected dates. (A) May 9, 2001—no basin; (B) October 24, 2001—basin empty; (C) April 10, 2002—basin full; (D) October 4, 2002—basin empty; (E) March 27, 2003—basin full; and (F) October 16, 2003—basin empty.

Well identifications have been abbreviated by omitting the "cc" part of the name.





EXPLANATION

6269 **Water-level contour**—Contour interval is 1 foot from 6,269 feet to 6,276 feet above mean sea level (NGVD, 1929)

Surface-water flow direction

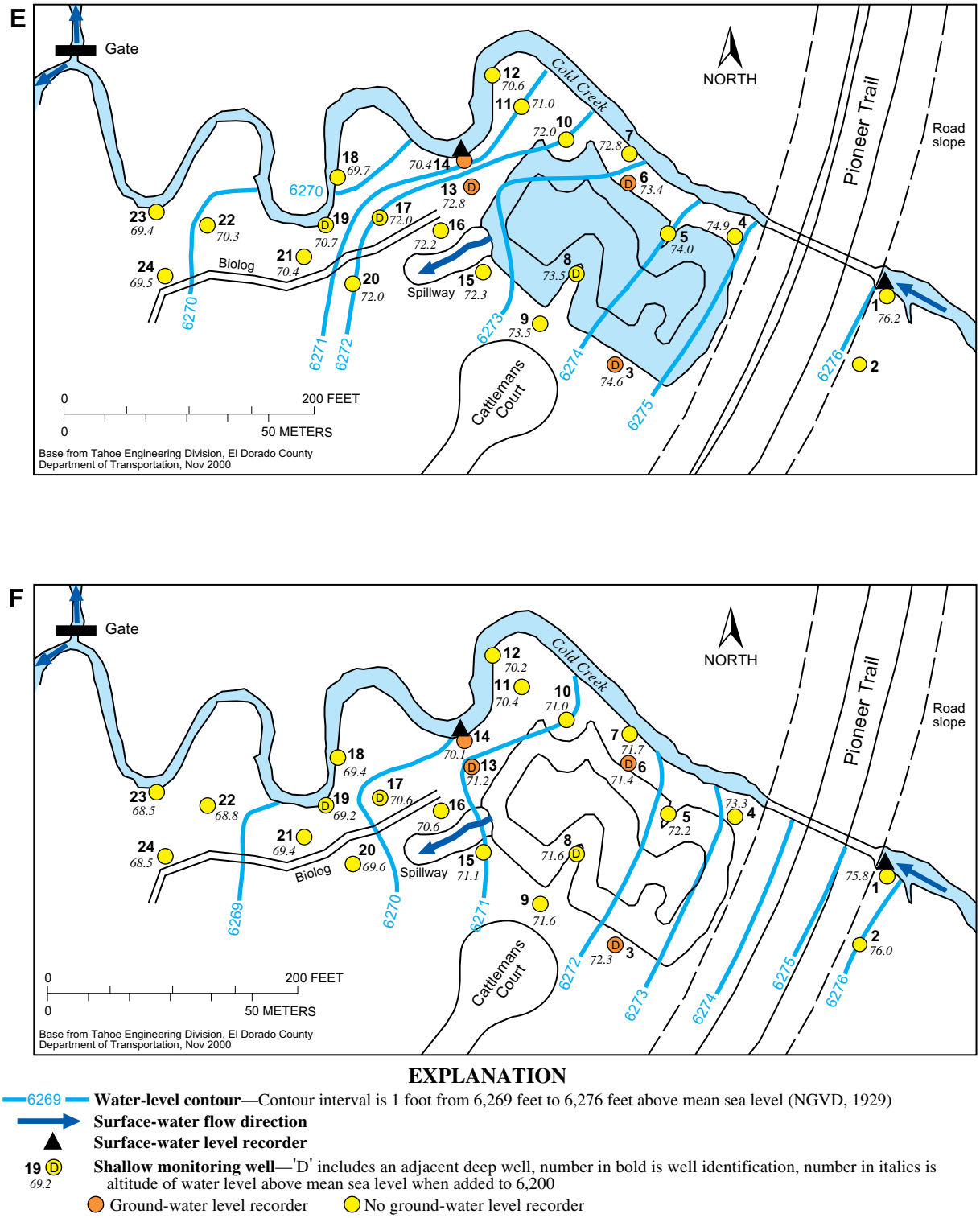
Surface-water level recorder

19 D 69.1 **Shallow monitoring well**—'D' includes an adjacent deep well, number in bold is well identification, number in italics is altitude of water level above mean sea level when added to 6,200

Ground-water level recorder No ground-water level recorder

Figure 6. Contours of ground-water levels at Cattlemans detention basin for selected dates. (A) May 9, 2001—no basin; (B) October 24, 2001—basin empty; (C) April 10, 2002—basin full; (D) October 4, 2002—basin empty; (E) March 27, 2003—basin full; and (F) October 16, 2003—basin empty—Continued.

Well identifications have been abbreviated by omitting the "cc" part of the name.



EXPLANATION

6269 **Water-level contour**—Contour interval is 1 foot from 6,269 feet to 6,276 feet above mean sea level (NGVD, 1929)

Surface-water flow direction

Surface-water level recorder

19 D 69.2 **Shallow monitoring well**—'D' includes an adjacent deep well, number in bold is well identification, number in italics is altitude of water level above mean sea level when added to 6,200

Ground-water level recorder

No ground-water level recorder

Figure 6. Contours of ground-water levels at Cattlemans detention basin for selected dates. (A) May 9, 2001—no basin; (B) October 24, 2001—basin empty; (C) April 10, 2002—basin full; (D) October 4, 2002—basin empty; (E) March 27, 2003—basin full; and (F) October 16, 2003—basin empty—Continued.

Well identifications have been abbreviated by omitting the "cc" part of the name.

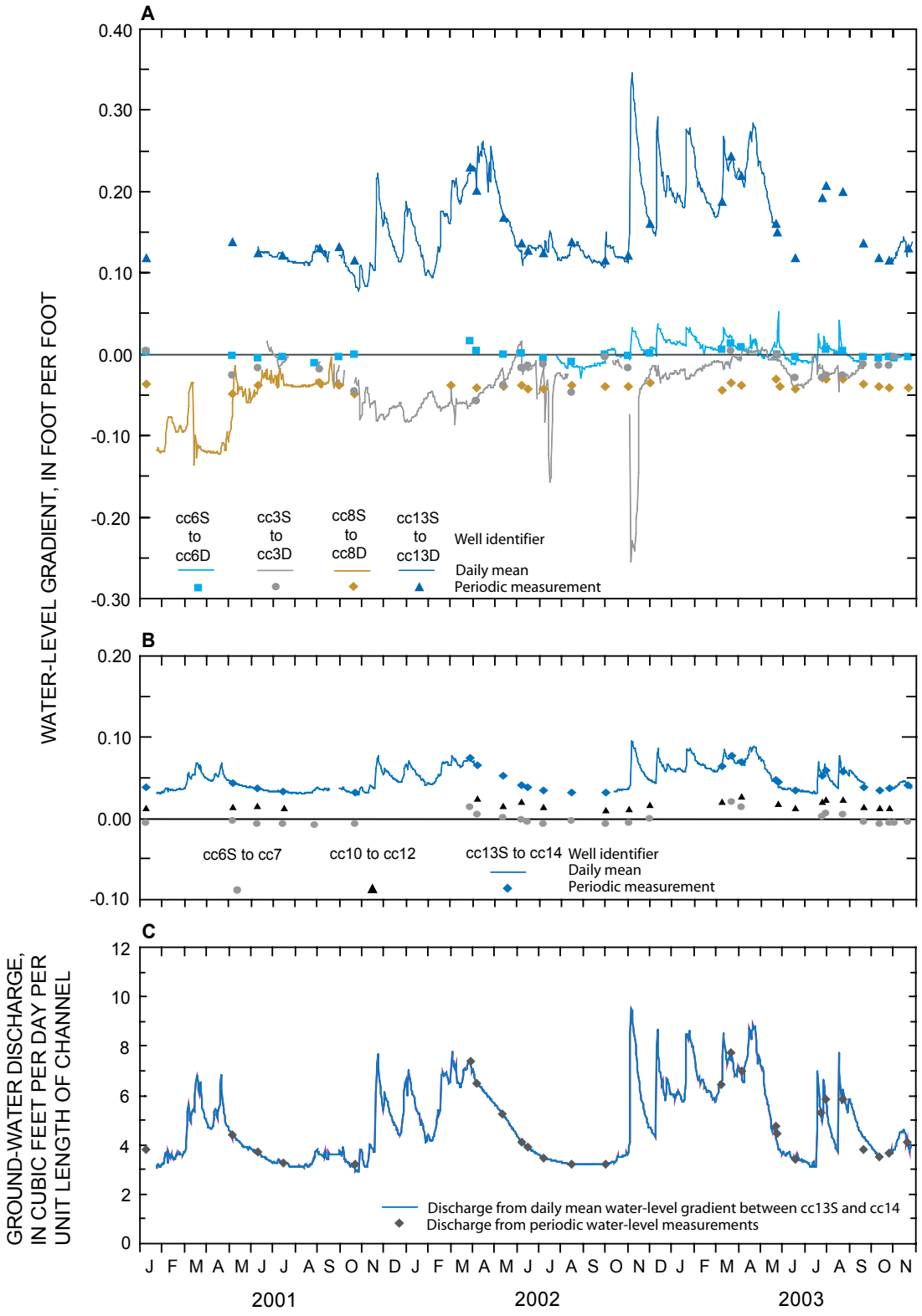


Figure 7. Ground-water gradients and ground-water discharge near Cattlemans detention basin. (A) ground-water gradients between shallow and deeper wells next to detention basin; (B) ground-water gradients between shallow wells next to detention basin and next to Cold Creek; and (C) daily ground-water discharge to Cold Creek next to well cc14.

Locations of wells are shown in figure 2.

a minimum of 0.03 ft/ft in January, August, and October to a maximum of 0.06 ft/ft in March and April. The maximum daily gradients increased to 0.07 ft/ft in March and April of 2002 and were as much as 0.09 ft/ft following runoff into the basin in November 2002. The gradients during the summer of 2002 and 2003 generally decreased to 0.03 ft/ft, although storms on July 23 and August 26, 2003 temporarily increased the gradient to 0.07 ft/ft (fig. 7B).

