In cooperation with the El Dorado County Department of Transportation, Tahoe Engineering Unit and California Tahoe Conservancy

The Effectiveness of Cattlemans Detention Basin, South Lake Tahoe, California

Scientific Investigations Report 2006-5259

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

Cover Photo: Cattlemans detention basin. Photograph by James L. Wood.

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Edited By Jena M. Green

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
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)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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

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

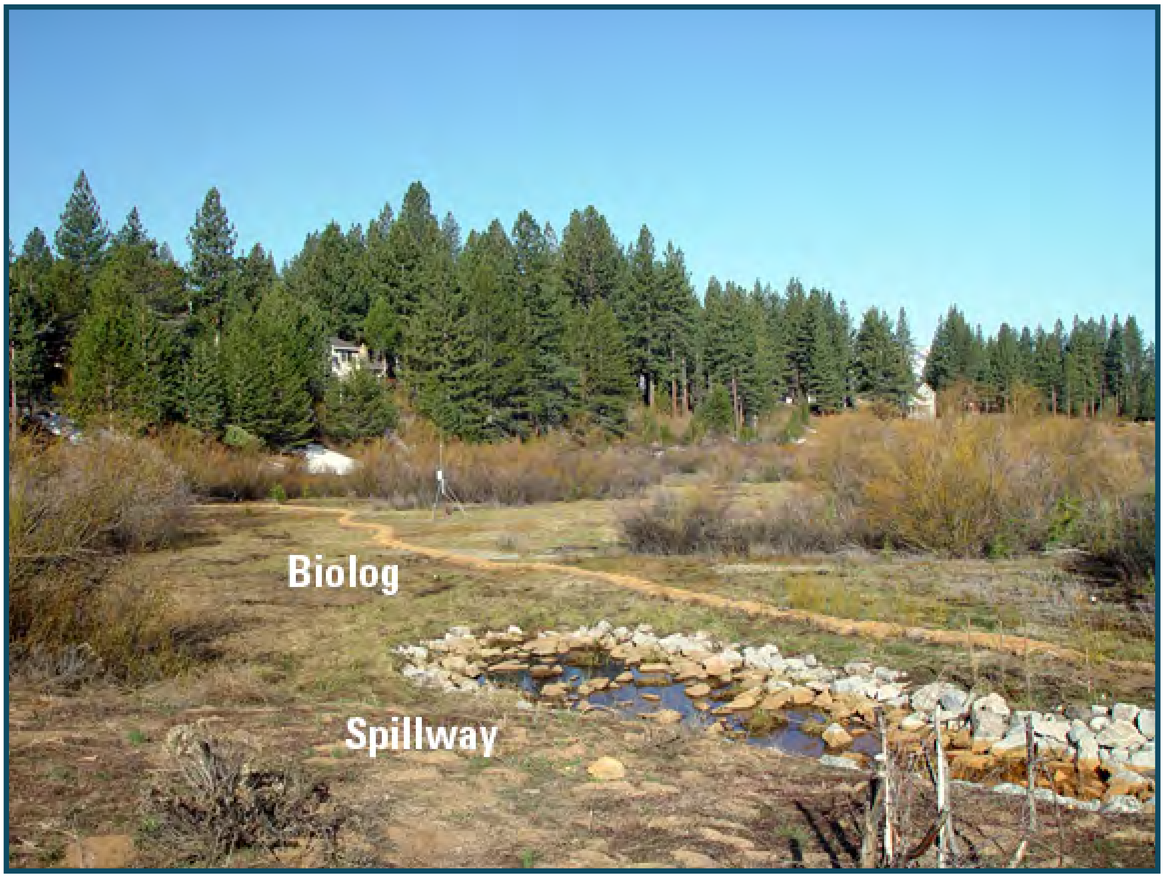
Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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).

Cattlemans detention basin looking southwest. Photograph by James L. Wood.



Southwest side of Cattlemans detention basin showing spillway and biolog. Photograph by Jena M. Green.

The Effectiveness of Cattlemans Detention Basin, South Lake Tahoe, California

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Abstract

Lake Tahoe (Nevada-California) has been designated as an “outstanding national water resource” by the U.S. Environmental Protection Agency, in part, for its exceptional clarity. Water clarity in Lake Tahoe, however, has been declining at a rate of about one foot per year for more than 35 years. To decrease the amount of sediment and nutrients delivered to the lake by way of alpine streams, wetlands and stormwater detention basins have been installed at several locations around the lake. Although an improvement in stormwater and snowmelt runoff quality has been measured, the effectiveness of the detention basins for increasing the clarity of Lake Tahoe needs further study. It is possible that poor ground-water quality conditions exist beneath the detention basins and adjacent wetlands, and that the presence of these basins has altered ground-water flow paths to nearby streams. A hydrogeochemical and ground-water flow modeling study was done at Cattlemans detention basin, situated adjacent to Cold Creek, a tributary to Lake Tahoe, to determine whether the focusing of stormwater and snowmelt runoff into a confined area has (1) modified the ground-water flow system beneath the detention basin and affected transport of sediment and nutrients to nearby streams and (2) provided an increased source of solutes which has changed the distribution of nutrients and affected nutrient transport rates beneath the detention basin.