Changes in Flow to Cold Creek

Ground-water flow from the area near well cc13S to Cold Creek next to well cc14 was estimated by applying Darcy's Law, which can be expressed as:

$$Q = KA\,{}^{dh}/_{dl}, \qquad (1)$$

where:

Q is the volumetric rate of ground-water flow, in cubic feet per day;

K is the hydraulic conductivity of the meadow deposits between the detention basin and Cold Creek, in feet per day;

A is the area of ground-water flow, in square feet; and

${}^{dh}/_{dl}$ is the ground-water gradient, in foot per foot.

The area of the meadow deposits that contribute flow to Cold Creek was assumed to be the saturated thickness of the meadow deposits near Cold Creek (about 5 ft) as determined from well logs (Green and others, 2004) times a unit length (1 ft) of the channel. A hydraulic conductivity of 20 ft/d was used in the calculation, and was based on the median value determined from slug-test analyses of 27 wells (Green and others, 2004). Hydraulic conductivities ranged from 0.5 to 70 ft/d. The highest estimates of hydraulic conductivity were at wells cc6S and cc6D. The hydraulic conductivity at wells cc13S and cc14 were estimated at 20 ft/d. The estimated daily discharge to Cold Creek near well 14 ranged from about 3 to 10 ft^3/d per unit length of channel (fig. 7C). The length of the channel that receives ground-water flow is assumed to be about 135 ft and limited to the reach from well cc12 to about 35 ft downstream of well cc14. Estimated ground-water discharge to Cold Creek ranges from about 400 to 1,400 ft^3/d or from 0.005 to 0.02 ft^3/s. This is a small fraction of the estimated daily mean discharge of Cold Creek at Pioneer Trail, which ranged from 3 to 40 ft^3/s (Stockton and others, 2004; fig. 8). Ground-water discharge was increased by a factor of 4 when a value of 80 ft/d was used for hydraulic conductivity (fig. 8).

Using the range in estimated ground-water discharge shown in figure 8, the annual mean ground-water discharge ranged from 0.006 to 0.024 ft^3/s for water year 2001, from 0.007 to 0.029 ft^3/s for water year 2002, and 0.009 to 0.035 ft^3/s for water year 2003. Periods of missing data were prorated between measured gradients. A constant rate of 0.005 ft^3/s was assumed from October 1, 2000 to January 24, 2001, before data collection began, that was equal to the average rate from January 24, 2001 to when snowmelt began in March 2001. The ground-water discharge was small compared with the annual mean discharge of Cold Creek, which was 6.96 ft^3/s during water year 2002 and 8.89 ft^3/s during water year 2003 (Stockton and others, 2004, p. 338-340).

Runoff into the detention basin extended the period of increased ground-water flow from well cc13S to well cc14. Increased ground-water discharge to Cold Creek was limited to the snowmelt period from March to May during 2001, whereas a combination of increased precipitation and runoff into the detention basin extended the period from November to May during water years 2002 and 2003. Summer thunderstorms in July and August 2003 caused additional increases in ground-water discharge (fig. 7C).

Changes in Ground-Water Quality

Chemical Composition

The chemical composition of ground water in the area of the detention basin for two years after completion of the detention basin did not change substantially from analyses of samples collected before completion of the detention basin (tables 1 and 2). Water collected from deeper wells in the brown sand and gravel had a similar chemical composition as water from shallow wells in the meadow deposits, except sulfate concentrations generally were higher and dissolved iron concentrations were about two times less (tables 1 and 2). The principal dissolved cations remained sodium, iron, and calcium, and the principal dissolved anions were bicarbonate and chloride in both the shallow and deeper wells. Comparisons of the range in concentrations of selected dissolved constituents for the shallow wells in the meadow deposits before and after completion of the detention basin are shown graphically in figure 9.

The median and mean sulfate concentrations analyzed of samples collected from shallow wells in the meadow deposits remained near 0.4 mg/L after completion of the detention basin (table 1), although concentrations increased periodically in wells cc3S and cc14. Dissolved oxygen concentrations were low (<0.3 mg/L). The low sulfate and dissolved oxygen concentrations indicate that shallow ground water in the meadow deposits remained largely anoxic after completion of the detention basin. The median and mean chloride concentrations increased slightly after completion of the detention basin (fig. 9). The likely source of the chloride is from the application of a mixture of cinders and salt (sodium chloride) used to prevent icing of the surface streets during the winter (Prudic and others, 2005). The highest concentration of chloride before completion of the detention basin was 104 mg/L in a sample collected from well cc21 on May 10, 2001. The source of this chloride in the meadow west of the detention basin was uncertain; however, chloride concentrations of 160 and 114 mg/L were analyzed from samples collected in April and May 2002 from wells cc9 and cc15, respectively. The source of the high chloride concentrations in these wells most likely is

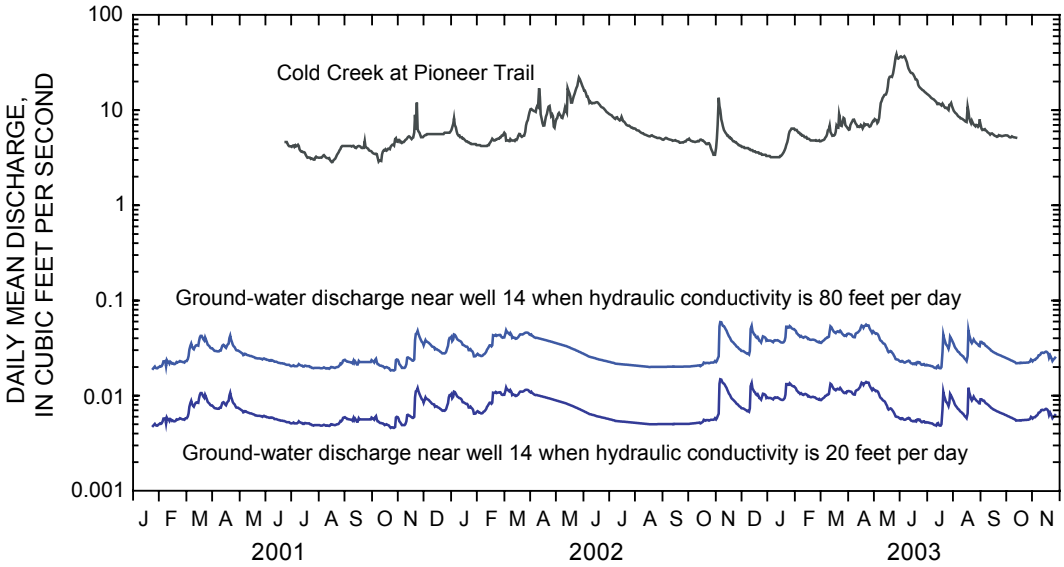


Figure 8. Comparison of daily mean ground-water discharge to Cold Creek below Cattlemans detention basin near well cc14 with daily mean discharge of Cold Creek at Pioneer Trail, South Lake Tahoe, California. Locations of well cc14 and streamflow gage on Cold Creek at Pioneer Trail (near well cc1) are shown in figure 2.

from runoff that enters a sump at the end of Cattlemans Court. The sump is used for the purpose of settling coarse sediments in the runoff before discharging the runoff through a culvert into the detention basin. The sump is not sealed at the bottom and much of the runoff that enters it recharges ground water near well cc9 (see fig. 2). In the past, runoff from Cattlemans Court would flow northwestward past well cc15 and into the meadow and may explain the relatively high concentrations of chloride in the meadow at well cc21.

Trace elements were analyzed in ground-water samples collected before completion of the detention basin and for the first year after completion (table 3). Concentrations of the trace elements did not change after completion of the detention basin and most were below laboratory reporting limits. Thus, only trace elements bromide, iron, and manganese routinely were analyzed after October 2002.

Seasonal variations in the chemical composition of ground water show different patterns depending on location of the well with respect to the detention basin (fig. 10). Peak concentrations of bicarbonate, chloride, sodium, and iron in ground water from meadow deposits at well cc3S generally occurred in April and May of each year, whereas peak concentrations at well cc8S generally occurred later during June and July. Other than seasonal variations, concentrations of most constituents did not change substantially except for bicarbonate concentrations at well cc8S. At well cc8S, bicarbonate concentrations slowly decreased during the two-year period after completion of the detention basin in August and September 2001 (fig. 10). The decrease in bicarbonate concentrations at well cc8S may be related to a change in microbial activity in the meadow deposits beneath the detention basin.

Although peak concentrations for most dissolved constituents in ground water from well cc13S occurred in July (similar to the timing of peak concentrations at well cc8S), bicarbonate concentrations decreased seasonally in July after completion of the detention basin (fig. 10). The chloride concentration peaked in July 2002 at a concentration greater than either well cc3S or well cc8S. One possibility is ground water near well 9 mixed with chloride-rich water from the detention basin. Most of the urban runoff into the detention basin was from the 30-in. diameter culvert on Pioneer Trail (see fig. 2), whereas runoff from Cattlemans Court mostly infiltrated into the ground at the large sump at the end of the cul-de-sac as suggested by the large increases in chloride concentration at wells cc9 and cc15. Another possibility is that during the spring and summer, ground-water beneath the detention basin near and east of well pair cc8S and cc8D may have discharged into the detention basin because of the upward gradients at well pairs cc8S and cc8D, and cc3S and cc3D, whereas west of well pair cc8S and cc8D, water in the pond seeped into the meadow deposits as indicated by the downward gradient at well pair cc13S and cc13D. The change from an upward gradient to a downward gradient beneath the detention basin between well cc8S and cc13S may be caused by an abrupt thickening of the unconsolidated deposits.