Results of slug tests and ground-water flow modeling suggest that ground water flows unrestricted northwest across the detention basin through the meadow. The modeling also indicates that seasonal flow patterns and flow direction remain similar from year to year under transient conditions. Model results imply that about 34 percent (0.004 ft^3/s) of the total ground water within the model area originates from the detention basin. Of the 0.004 ft^3/s, about 45 percent discharges to Cold Creek within the modeled area downstream of the detention basin. The remaining 55 percent of ground water is either consumed by evapotranspiration, is discharged to Cold Creek outside the modeled area downstream of the detention basin, or is discharged directly to Lake Tahoe. Of the 45 percent discharging to Cold Creek, about 9 percent enters directly downstream of the detention basin and 36 percent enters further downstream.

Geochemical and microbial data suggest that a seasonal variation of chemical constituents and microbe population size is present at most wells. The geochemical data also indicate that construction of Cattlemans detention basin has not substantially changed the composition of the ground water in the area. High concentrations of ammonia, iron, and dissolved organic carbon, low concentrations of sulfate and nitrate, and large populations of sulfate-reducing microbes imply that the major geochemical process controlling nutrient concentrations beneath the detention basin is sulfate reduction. High concentrations of total nitrogen indicate that oxidation of organic carbon is a second important geochemical process occurring beneath the basin. The influx of surface runoff during spring 2002 apparently provided sufficient oxidized organic carbon to produce iron-reducing conditions and an increase in reduced iron, sulfate, and iron-reducing microorganisms. The increase in recharge of oxygenated water to the ground-water system beneath the basin in future intervals of increased recharge may eventually redistribute nutrients and speed up transport of dissolved nutrients from the ground-water system to Cold Creek.

Introduction

Lake Tahoe is a scenic alpine lake and a popular year-round tourist destination. The oval-shaped lake is nearly 22 mi from north to south and 12 mi from east to west and straddles the Nevada-California State line (fig. 1). Ranked tenth deepest lake in the world, it has an average depth of 1,000 ft (greatest depth is 1,645 ft; Crippen and Pavelka, 1970) and has been designated an “outstanding national water resource” by U.S. Environmental Protection Agency (1983). Lake Tahoe has been noted for its exceptional clarity; however, decreasing clarity is a present concern (Coats and others, 2002). This decreasing clarity has been attributed to increased inputs of sediments and nutrients as a result of increased human activity over the last few decades (Crippen and Pavelka, 1970; Goldman and Byron, 1988).

The concern about decreasing lake clarity has resulted in regulations designed to decrease potential sources of sediment and nutrients from reaching the lake. The Tahoe Regional Planning Agency (a bi-state agency) was tasked to