Trends in dissolved constituents differed considerably at well cc14 compared with the other wells (fig. 10). Peak concentrations generally occurred from October to March when the water-level gradient was the greatest between wells cc13S and cc14 (fig. 7B). Assuming that the peak chloride concentration in well cc14 in October 2002 was from the transport of the peak chloride concentration in well cc13S in July 2002,

Table 1. Comparison of dissolved inorganic constituents and properties in ground water from shallow wells sampled before completion of Cattlemans detention basin (January to November 2001) with ground water sampled for two years after completion of detention basin (December 2001 to November 2003)

[Units of measure and symbols: µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; —, not determined]

Constituent	Ground water from shallow wells before detention basin[1] (concentrations in milligrams per liter)				Ground water from shallow wells after detention basin[2] (concentrations in milligrams per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Silica (SiO_2)	12	18	28	18	7	18	28	17
Iron (Fe)	0.66	15	60	19	1.1	14	59	17
Calcium (Ca)	4.5	10	32	14	3.3	11	32	13
Magnesium (Mg)	0.68	1.6	5.3	2.3	0.50	1.8	5.1	2.2
Sodium (Na)	6.7	25	43	22	9.2	22	66	24
Potassium (K)	0.67	2.0	7.6	2.5	0.75	2.2	7.5	2.6
Bicarbonate (HCO_3)	46	100	270	120	40	85	259	100
Sulfate (SO_4)	0.1	0.4	0.8	0.4	0.1	0.2	5.9	0.6
Chloride (Cl)	3.0	31	104	31	9.1	36	160	41
Bromide (Br)	<0.02	0.12	1.2	0.19	<0.02	0.22	0.82	0.26
Fluoride (F)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Organic carbon (DOC)	2.5	5.2	14	5.5	2.3	5.8	15	6.6
Dissolved oxygen (DO)	0.1	0.3	2.4	0.4	0.1	0.3	2.1	0.3
pH (standard units)	5.8	6.5	6.9	—	5.5	6.4	7.0	—
Specific conductance (µS/cm)	84	260	550	280	120	280	520	280
Dissolved solids	61	130	340	160	77	170	320	180

[1]Water was sampled from shallow wells before and during completion of detention basin (Prudic and others, 2005). Values are based on 34 samples collected from wells cc3S, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, and cc21 between January and November 2001, except for ironand dissolved oxygen, which are based on 70 and 54 samples, respectively, collected from wells cc1, cc3S, cc4, cc5, cc6S, cc7, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, cc16, cc17S, cc18, cc19S, cc20, cc21, cc22, cc23, and cc24. Locations of wells are shown in figure 2.

[2]Water was sampled from shallow wells after completion of detention basin. Values are based on 58 samples collected between December 2001 and November 2003 except for iron iron and dissolved oxygen, which are based on 131 and 36 samples, respectively, collected from wells cc1, cc3S, cc4, cc5, cc6S, cc7, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, cc16, cc17S, cc18, cc19S, cc20, cc21, cc22, cc23, and cc24.

Table 2. Comparison of dissolved inorganic constituents in ground water from deeper wells sampled before completion of Cattlemans detention basin (January to November 2001) with ground water sampled for two years after completion of detention basin (December 2001 to November 2003)

[Units of measure and symbols: µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; —, not determined]

Constituent	Ground water from deeper wells before detention basin[1] (concentrations in milligrams per liter)				Ground water from deeper wells after detention basin[2] (concentrations in milligrams per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Silica (SiO_2)	15	22	26	20	12	21	24	19
Iron (Fe)	0.035	5.9	19	8.3	0.024	8.9	29	9.8
Calcium (Ca)	5.6	11	20	11	5.4	11	22	11
Magnesium (Mg)	0.82	1.9	3.2	1.9	0.88	1.8	3.7	2.0
Sodium (Na)	15	26	63	31	13	24	59	30
Potassium (K)	1.2	1.7	2.2	1.7	1.4	1.8	2.9	1.9
Bicarbonate (HCO_3)	60	73	99	77	58	76	104	81
Sulfate (SO_4)	0.3	1.1	3.4	1.4	0.2	1.0	7.0	1.5
Chloride (Cl)	5.5	33	96	40	9.2	32	94	41
Bromide (Br)	<0.02	0.065	0.34	0.1	<0.02	0.085	0.44	0.13
Fluoride (F)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Organic carbon (DOC)	1.2	2.0	5.8	2.2	0.9	2.2	8.3	2.6
Dissolved oxygen (DO)	0.2	0.4	1.0	0.5	0.1	0.4	0.7	0.4
pH (standard units)	6.2	6.5	6.8	—	6.2	6.7	7.1	—
Specific conductance (µS/cm)	160	260	350	270	160	240	450	270
Dissolved solids	82	150	240	150	90	150	240	160

[1]Water was sampled from deeper wells before and during completion of detention basin. Values are based on 12 samples collected from wells cc3D, cc8D, and cc13D between January and November 2001, except for iron and dissolved oxygen, which are based on 20 and 17 samples, respectively, collected from wells cc3D, cc6D, cc8D, cc13D, cc17D, and cc19D. Locations of wells are shown in figure 2.

[2]Water was sampled from deeper wells after completion of detention basin. Values are based on 18 samples collected between December 2001 and November 2003 except for iron and dissolved oxygen, which are based on 35 and 15 samples, respectively, collected from the same wells as before detention basin.

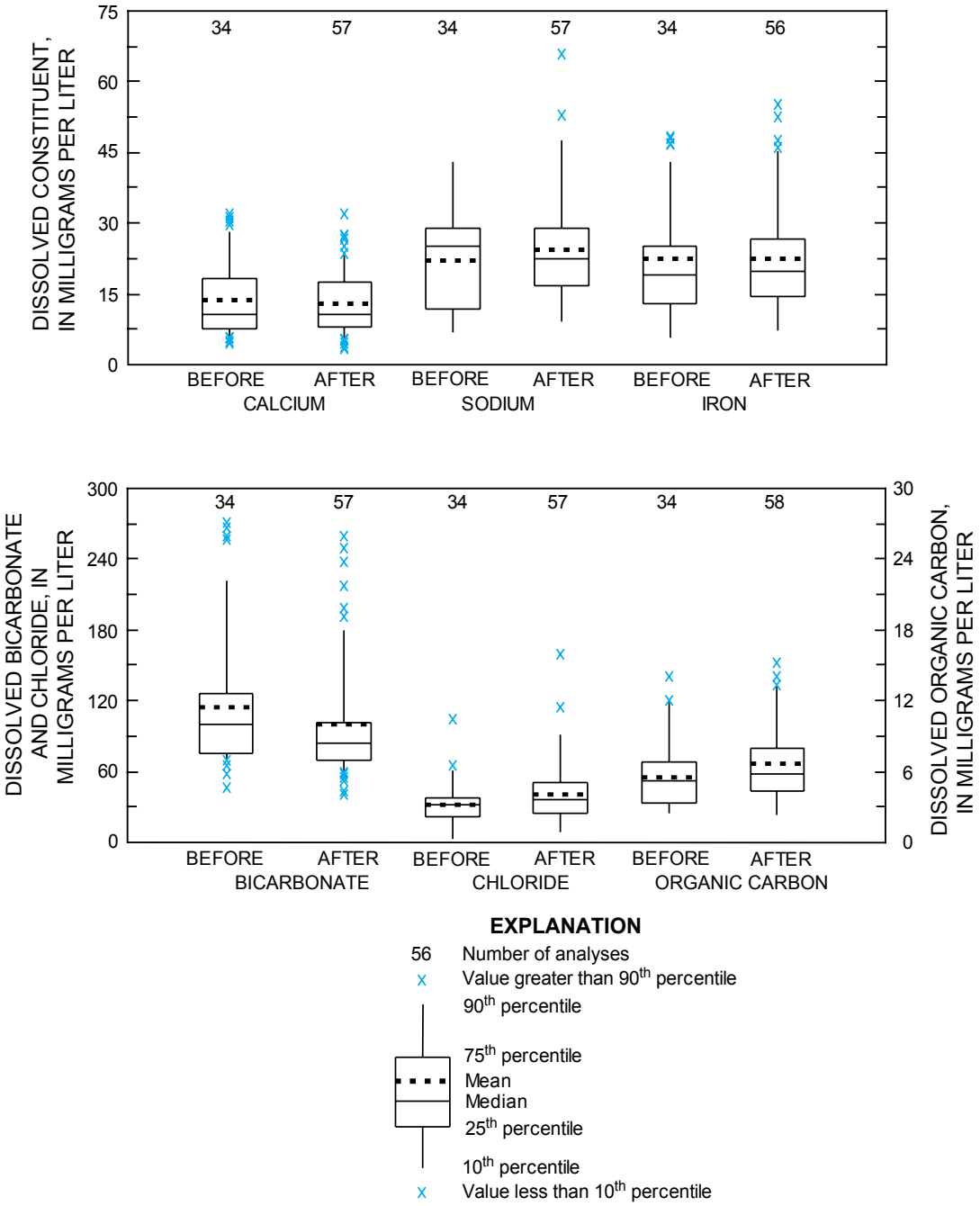


Figure 9. Changes in concentrations of selected dissolved constituents in ground water from shallow wells before completion (January 2001 to November 2001) and for two years after completion of Cattlemans detention basin (December 2001 to November 2003).

Dissolved constituents are based on samples collected from wells cc3s, cc8s, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, and cc21. Locations of wells are shown in figure 2.

the estimated traveltime between the two wells was about 0.3 ft/d (30 ft between wells and 105 days between sample dates). This estimate is an order of magnitude lower than that estimated from Darcy's Law using a mean gradient of 0.04 ft/ft (during July and October 2002), a hydraulic conductivity of 20 ft/d, and a porosity of 0.3. The difference in estimated rates probably was caused by infrequent sampling dates at the wells. Thus, the peak chloride concentration at well cc13S probably occurred after July 2, 2002, and the peak chloride concentration at well cc14 probably occurred before October 16, 2002.

Nutrient Concentrations

Nutrient concentrations in ground water from the meadow deposits did not change substantially after completion of the detention basin (table 4). Ammonia was the most common form of nitrogen both before and after completion of the detention basin. Concentrations ranged from 0.004 to 18 mg/L before completion and 0.001 to 15 mg/L after completion. Nitrate plus nitrite concentrations remained substantially the same and were always less than 0.33 mg/L. There were slight increases in the median and mean concentrations of dissolved phosphorus, orthophosphate, and organic carbon, although the range in the concentrations did not change substantially (table 4).