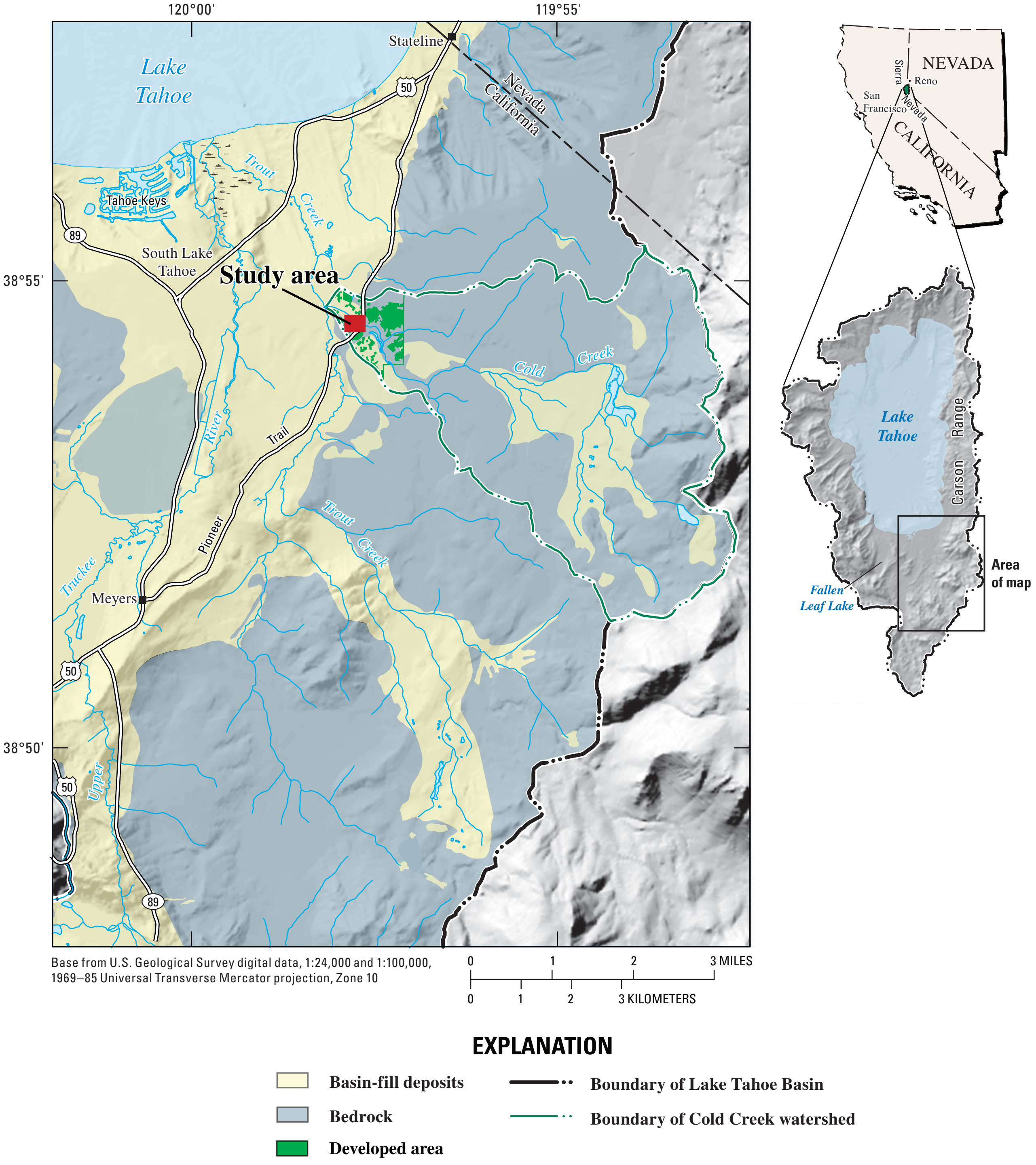


Figure 1. Cattlemans detention basin in the Cold Creek watershed and Lake Tahoe, California and Nevada.

implement these regulations. After a 1970–73 study, roadways in urbanized areas were identified as a major source of sediment (Glancy, 1988). The Clean Water Act of 1987 (U.S. Environmental Protection Agency, 1992) mandated that transportation agencies begin addressing this problem (Yu and others, 1998). In response to the Clean Water Act, wetlands and stormwater detention basins were built across the country, including several in the Lake Tahoe Basin (Reuter and others, 1992). Detention basins often are located in the lower parts of the drainages, therefore receive water from a large portion of the drainage. The potential for contaminants occurring throughout the drainage to infiltrate to the water table is increased, which therefore potentially affects the quality of ground water beneath detention basins.

In the past, detention basin studies focused more on suspended sediment reductions than nutrient reductions. Martin (1988) experimented with routing flow through a detention basin and wetlands in series. He found that the detention basin reduced suspended sediment loads, but had variable success with reducing nutrients. Depending on the type of nutrient, the detention basin and wetlands had efficiency rates between 0 and 72 percent (Martin, 1988). Reuter and others (1992) routed flow through a wet meadow. Although a reduction in suspended solids was observed, little change in nutrient concentrations were noted. Ground water underlying detention basins near Lake Tahoe may have water-quality degradation because much of the stormwater runoff occurs during snowmelt, when vegetation is dormant (Prudic, Sager, and others, 2005). Although Reuter and others (1992) have shown that sediment loads are less when stormwater flows across a wetland or through a detention basin, these findings could be due to decreased surface flows in response to increased infiltration and not lower sediment concentrations (Prudic, Sager, and others, 2005).

The water quality and geochemical processes occurring in close proximity to Cattlemans detention basin were studied. Before construction of the detention basin, stormwater and snowmelt entered the meadow area by direct runoff from Pioneer Trail and the adjacent developed area. Construction of the detention basin included building two main culverts that collected water from road runoff (Pioneer Trail) and the developed area. This water currently is discharged directly into the detention basin. As the surface runoff infiltrates in the confined area of the detention basin, it has the potential to modify the ground-water flow system and provide an increased source of solutes, including dissolved oxygen, which could change the geochemical processes taking place beneath the basin.

The effectiveness of the detention basin and its potential effects on water quality within the study area was determined by collecting samples from Cold Creek, ground water, stormwater, and precipitation within the study area. Cold Creek and ground-water wells were sampled on a predetermined schedule (spring, summer, and fall) and the water entering and leaving the detention basin was sampled during precipitation or runoff events. Local precipitation was collected and analyzed for major ions and nutrients to determine the input from this source.

The transport of nutrients through the sediments beneath the detention basin can be affected by the chemical reactions that occur within the subsurface. The types and rates of these reactions are dependent on the oxidation-reduction (redox) potential, geochemistry, and microbial ecology in the sediments, and the chemical characteristics of the reactants. The subsurface microbial population can be particularly important in transforming nutrients in water infiltrating into the sediments beneath the detention basin.