Nutrient concentrations of ground water in the meadow deposits were divided into three groups to evaluate changes resulting from the different locations of the wells. The three groups were: (1) wells near the detention basin (wells cc3S, cc4, cc5, cc6S, cc8S, cc9, cc10, cc13S, cc15, and cc16); wells near Cold Creek (wells cc1, cc7, cc12, cc14, cc18, cc19S, and cc23); and wells in the meadow (wells cc17S, cc20, cc21, cc22, and cc24). Distributions of nutrient concentrations within each group before and after completion of the detention basin are shown in figure 11. Total dissolved nitrogen concentrations were highest in the area of the detention basin before its completion and remained high after completion of the detention basin. Concentrations of total dissolved nitrogen were anomalous at well cc8S both before and after completion of the detention basin. Total dissolved nitrogen concentrations in shallow ground water generally were the same near Cold Creek and in the meadow.

Dissolved phosphorus concentrations generally were higher in wells near Cold Creek than in the area of the detention basin or in the meadow (fig. 11). Five of the seven wells along Cold Creek were placed in areas of suspected ground-water discharge to the creek (wells cc12, cc14, cc18, cc19S, and cc23). The higher dissolved concentrations along the creek in areas of suspected ground-water discharge are consistent with increasing dissolved phosphorus in the direction of ground-water flow observed before completion of the detention basin (Prudic and others, 2005). Except for the anomalously high dissolved iron concentrations at well cc8S in the middle of the detention basin, iron concentrations were similar

Table 3. Concentrations of dissolved inorganic trace elements in ground water sampled from shallow wells before completion of Cattlemans detention basin (January to November 2001) and ground water sampled for one year after completion of detention basin (December 2001 to November 2002)

[Symbol: <, less than]

Constituent	Ground water from shallow wells before detention basin[1] (concentrations in micrograms per liter)				Ground water from shallow wells after detention basin[2] (concentrations in micrograms per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Aluminum (Al)	4	11	65	22	3	15	62	19
Antimony (Sb)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.08	<0.05
Arsenic (As)	<2	<2	5	<2	<2	<2	5	<2
Barium (Ba)	6.1	22	100	33	10	26	110	36
Beryllium (Be)	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Cadmium (Cd)	<0.04	<0.04	0.14	0.05	<0.04	<0.04	0.4	0.07
Chromium (Cr)	<0.8	<0.8	1.7	<0.8	<0.8	<0.8	1.0	<0.8
Cobalt (Co)	0.04	0.82	3.3	0.94	0.04	0.50	3.2	0.81
Copper (Cu)	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Lead (Pb)	<0.08	<0.08	0.44	0.09	<0.08	<0.08	<0.08	<0.08
Manganese (Mn)	59	230	1,500	390	84	260	1,600	390
Molybdenum (Mo)	1.7	6.0	39	8.5	1.4	5.0	39	8.3
Nickel (Ni)	<0.06	<0.06	0.49	0.15	<0.06	0.30	0.86	0.35
Selenium (Se)	<2.4	<2.4	<2.4	<2.4	<2	<2	<2	<2
Silver (Ag)	<1	<1	<1	<1	<1	<1	<1	<1
Uranium (U)	0.7	2.1	30	4.2	0.6	2.9	14	3.4
Zinc (Zn)	<2	<2	<2	<2	<1	<1	7	2

[1]Water was sampled from shallow wells between January and November 2001. Values are based on 34 samples collected from wells cc3S, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, and cc21. Locations of wells are shown in figure 2.

[2]Water was sampled from shallow wells between December 2001 and November 2002. Values are based on 28 samples collected from same wells as before detention basin, except manganese, which is based on 58 samples collected from same wells between December 2001 and November 2003.

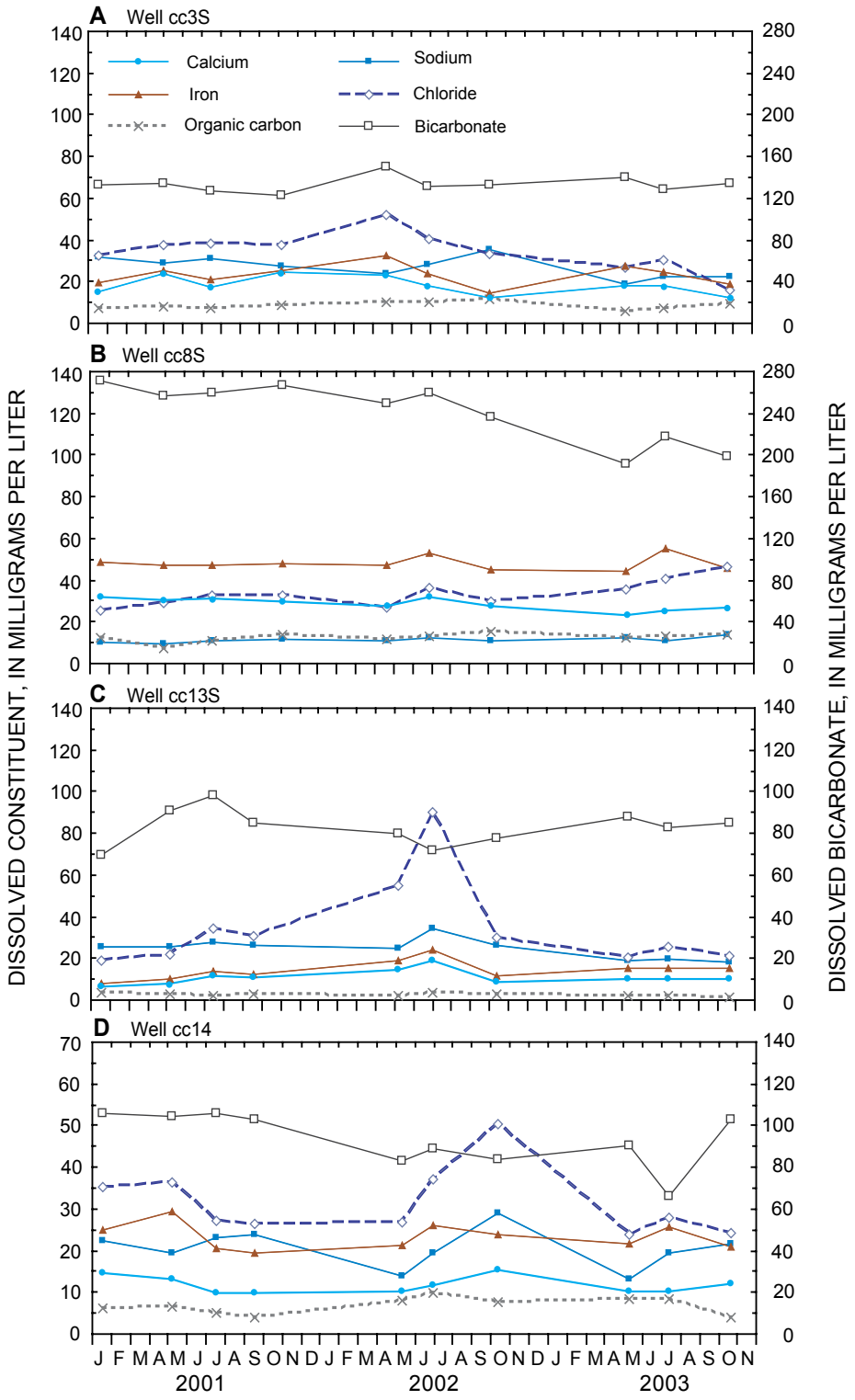


Figure 10. Trends in concentrations of selected dissolved constituents in ground water from shallow wells (A) cc3S, (B) cc8S, (C) cc13S, and (D) cc14 at Cattlemans detention basin from January 2001 to November 2003.

Locations of wells are shown in figure 2.

in all three groups. The relatively high iron concentrations of ground water in the meadow deposits are consistent with anoxic conditions.

Concentrations of nutrients in the deeper sand and gravel before and after completion of the detention basin are summarized in table 5. In general, mean and median concentrations increased slightly for dissolved nitrogen, phosphorus, and organic carbon, although the ranges in concentrations were similar. The slight increase in the mean and median concentrations in the deeper sand and gravel may be an artifact of the limited number of samples that were analyzed before and after completion of the detention basin.

Dissolved nitrogen and phosphorus in ground water within the meadow deposits varied depending on location and season (fig. 12). Ammonia generally was the dominant form of nitrogen before and after completion of the detention basin. Nitrate and nitrite concentrations were but a small fraction of the dissolved nitrogen. There were no consistent trends in nitrogen concentrations. Ammonia concentrations at wells cc8S, cc14, and cc16 decreased during April and May after completion of the detention basin. Organic nitrogen concentrations generally increased during the summer and fall, as did nitrate and nitrite, and were higher than ammonia at well cc14 during the summer and fall of 2003. Generally, orthophosphate had similar concentrations as dissolved phosphorus except for specific dates at some wells (for example, January 2001 and July 2002 at well cc8S and July 2002 at well cc21). This contrasts with a consistent pattern of little orthophosphate at wells cc14 and cc16 before completion of the detention basin and much higher concentrations afterwards (fig. 12). The change in the concentration of orthophosphate at wells cc14 and cc16 suggests that additional flow through the detention basin may be affecting the orthophosphate concentrations of ground water in the meadow deposits below the detention basin.

Cold Creek

Chemical Composition

Water samples were collected from Cold Creek above the detention basin, upstream of Pioneer Trail near well cc1, and below the detention basin next to well cc14 (fig. 2). The first sample was collected in September 2001. The samples were analyzed for major and trace constituents, dissolved organic carbon, and dissolved nutrients. The results are summarized in table 6.

Total dissolved solids in Cold Creek (above and below the detention basin) were considerably less than those in the ground water from the meadow deposits (compare table 6 with table 1). In general, mean and median concentrations were slightly higher for most major and trace constituents in Cold Creek below the detention basin compared with those above the detention basin (except silica, calcium, chloride, and bicarbonate). Concentrations of dissolved iron and manganese were consistently higher in Cold Creek below the detention basin compared with concentrations above the detention basin (fig. 13), whereas concentrations of sodium, sulfate, and chloride were not consistently higher or lower below the detention basin compared to concentrations above the detention basin.