The evolution of an environmental microbial ecosystem can be thought of as a succession of integrated redox reactions wherein microorganisms mediate and derive energy from the transfer of electrons from electron donors to electron acceptors. Organic carbon, rich in electrons, often is the electron donor. Because microorganisms derive the most energy from the reduction of oxygen, it is the preferential electron acceptor. Other electron acceptors in the subsurface, in order of most to least favorable in terms of redox energetics, are nitrate, oxidized manganese and iron, sulfate, and carbon dioxide. A microbial population capable of using a specific electron acceptor expands as chemical conditions become optimal, and dies back as the electron acceptor is depleted (Madigan and others, 2000).

A reconnaissance of the physiological groups of microorganisms and the ground-water geochemistry, can provide information about the major microbial processes that may be occurring in the subsurface environment (Bekins and others, 1999). The microbial ecology can be inferred from the determination of concentrations of six, non-exclusive physiological groups of microorganisms, classified based on their electron-accepting reactions:

1. Aerobic bacteria;
2. Denitrifying bacteria;
3. Anaerobic, heterotrophic fermenting microorganisms;
4. Iron-reducing bacteria
5. Sulfate-reducing bacteria; and
6. Methanogenic microorganisms.

Aerobic microorganisms utilize oxygen as the terminal electron acceptor and those that can only use oxygen are termed obligate aerobes. The use of oxygen as the electron acceptor always provides the most energy from a given compound and aerobic microorganisms capable of using other electron acceptors (facultative aerobes) will always use oxygen first (Madigan and others, 2000).

Because diffusion of molecular oxygen in water is about 100,000 times slower than in the gas phase, oxic systems can quickly become anoxic in saturated sediments. If that happens, the next most thermodynamically efficient electron acceptor commonly found in the environment is nitrate. Nitrate, nitrite, and nitrous oxide are used as electron acceptors by many common facultative aerobic soil microorganisms through the process of denitrification. When nitrate has been utilized or is not present, most, but not all, of these microorganisms can switch to oxidized iron, the next best common electron acceptor based on free energy yields.

Anaerobic heterotrophic fermenting microorganisms only use organic compounds to give a stoichiometric balance of protons and electrons in lieu of an electron acceptor (that is, oxidation and reduction of the same organic compound). Many of these microorganisms produce hydrogen and lower molecular weight organic compounds, which often are used by other anaerobic microorganisms that include iron-reducing, sulfate-reducing or methanogenic microorganisms. These groups work together with anaerobic heterotrophic fermenting microorganisms to complete the degradation of organic compounds: obligate iron-reducing, sulfate-reducing, and methanogenic microorganisms can use acetate or molecular hydrogen excreted by fermenting bacteria as their energy source. Although the obligate anaerobes obtain little energy from each reaction, they are able to survive under these meager conditions. Elevated concentrations of these microorganisms are indicators of the dominant terminal electron process and redox condition. However, because these organisms rely on heterotrophic microorganisms, their concentrations can still be relatively low.

Purpose and Scope

Cattlemans detention basin project began in 2000 as a cooperative study between the U.S. Geological Survey (USGS), the El Dorado County Department of Transportation, Tahoe Engineering Unit and the California Tahoe Conservancy. The central goal of the study was to determine the effectiveness of the detention basin in preventing sediments and nutrients from entering nearby Cold Creek. Numerical ground-water flow models were used to determine how ground-water flow beneath and in the vicinity of Cattlemans detention basin varies. Ground-water flow characteristics were then used to estimate ground-water discharge from Cattlemans detention basin to Cold Creek.

Water-quality sampling results and analysis at Cattlemans detention basin during 2001–05 are reported. Water-quality data were collected from 30 wells, 3 stormwater sites (2 entering the basin and 1 outflow from the basin), 3 sites on Cold Creek, and 1 site where precipitation was collected. Processes that control the observed water quality, temporal and spatial changes in water quality, and changes due to construction of the basin were examined. Ultimately, changes in water quality observed during this study indicate the effectiveness of the basin for controlling nutrient transport to Lake Tahoe.

Methods used to collect the water and core samples and the methods used to analyze the samples for chemistry, nutrients, and the different physiological groups of microorganisms also are described. The results are presented along with trend discussions in the different microorganism groups followed by an assessment of the effects of stormwater runoff on changes in the redox conditions in the subsurface beneath the detention basin and how changes in the microbial ecology affected the transport of nutrients from the detention basin to nearby Cold Creek.

Acknowledgments

The authors acknowledge the California Tahoe Conservancy, and the El Dorado County Department of Transportation, Tahoe Engineering Unit, especially Jennifer Quickel for participation in this study. The authors thank James L. Wood of the U.S. Geological Survey for his dedicated assistance during all stages of this study. Thanks also to the people who helped collect and analyze microbial samples. Victor Paganelli, Ana Acosta, Chace Warren, and Bjorn Lake assisted in the collection of samples in the field. Katherine Henkelman assisted with the collection of water samples in 2002 and 2003 and analyzed samples for alkalinity, bicarbonate, pH, and specific conductance. Chris Fuller analyzed samples for metals. Bill Evans and Mark Huebner measured anion and dissolved gasses. All assistance was very much appreciated.

Cattlemans Detention Basin Site Description

The drainage area of Cold Creek lies in the mountains south of Lake Tahoe (fig. 1). Cold Creek flows northwest and is tributary to Trout Creek about 3.6 mi from Lake Tahoe (Prudic, Sager, and others, 2005). Covering 12.8 mi^2, Cold Creek's drainage area is mostly undeveloped and is Trout Creek's largest tributary (Rowe and Allander, 2000). About 0.6 mi upstream of the confluence with Trout Creek, Cold Creek enters a large meadow after flowing under Pioneer Trail (fig. 1).

Since the 1950s, Cold Creek and the meadow it flows through have undergone numerous changes (fig. 2). Originally, the creek flowed through the meadow in a fairly narrow, shallow channel. The channel bottom, composed of sandy deposits, probably did not extend far below the water table. Streamflow likely was controlled by the ground-water level, which in the meadow is only a few feet below land surface (Prudic, Sager, and others, 2005). During peak snowmelt in the spring, the meadow would be inundated with water when Cold Creek overfilled its banks. Under these conditions, the meadow would act as a natural filter for sediments and nutrients. By 1969, Lake Christopher was created when a dam was built across Cold Creek about halfway between Pioneer Trail and the confluence with Trout Creek. After filling the lake, Cold Creek was diverted into a ditch that was dug along the northern edge of Lake Christopher (Prudic, Sager, and others, 2005; fig. 2). After a number of years, the dam was removed and a new channel for Cold Creek dug through the meadow emptying into three wildlife ponds in series. In 1994, the channel was engineered to its present path. Figure 2 shows the remnants of one pond and how much more sinuous the present day channel is as compared to the original creek. It also was constructed to be much wider and deeper than the original channel, keeping most, if not all, of the flow within the banks. Due to the excavation of the channel below the water table and the establishment of meanders that intersect ground-water flow paths in the meadow, there is an expected increase in ground-water exchange with the stream (Prudic, Sager, and others, 2005). To date, much erosion has been seen on the banks of Cold Creek. Ground-water interaction with the channel may be the reason for the excessive erosion.

Well Construction

In November and December 2000, approximately 9 months prior to the construction of Cattlemans detention basin, 30 monitoring wells were installed around the proposed detention basin and in the adjacent meadow (Appendix A; Prudic, Sager, and others, 2005). Monitoring ground-water levels in these wells provided data to determine the direction of ground-water flow in the area. The wells also were used to evaluate the interaction of ground water with Cold Creek and to measure the hydraulic conductivity of the aquifer. A number of deeper wells were installed adjacent to corresponding shallow wells (wells cc03D, cc06D, cc08D, cc13D, cc17D and cc19D; table 1, fig. 3). These deeper wells were installed to collect information on vertical gradients and for geochemical sampling. Construction information for all 30 wells is listed in table 1.

Most boreholes used for well installation were drilled using a trailer-mounted hollow-stem auger that produced a borehole diameter of about 4.5 in. Shallow wells were installed in boreholes drilled to depths of 5–7 ft, whereas deep wells were installed in boreholes 10- to 11-ft deep. Those wells located in areas of artificial fill (see Aquifer Characteristics section) were drilled to depths of 9 to 10 ft for shallow wells and 15 ft for deeper wells. All wells, except well cc02 and cc19D, were constructed of nominal 2-in. schedule 40 polyvinyl chloride (PVC) pipe. Openings were cut into the pipe from 0.5 and 1.5 ft from the bottom at a width of 0.020 in. to form a 1-ft screened interval. Wells cc02 and cc19D were installed in the same manner except with 1-in. schedule 40 PVC pipe as a smaller diameter bucket was needed to reach the desired well depth. A lockable and tightly sealed cap, consisting of two O-rings, was placed at the top of each 2-in. diameter PVC pipe to prevent surface runoff from entering the well. The 1-in. diameter PVC pipes also had lockable caps, and rubber gaskets installed to seal the tops.

The wells were completed by filling the annular space with very coarse silica sand, silica flour, native material, and cement grout (fig. 4). The coarse silica sand was placed around the screen followed by 1 to 3 ft of silica flour. The silica flour was used instead of the more standard bentonite to limit changes in water chemistry (Prudic, Sager, and others, 2005). Native material, which was removed from the hole during drilling, was placed on top of the silica flour up to the last 1.5–3 ft and cement grout was used to fill the remaining annular space around the well in order to seal the annulus from water infiltration from land surface.