Table 4. Comparison of dissolved nutrient concentrations in ground water from shallow wells sampled before completion of Cattlemans detention basin (January to November 2001) with ground water sampled for two years after completion of detention basin (December 2001 to November 2003)

Dissolved nutrient	Ground water from shallow wells before detention basin[1] (concentrations in milligrams per liter)				Ground water from shallow wells after detention basin[2] (concentrations in milligrams per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Ammonia (NH^3) as nitrogen (N)	0.004	0.31	18	1.5	0.001	0.28	15	1.0
Nitrate (NO^3) + nitrite (NO^2) as N	0.002	0.054	0.3	0.075	0.004	0.063	0.25	0.073
Ammonia (NH^3) + organic nitrogen as N	0.04	0.44	18	1.9	0.04	0.58	16	1.5
Phosphorus (P)	0.006	0.10	0.34	0.12	0.01	0.12	0.41	0.13
Orthophosphate as P	0.001	0.022	0.34	0.069	0.001	0.094	0.38	0.11
Organic carbon (DOC)	2.5	5.2	14	5.5	2.3	5.8	15	6.6

[1]Water was sampled from shallow wells between January and November 2001. Nitrogen and phosphorus concentrations are based on 70 samples collected from wells cc1, cc3S, cc4, cc5, cc6S, cc7, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, cc16, cc17S, cc18, cc19S, cc20, cc21, cc22, cc23, and cc24. Organic carbon concentrations are based on 34 samples collected from wells cc3S, cc8S, cc9, cc10, cc11, cc12, cc13S, cc14, cc15, and cc21. Locations of wells are shown in figure 2.

[2]Water was sampled from shallow wells between December 2001 and November 2003, after completion of detention basin. Nitrogen and phosphorus concentrations are based on 134 samples collected from same wells as before detention basin. Organic carbon concentrations are based on 58 samples.

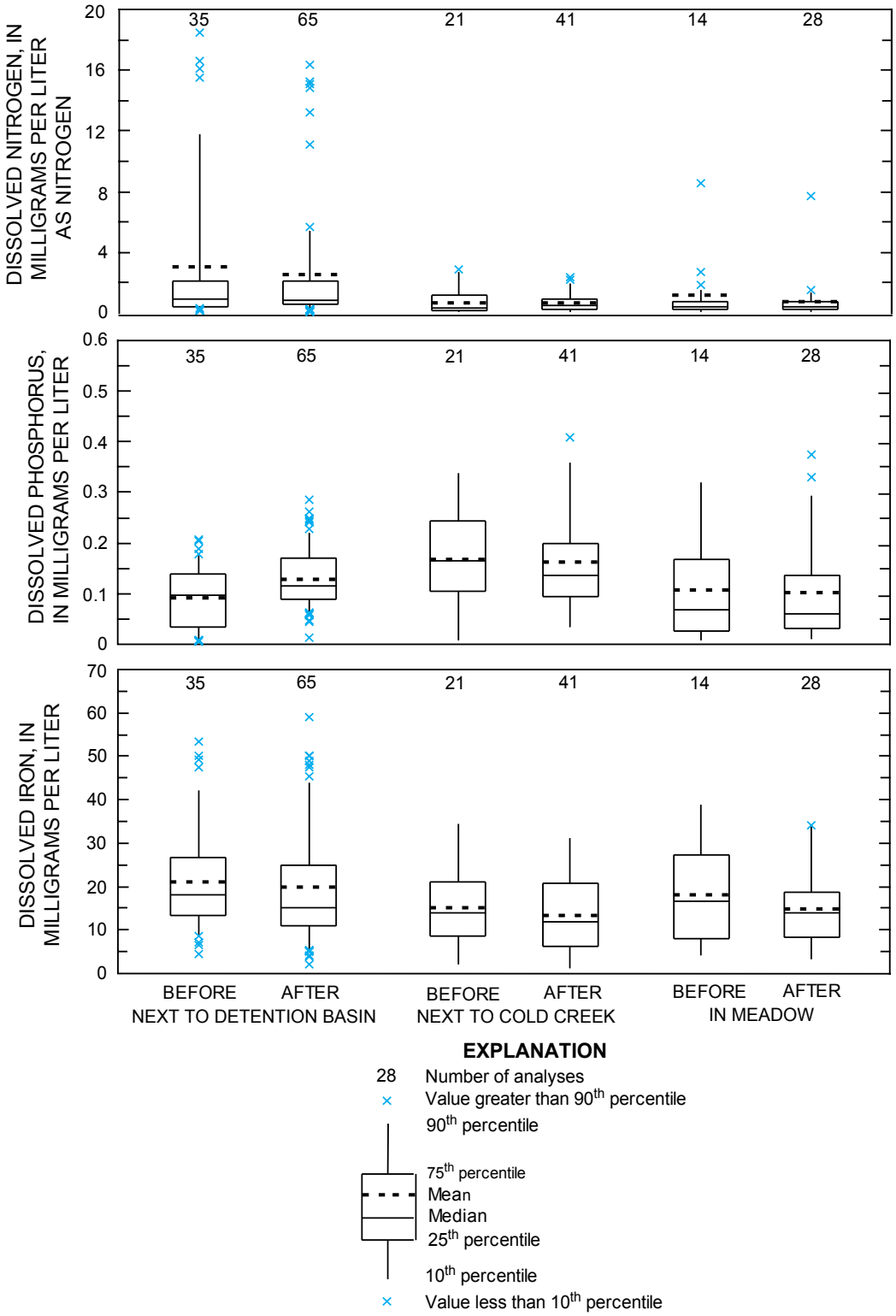


Figure 11. Changes in concentrations of dissolved nitrogen, phosphorus, and iron in ground water from shallow wells next to Cattlemans detention basin, next to Cold Creek, and in meadow before completion (January 2001 to November 2001) and for two years after completion of detention basin (December 2001 to November 2003)

Table 5. Comparison of dissolved nutrient concentrations in ground water from deeper wells sampled before completion of Cattlemans detention basin (January to November 2001) with ground water sampled for two years after completion of detention basin (December 2001 to November 2003)

Dissolved nutrient	Ground water from deeper wells before detention basin[1] (concentrations in milligrams per liter)				Ground water from deeper wells after detention basin[2] (concentrations in milligrams per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Ammonia (NH_3) as nitrogen (N)	0.01	0.062	0.64	0.15	0.008	0.09	0.60	0.16
Nitrate (NO_3) + nitrite (NO_2) as N	0.004	0.043	0.12	0.047	0.007	0.051	0.19	0.066
Ammonia (NH_3) + organic nitrogen as N	0.015	0.14	0.64	0.22	0.012	0.27	1.2	0.33
Phosphorus (P)	0.004	0.025	0.40	0.056	0.002	0.055	0.35	0.090
Orthophosphate as P	0.001	0.005	0.40	0.039	0.002	0.019	0.35	0.063
Organic carbon (DOC)	1.2	2.0	5.8	2.2	0.9	2.2	8.3	2.6

[1]Water was sampled from deeper wells between January and November 2001. Nitrogen and phosphorus concentrations are based on 21 samples collected from wells cc3D, cc6D, cc8D, cc13D, cc17D, and cc19D. Organic carbon concentrations are based on 12 samples collected from wells cc3D, cc8D, and cc13D. Locations of wells are shown in figure 2.

[2]Water was sampled from deeper wells between December 2001 and November 2003, after completion of the detention basin. Nitrogen and phosphorus concentrations are based on 35 samples collected from same wells as before detention basin. Organic carbon concentrations are based on 18 samples collected from same wells as before detention basin.

Sulfate was nearly absent in ground water from the meadow deposits so the source of higher sulfate in Cold Creek below the detention basin during September 2001 and September 2003 is uncertain. The higher sodium and chloride concentrations below the detention basin correspond to increased sodium and chloride concentrations measured in well cc14 during 2002 (see fig. 10D).

Assuming that the increase in dissolved chloride in Cold Creek below the detention basin between May and October 2002 was from ground-water discharge near well cc14, the estimated daily ground-water discharge during that period was determined from the chloride-balance method expressed as:

$$Cl_{gw}(Q_{gw}) = Cl_{bl}(Q_{ab}+Q_{gw})-Cl_{ab}(Q_{ab}), \qquad (2)$$

where:

Cl_{gw} is the mean chloride concentration in ground water, (mg/L);

Q_{gw} is the mean ground-water discharge, (ft^3/s);

Cl_{bl} is the mean chloride concentration in Cold Creek below detention basin, (mg/L);

Q_{ab} is the mean discharge of Cold Creek above detention basin, (ft^3/s); and

Cl_{ab} is the mean chloride concentration in Cold Creek above detention basin, (mg/L).

The mean chloride concentration at well cc14 between May 2002 and October 2002 was 38 mg/L, the mean chloride concentration in Cold Creek below the detention basin near well cc14 was 0.58 mg/L, and the mean concentration above the detention basin was 0.42 mg/L. The mean discharge of Cold Creek above the detention basin during the same period was 8.0 ft^3/s. The estimated ground-water discharge to Cold Creek between wells cc1 and cc14 using these data was 0.034 ft^3/s. This estimate is slightly more than the range of 0.007 to 0.029 ft^3/s estimated for the same period using the daily mean gradient between wells cc13S and cc14 (fig. 7B), a range in hydraulic conductivity between 20 and 80 ft/d, a thickness of 5 ft, and a distance along the channel of 135 ft. The chloride-balance method integrates contributions from both sides of Cold Creek and because another but smaller detention basin was constructed on the opposite side of Cold Creek north of Cattlemans detention basin, some additional chloride may have discharged as ground water along the northern side of Cold Creek. Nevertheless, increases in dissolved constituents (particularly iron and manganese) in Cold Creek above and below the detention basin are likely the result of ground-water discharge into Cold Creek. The area of discharge from Cattlemans detention basin is concentrated between wells cc12 and cc14, and between wells cc18 and cc19S (fig. 6).