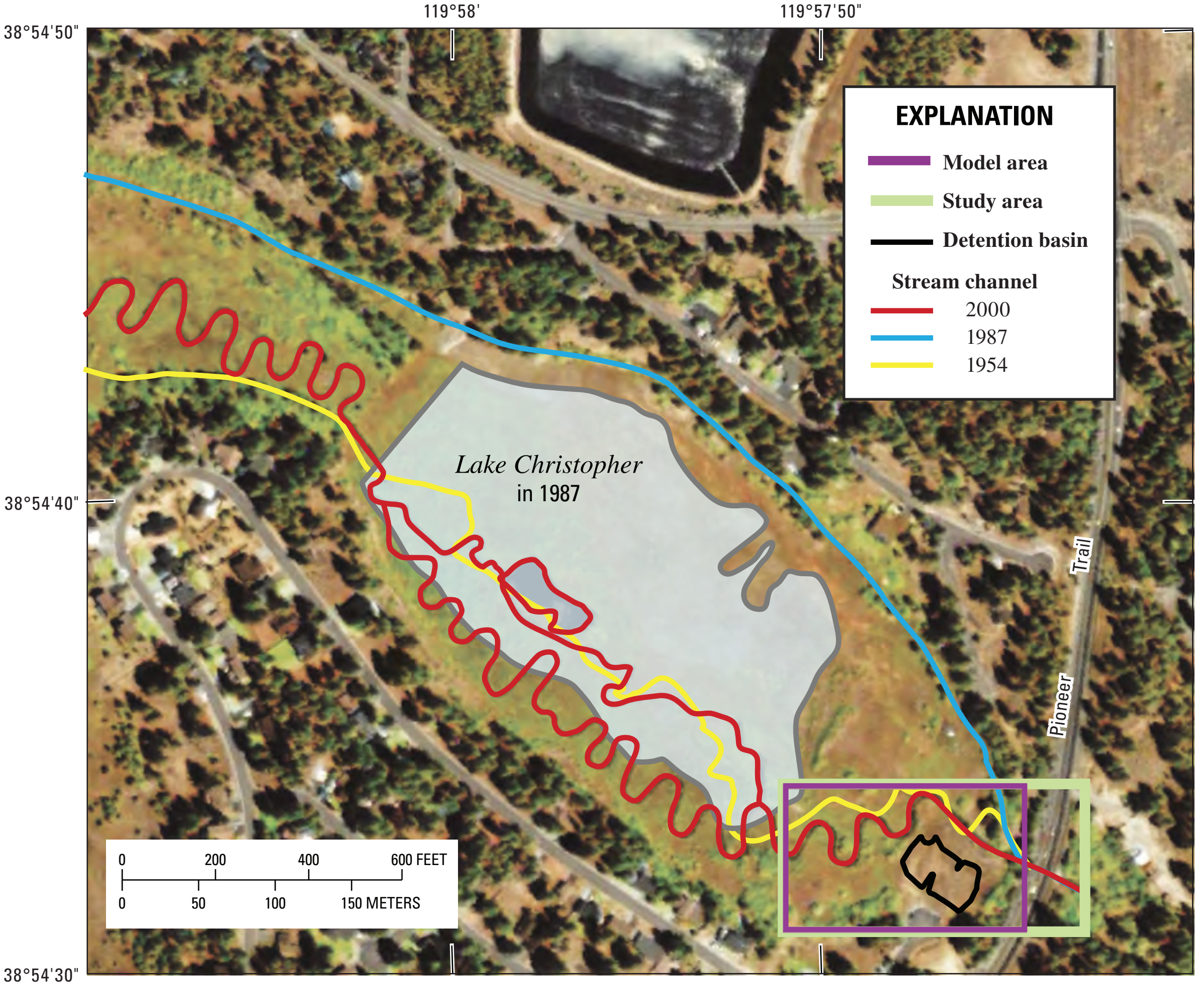


Image base from Space Imaging, IKONOS-2, Pan sharpened natural color, Aug 10, 2000
Universal Transverse Mercator projection, Zone 10, NAD 1983

Figure 2. Aerial photograph (August 10, 2000) showing historic Cold Creek channel changes.

Aquifer Characteristics

The basin-fill deposits of the Cattlemans detention basin field site are characteristic of the sediment deposited on the meadow. Away from the stream, the deposits are comprised of sand and gravel, whereas stream deposits are comprised of sand and gravel with interbedded silt and clay (Harrill, 1977). The basin-fill deposits, which are underlain by Quaternary glacial deposits and granitic bedrock, thicken from 10- to 20-ft thick near the study site to as much as 500-ft thick toward Lake Tahoe (Gardner and others, 2000).

Three lithologies are represented in the study area: artificial fill, organic silt, and sand and gravel. The uppermost layer is artificial fill, characterized as red-brown loamy sand with some gravel and scarce cobbles that were placed on the meadow surface prior to construction of the detention basin during an intended housing plan extension. The majority of the artificial fill was removed during the detention basin excavation (fig. 5). The artificial fill is underlain by the original meadow surface and consists of a thin layer of dark gray, organic-rich soil with decomposing vegetation. Below the organic-rich layer is a brown sand and gravel with stringers of coarse sand.

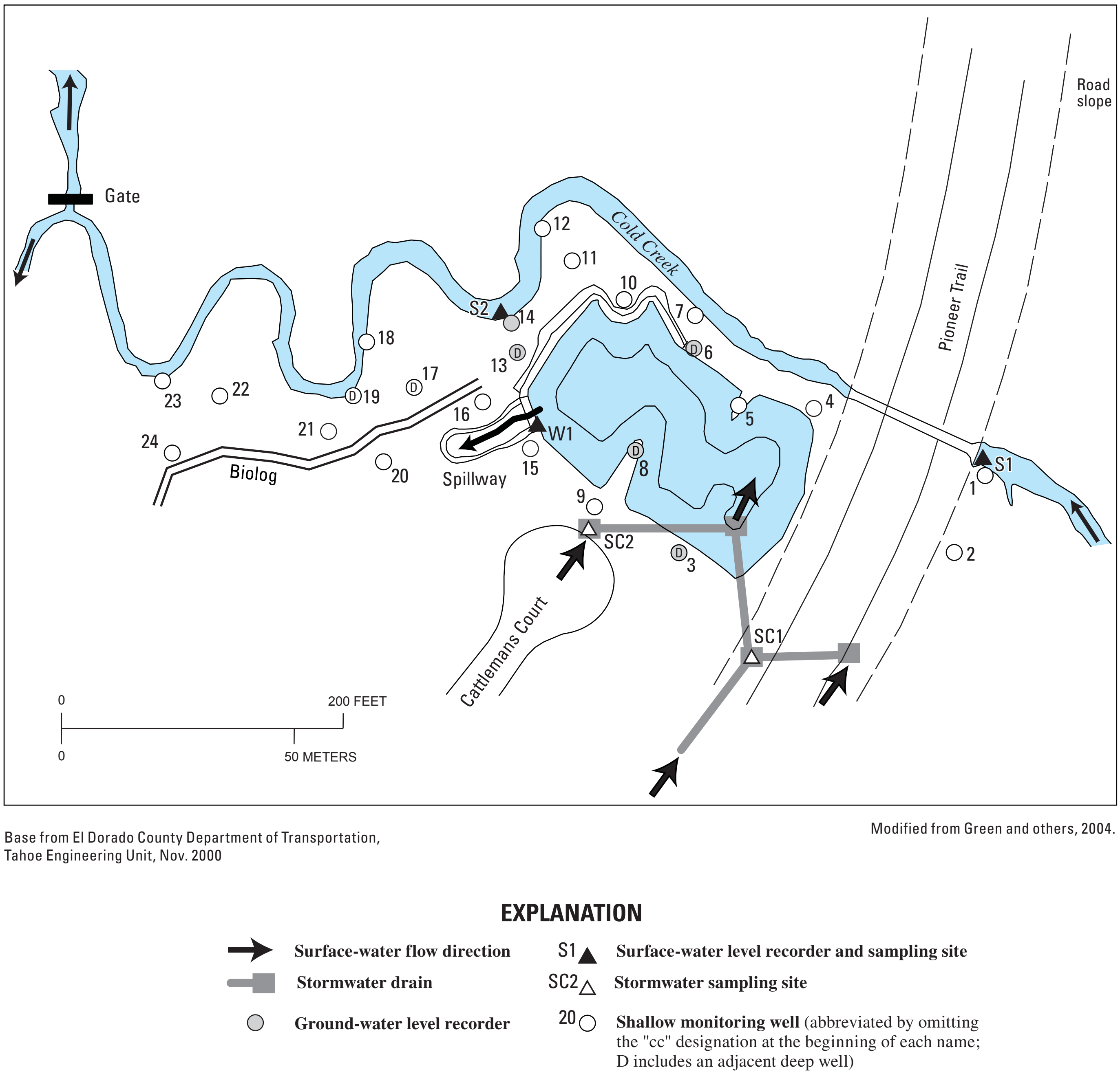
Thickness of the sand and gravel layer is uncertain for most of the study area. Evidence from water-level measurements, based on vertical gradients between shallow and deep wells, suggests an increase in thickness of these unconsolidated deposits between wells cc08S and cc13S (Prudic, Sager,

Table 1. Well name, land-surface altitude, and construction data from monitoring wells at Cattlemans detention basin.

Well name[1]	USGS Standard identification number (see Appendix A)	Land-surface altitude[2] (feet)	Depth in feet below land surface		
				Screened interval	
			Bottom of well	Top	Bottom
cc01	385432119574001	6,278.84	5.6	4.1	5.1
cc02	385432119574002	6,281.57	6.8	5.3	6.3
cc03S	385432119574301	6,281.23	10.2	8.7	9.7
cc03D	385432119574302	6,281.21	15.1	13.6	14.6
cc04	385433119574201	6,279.12	10.2	8.7	9.7
cc05	385433119574202	6,278.03	10.2	8.7	9.7
cc06S	385433119574301	6,277.37	9	7.5	8.5
cc06D	385433119574302	6,277.4	15	13.5	14.5
cc07	385433119574203	6,273.29	5	3.5	4.5
cc08S	385432119574303	6,278.13	9.2	7.7	8.7
cc08D	385432119574304	6,278.15	15	13.5	14.5
cc09	385432119574305	6,279.3	9.9	8.4	9.4
cc10	385433119574303	6,276.39	10.2	8.7	9.7
cc11	385434119574401	6,272.83	5.6	4.1	5.1
cc12	385434119574402	6,272.64	5.1	3.6	4.6
cc13S	385433119574401	6,275.14	10.2	8.7	9.7
cc13D	385433119574402	6,275.69	15.2	13.7	14.7
cc14	385433119574403	6,272.6	5.5	4	5
cc15	385432119574401	6,278.33	10.2	8.7	9.7
cc16	385433119574404	6,273.47	7.2	5.7	6.7
cc17S	385433119574501	6,272.71	6.7	5.2	6.2
cc17D	385433119574502	6,272.82	10.6	9.1	10.1
cc18	385433119574503	6,271.93	5.1	3.6	4.6
cc19S	385433119574504	6,272.19	5.6	4.1	5.1
cc19D	385433119574505	6,272.11	10	8.5	9.5
cc20	385432119574501	6,272.77	7.2	5.7	6.7
cc21	385432119574601	6,272.19	5	3.5	4.5
cc22	385433119574701	6,271.94	5.6	4.1	5.1
cc23	385433119574702	6,271.08	5.4	3.9	4.9
cc24	385432119574701	6,271.97	5.5	4	5