An estimate of ground-water discharge above and below the detention basin can also be calculated using dissolved iron similar to that of chloride in equation 2 and assuming that dissolved iron in ground water does not precipitate in the streambed as a result of mixing with the oxygenated water in Cold Creek. The mean concentration of dissolved iron in Cold Creek above and below the detention basin during the period May to October 2002 was 0.053 and 0.090 mg/L, respectively, and the mean concentration in ground water from well cc14 was 22.8 mg/L. Using these concentrations in place of chloride in equation 2 yields an estimate of 0.013 ft^3/s, which is within the range estimated from Darcy's Law (equation 1).

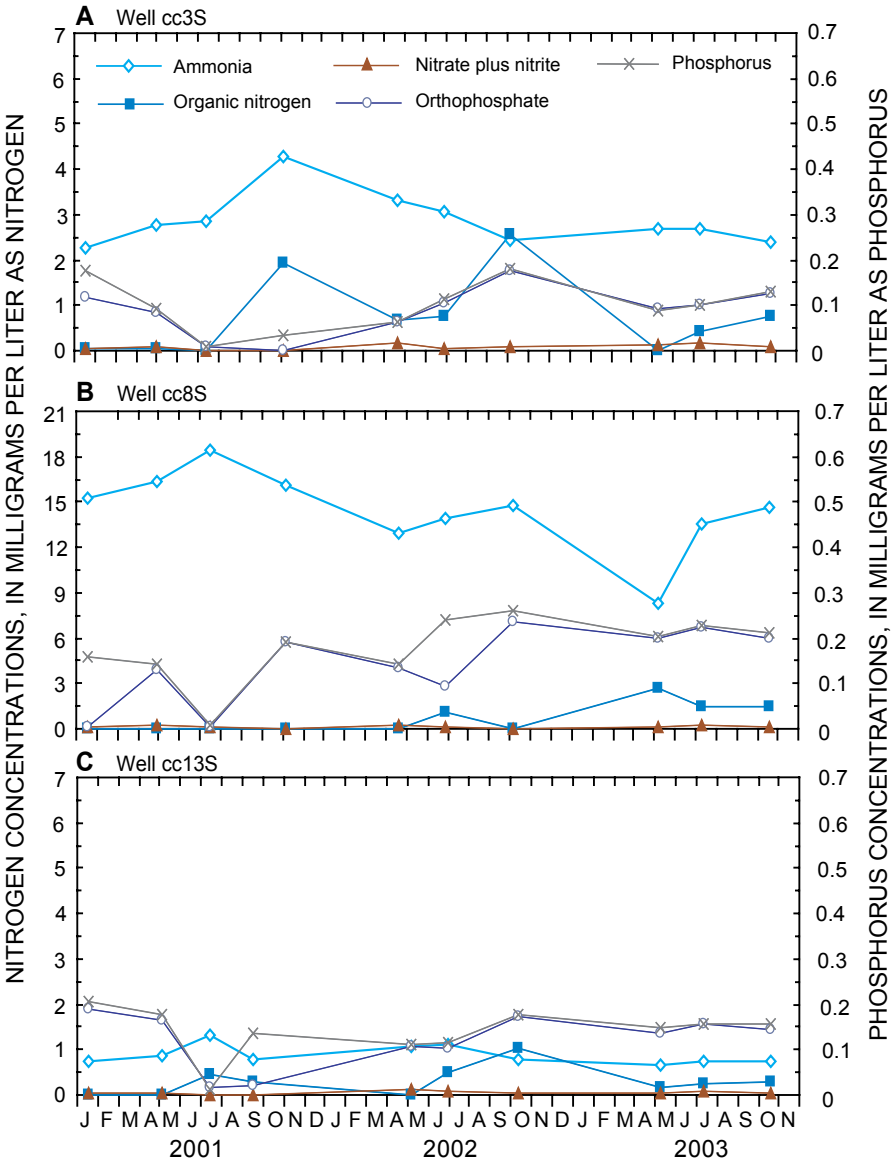


Figure 12. Trends in concentrations of dissolved nutrients in ground water from shallow wells (A) cc3S, (B) cc8S, (C) cc13S, (D) cc14,(E) cc16, and (F) cc21 at Cattlemans detention basin from January 2001 to November 2003.

Locations of wells are shown in figure 2.

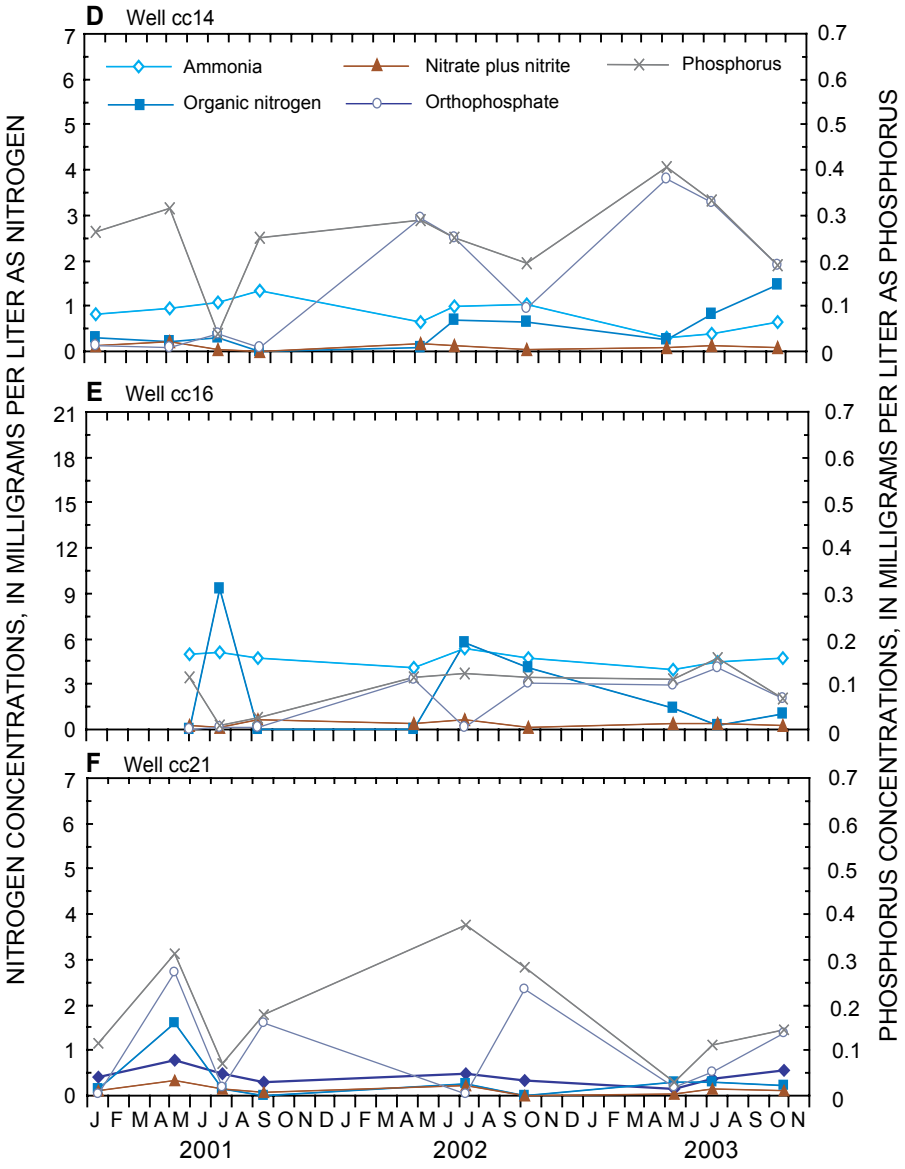


Figure 12. Trends in concentrations of dissolved nutrients in ground water from shallow wells (A) cc3S, (B) cc8S, (C) cc13S, (D) cc14,(E) cc16, and (F) cc21 at Cattlemans detention basin from January 2001 to November 2003—Continued.

Locations of wells are shown in figure 2.

Table 6. Comparison of dissolved constituents and properties in water from Cold Creek above and below detention basin

[Units of measure and symbols: µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; —, not determined]

Constituent	Cold Creek above detention basin[1] (concentrations in milligrams per liter)				Cold Creek below detention basin[1] (concentrations in milligrams per liter)			
	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum	Mean
Silica (SiO_2)	14	16	17	16	14	16	17	16
Aluminum (Al)	0.003	0.009	0.015	0.009	0.003	0.012	0.018	0.011
Iron (Fe)	0.028	0.053	0.092	0.053	0.042	0.091	0.131	0.084
Manganese (Mn)	0.0014	0.0022	0.0032	0.0021	0.0016	0.0028	0.0048	0.0029
Calcium (Ca)	3.3	4.2	5.5	4.3	3.3	4.2	5.5	4.3
Magnesium (Mg)	0.46	0.61	0.63	0.59	0.47	0.62	0.67	0.60
Sodium (Na)	3.2	3.9	5.1	4.0	3.2	4.0	5.0	4.1
Potassium (K)	0.71	0.87	0.99	0.86	0.70	0.92	1.0	0.90
Bicarbonate (HCO_3)	17	22	24	22	18	21	24	21
Sulfate (SO_4)	1.2	1.6	2.3	1.7	1.1	1.9	2.3	1.8
Chloride (Cl)	0.23	0.54	0.75	0.49	0.29	0.48	1.0	0.56
Uranium natural (U)	0.0024	0.0037	0.0042	0.0035	0.0029	0.0037	0.0049	0.0037
Ammonia (NH_3) as nitrogen (N)	<0.001	0.0075	0.019	0.0089	<0.001	0.0021	0.011	0.0037
Ammonia (NH_3) + organic nitrogen as (N)	0.10	0.11	0.18	0.13	0.07	0.10	0.11	0.10
Nitrate (NO_3) + nitrite (NO_2) as (N)	0.001	0.013	0.029	0.013	0.003	0.014	0.022	0.013
Phosphorus (P)	0.010	0.015	0.019	0.015	0.012	0.017	0.024	0.017
Orthophosphate as P	0.006	0.008	0.011	0.008	0.005	0.007	0.009	0.007
Organic carbon (DOC)	0.7	1.8	4.3	2.0	0.8	2.2	4.2	2.3
Dissolved oxygen (DO)	6.7	8.9	9.3	8.4	4.8	7.1	10	7.3
pH (standard units)	5.8	6.5	6.9	—	6.0	6.8	7.4	—
Specific conductance (µS/cm)	36	43	45	42	38	42	47	42
Dissolved solids	32	42	45	40	30	44	46	42

[1]Values are based on 6 samples collected between September 2001 and November 2003. Bromide and fluoride were consistently below laboratory reporting limits. Sampling locations are shown in figure 2.

However, some dissolved iron in ground water likely precipitates onto the streambed because the rocks in the streambed are stained with iron oxide (Prudic and others, 2005).

Nutrient Concentrations

The median and mean concentrations of Kjeldahl nitrogen (ammonia and ammonia plus organic nitrogen) in Cold Creek generally decreased from above to below the detention basin and nitrate plus nitrite was consistently low (<0.03 mg/L; table 6). Concentrations of total dissolved nitrogen were nearly the same in Cold Creek above and below the detention basin during the spring and summer of 2002 but were considerably less below the detention basin in October 2002 and May 2003 (fig. 14) even though ground-water discharge contributed additional nitrogen, including nitrate and nitrite (see table 4 for range in nitrate plus nitrite and fig. 12D for nutrient concentrations at well cc14). The lack of higher nitrogen concentrations below the detention basin is unknown but may be caused by microbial activity in the creek or its streambed.

Dissolved phosphorus in Cold Creek above and below the detention basin follow the same pattern as dissolved phosphorus in ground water at shallow wells completed in the meadow deposits (fig. 12A–F). Concentrations generally peaked in May and decreased during the summer and fall and into the winter (sample collected in January 2003; fig. 14). Phosphorus concentrations below the detention basin generally were higher than those above the detention basin during the spring (May) and fall (September and October) but were less in July 2002. The decrease in phosphorus from above to below the detention basin in July 2002 may be caused by increased microbial activity in the creek or its streambed during the warm summer months compared with decreased microbial activity during the cooler spring and fall. The decrease in phosphorus concentrations in Cold Creek below the detention basin is consistent with a marked decrease in dissolved organic carbon from May to July both above and below the creek (fig. 14) even though organic carbon generally increased in well cc14 during the spring and summer (fig. 10D). Higher dissolved organic carbon during the spring (May) and lower concentrations during the summer and fall generally followed the same pattern as dissolved phosphorus. This pattern may reflect more on the microbial or aquatic uptake of nutrients during the warm summer months than on the discharge of nutrients from ground water into Cold Creek.

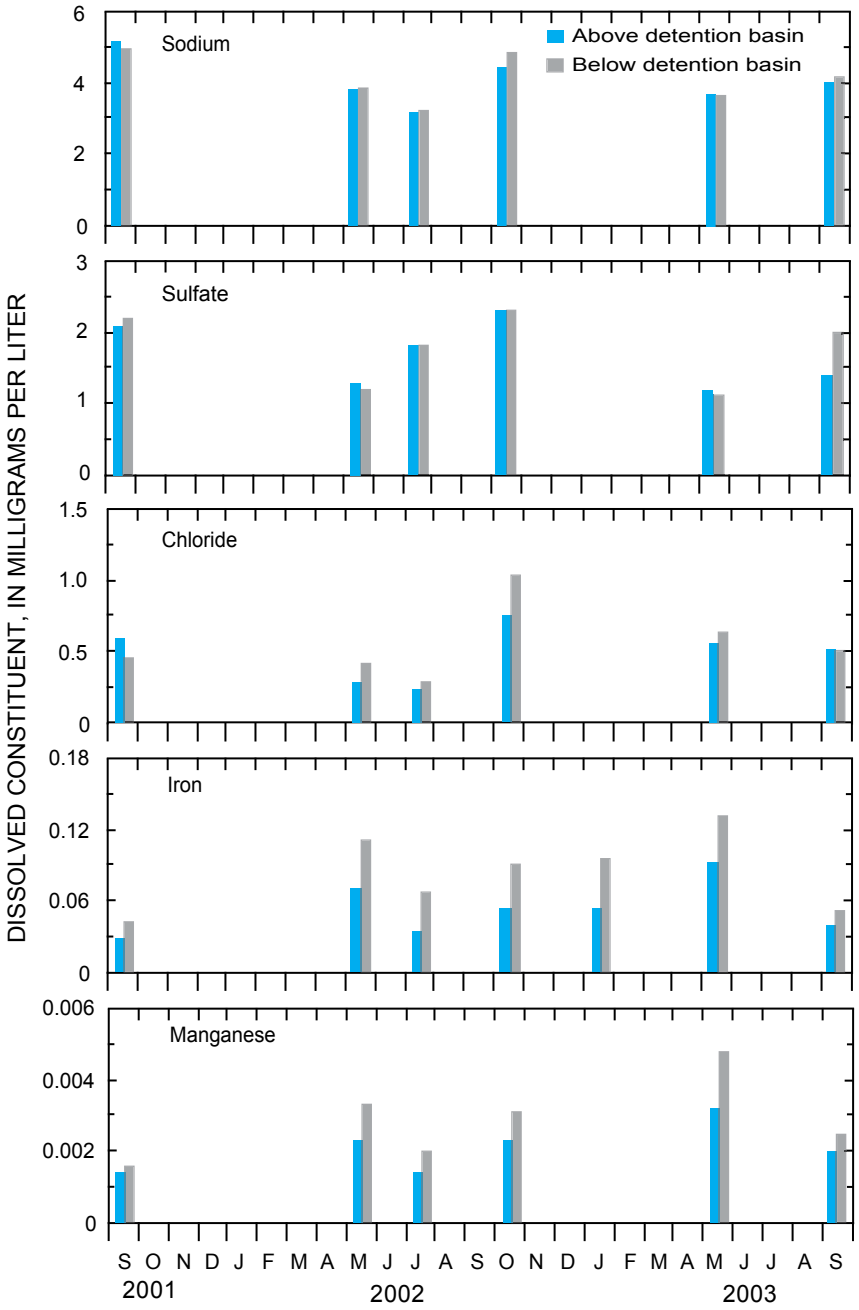


Figure 13. Trends in concentrations of dissolved constituents in Cold Creek above and below Cattlemans detention basin from September 2001 to September 2003.

Sampling location above detention basin was next to well cc1 and sampling location below detention basin was next to well cc14. Locations of wells are shown in figure 2.

Nutrient Loads

Nutrient loads from ground-water discharge to Cold Creek were estimated for the reach between wells cc12 and cc14 by multiplying annual ground-water discharge presented in the section "Changes in Flow to Cold Creek" with annual mean nutrient concentrations at well cc14 for water years 2001, 2002, and 2003 (table 7). Well cc14 is immediately next to Cold Creek in the area of ground-water discharge (fig. 6). Total dissolved nitrogen and iron concentrations in well cc14 generally remained unchanged before and after completion of the detention basin, and consequently, estimated loads for these nutrients increased from 2001 to 2003 because of the increase in ground-water discharge. Contrastingly, the mean concentration of dissolved phosphorus and organic carbon increased from water year 2001 to 2003. The estimated increase in loads for water years 2002 and 2003 of these nutrients is a combination of increased concentrations and increased ground-water discharge. Mean nutrient concentrations are included in table 7.

Except for iron, the estimated loads from ground water discharging to Cold Creek (table 7) were but a fraction of the estimated loads in Cold Creek above the detention basin (table 8). Stream discharge and nutrient loads in Cold Creek above the detention basin were mostly from ground-water discharge to Cold Creek in the upland areas above Pioneer Trail (Allander, 2004). Although the concentrations of dissolved nitrogen and phosphorus were an order of magnitude less than the concentrations in ground water, the much greater annual mean discharge of Cold Creek compared with the ground-water discharge results in dissolved nutrient loads in Cold Creek that were much greater than the loads estimated from ground-water discharge below the detention basin. Dissolved iron loads from ground-water discharge are a much larger fraction of the dissolved load in Cold Creek. These iron loads result in consistently higher dissolved iron concentrations measured in Cold Creek below the detention basin (table 6 and fig. 13).

Summary and Conclusions

Detention basins commonly are used to minimize sediment and nutrient loads from urban runoff in the Lake Tahoe Basin. However, the potential exists for degrading water quality in ground water beneath detention basins and associated wetlands. Because effects of detention basins on changes in ground-water flow and chemistry are largely unknown in the Lake Tahoe Basin, a study at Cattlemans detention basin in South Lake Tahoe, California began in November 2000, about 1 year before completion of the detention basin. The purpose of the study was to determine the effectiveness of the detention basin in reducing sediment and nutrient loads from urban runoff to nearby Cold Creek, including the transport of nutrients through ground water. The study was done in cooperation with the Tahoe Engineering Division, El Dorado County Department of Transportation and the California Tahoe Conservancy. This report summarizes changes in: (1) ground-water flow; (2) ground-water discharge to Cold Creek; (3) ground-water quality; and (4) comparison of ground-water nutrient loads to Cold Creek with dissolved nutrient loads in Cold Creek for a two-year period after completion of the detention basin.

Because of a concern for nutrient transport through ground water from the detention basin to Cold Creek, a series of 30 monitoring wells were installed during November and December 2000. Data collection summarized in this report includes measurements of ground-water levels from January 2001 to November 2003; analyses of dissolved major and trace constituents including organic carbon in ground water from 13 selected wells and in Cold Creek above and below the detention basin; and analyses of dissolved nitrogen, phosphorus, and iron in all wells and in Cold Creek above and below the detention basin.

Cattlemans detention basin is adjacent to Cold Creek at the head of a large meadow. Cold Creek is the largest tributary to Trout Creek, which is the second largest stream that discharges into Lake Tahoe. The drainage above the detention basin is largely undeveloped and is composed primarily of granodiorite and glacial deposits. The detention basin was constructed during August and September 2001 to capture runoff from Pioneer Trail and a neighboring subdivision. No runoff enters Cold Creek directly. Overflow from the detention basin is routed into the large meadow.

The principal aquifer beneath the detention basin consists of sand and gravel lenses within unconsolidated deposits. Meadow deposits that are 5 to 8 ft thick consist of a gray silt and sand with lenses of sand and gravel. Beneath the gray silt and sand is a brown sand and gravel with lenses of silt and sand. Total thickness of unconsolidated deposits ranges from 6 ft near the upper edge of the meadow east of the detention basin to 80 ft west of the detention basin.

Ground-water levels beneath the detention basin and in the adjacent meadow were highest in the spring and lowest in late summer and early fall. The general direction of ground-water flow remained persistent from east to west across the detention basin even when runoff into and precipitation on the detention basin during water years 2002 and 2003 caused an increase in ground-water levels along the western side of the basin. The vertical gradient between paired wells in the middle and southeast end of the detention basin remained generally upward after completion of the detention basin. The vertical gradient between paired wells on the west edge of the detention basin was consistently downward, even before completion of the detention basin. The consistent downward gradient as compared with the upward gradient near the middle of the detention basin indicates an abrupt thickening of the unconsolidated deposits. This allows ground water from the detention basin to flow underneath Cold Creek. Continued thickening of the unconsolidated deposits further downstream probably causes ground water beneath the detention basin to gradually flow deeper into the deposits.

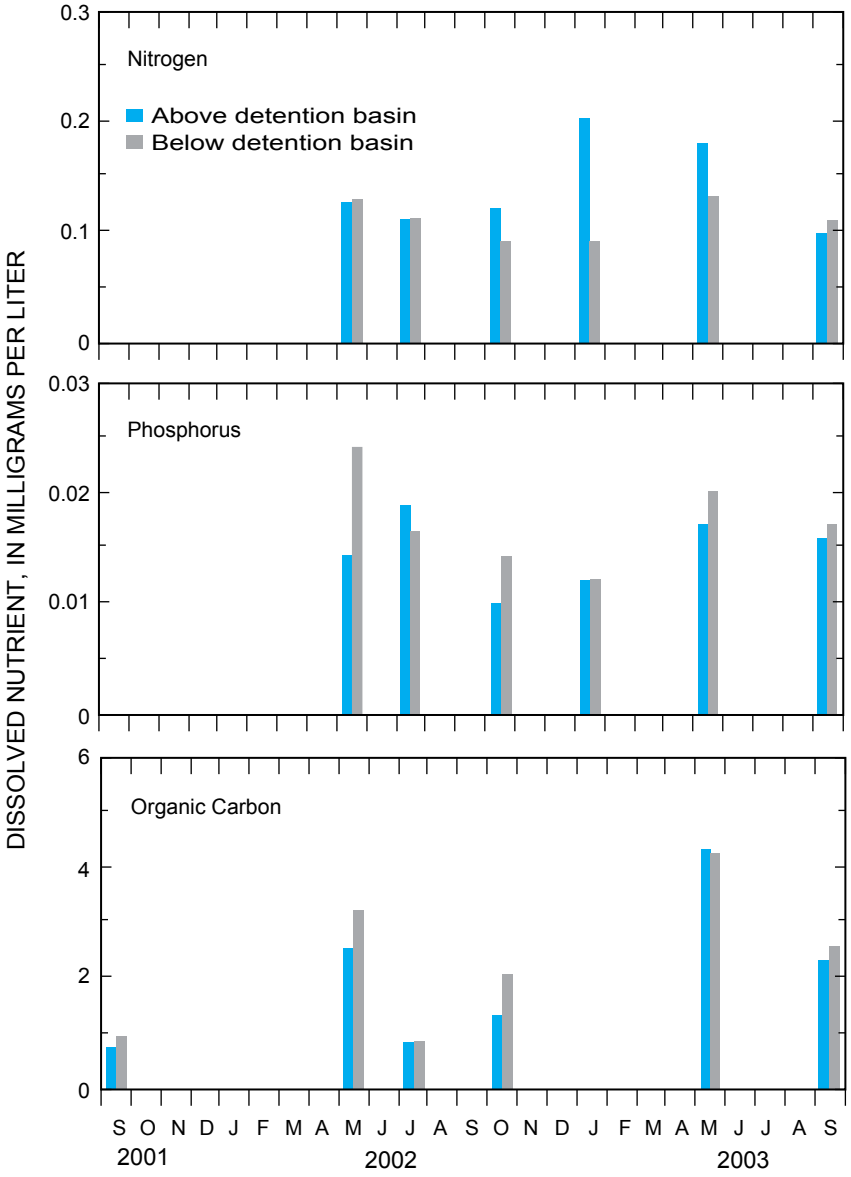


Figure 14. Trends in concentrations of dissolved nutrients in Cold Creek above and below Cattlemans detention basin from September 2001 to September 2003.

Sampling location above detention basin was next to well cc1 and sampling location below detention basin was next to well cc14. Locations of wells are shown in figure 2.

Table 7. Estimates of dissolved nitrogen, phosphorus, iron, and organic carbon loads from ground-water discharge to Cold Creek below detention basin for water years 2001–2003

[Abbreviations: mg/L, milligrams per liter; lbs, pounds]

Dissolved constituent	Water year 2001		Water year 2002		Water year 2003	
	Mean concentration[1] (mg/L)	Load[2] (lbs)	Mean concentration[1] (mg/L)	Load[2] (lbs)	Mean concentration[1] (mg/L)	Load[2] (lbs)
Nitrogen (N)	1.3	15–61	1.5	24–86	1.4	24–97
Phosphorus (P)	0.22	2.6–10	0.24	3.8–14	0.31	5.5-21
Iron (Fe)	26	310–1,200	23	360–1,300	24	430–1,700
Organic carbon (DOC)	6.0	70–280	7.4	120–420	8.3	150–570

[1]Mean concentration of each dissolved constituent in ground water at well cc14. Mean concentrations were from four analyses in water year 2001, and three analyses each from water years 2002 and 2003. Well cc14 is adjacent to Cold Creek in an area of ground-water discharge to Cold Creek (see fig. 6).

[2]Loads of dissolved constituents to Cold Creek from ground-water discharge below detention basin were multiplied by the mean concentration in well cc14 and corrected for units. Ground-water discharge was calculated by summing daily discharge estimates calculated using Darcy's Law (see equation 1) and using: (1) the daily water-level gradient between wells cc13S and cc14, (2) a range in hydraulic conductivity of 20 to 80 feet per day, (3) a thickness of the meadow deposits of 5 feet, and (4) a length of channel where ground-water discharged of 135 feet. Annual ground-water discharge to Cold Creek below the detention basin near well cc14 ranged from 0.006 to 0.024 cubic feet per second for water year 2001; from 0.007 to 0.029 cubic feet per second for water year 2002, and from 0.009 to 0.035 cubic feet per second for water year 2003 (see section titled "Changes in Flow to Cold Creek").

Table 8. Comparison of nitrogen, phosphorus, iron, and organic carbon loads from ground-water discharge to Cold Creek below detention basin with dissolved loads in Cold Creek above detention basin for water years 2002 and 2003

[Abbreviations: mg/L, milligrams per liter; lbs, pounds]

Dissolved constituent	Load from ground-water discharge below detention basin[1]		Load in Cold Creek above detention basin[2]			
			Water year 2002		Water year 2003	
	Water year 2002	Water year 2003				
	Load (lbs)	Load (lbs)	Mean concentration (mg/L)	Load (lbs)	Mean concentration (mg/L)	Load (lbs)
Nitrogen (N)	24–86	24–97	0.12	1,700	0.16	2,800
Phosphorus (P)	3.8–14	5.5–21	0.014	200	0.015	260
Iron (Fe)	360–1,300	430–1,700	0.053	730	0.062	1,100
Organic carbon (DOC)	120–420	150–570	1.5	21,000	3.3	58,000

[1]Loads of dissolved constituents to Cold Creek are from table 7.

[2]Loads of dissolved constituents in Cold Creek above detention were estimated from annual mean discharge of 6.96 cubic feet per second in water year 2002 and 8.89 cubic feet per second in water year 2003 (Stockton and others, 2004, p. 338–340), and mean concentration of each dissolved constituent in Cold Creek above detention basin.

Water in Cold Creek seeped into the shallow meadow deposits near wells 6 and 7 before completion of the detention basin. However, the gradient reversed after completion of the detention basin whenever the detention basin was filled with water. The ground-water gradient in the meadow deposits was always toward Cold Creek on the western side of the detention basin, even after completion of the detention basin, indicating ground-water discharged to the creek. Much of this ground-water discharge was focused along a man-made meander immediately west of the detention basin.

The estimated annual mean ground-water discharge along the man-made meander was two to three orders of magnitude less than the annual mean discharge of Cold Creek for water years 2002 and 2003. Ground-water discharge to Cold Creek increased during the snowmelt period, which in water year 2001 was limited to the period from March to May. The combination of greater precipitation in water years 2002 and 2003 than 2001 and the impoundment of runoff in the detention basin extended the period of increased ground-water discharge from November to May during water years 2002 and 2003.

The chemical composition of ground water for two years after completion of the detention basin did not change from the chemical composition of ground water before completion of the detention basin. Concentrations of dissolved constituents generally were lower in the deeper sand and gravel. The principal dissolved cations remained sodium, iron, and calcium, and the principal dissolved anions were bicarbonate and chloride. Nutrient concentrations in ground water from the meadow deposits also did not change after completion of the detention basin. Ammonia remained the most common form

of nitrogen and ranged from 0.001 to 15 mg/L. Nitrate plus nitrite concentrations were always less than 0.33 mg/L. There were slight increases in the mean and median concentrations of dissolved phosphorus, orthophosphate, and organic carbon, although the range in the concentrations did not change substantially.

The estimated nutrient loads from ground-water discharge were at least two orders of magnitude less than the estimated annual load of dissolved nutrients in Cold Creek above the detention basin. Although the concentrations of dissolved nitrogen and phosphorus in Cold Creek were an order of magnitude less than the concentrations in ground water, the much greater annual mean discharge of Cold Creek compared with the ground-water discharge below the detention basin resulted in the large difference in estimated loads. The dissolved iron load from ground-water discharge was a larger fraction of the dissolved iron load in Cold Creek, which is consistent with the increased dissolved iron measured in Cold Creek from above to below the detention basin.

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