[1] For paired wells only: Shallow wells are suffixed with an ‘S’ (for example, cc06S) and deeper wells are suffixed with a ‘D’ (for example, cc13D).

[2] Land-surface altitude referenced to pin set by El Dorado County Department of Transportation at end of Cattlemans Trail cul-de-sac. Altitude referenced to NAVD of 1988.



Base from El Dorado County Department of Transportation,
Tahoe Engineering Unit, Nov. 2000

Modified from Green and others, 2004.

Figure 3. Cattlemans detention basin study area, South Lake Tahoe, California.

and others, 2005). An upward vertical gradient is observed between wells cc08S and cc08D, whereas a short distance away a downward vertical gradient is observed between wells cc13S and cc13D. In an otherwise unchanging aquifer, the sudden change in hydraulic gradient signifies an abrupt thickening of the unconsolidated deposits based on Darcy's Law.

Total thickness of the unconsolidated deposits were defined by examining outcrops and collections of surface and borehole geophysical data. Granitic bedrock outcrops are present east of Pioneer Trail and were intercepted at six feet when drilling monitoring well cc02 (fig. 3). A geophysical survey, using the seismic-refraction method, indicated the depth to bedrock was about 80 ft along a transect from monitoring well cc20 extending approximately 500 ft northeast (fig. 3; David L. Berger, U.S. Geological Survey, written commun., 2006). This supports the hypothesis of alluvium thickening toward Lake Tahoe.

Slug tests were done in 27 of the 30 monitoring wells in fall 2003 to estimate alluvium hydraulic conductivity (Green and others, 2004). Monitoring wells cc17S, cc17D and cc02 were not tested. Duplicate tests were done on each well to determine the test's repeatability. Data were analyzed using the Bouwer and Rice (1976) method in a spreadsheet (Halford and Kuniansky, 2002). Hydraulic conductivities of the

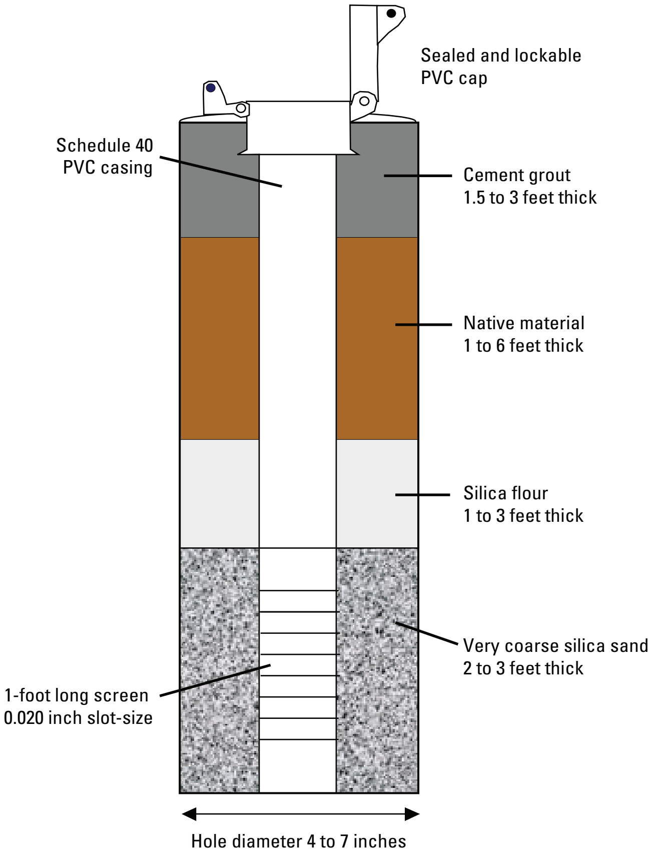


Figure 4. Schematic diagram showing general construction of observation wells used in study of Cattlemans detention basin, South Lake Tahoe, California.

alluvium estimated from the slug tests ranged from 0.5 to 70 ft/d. Most wells had hydraulic conductivity values between 1 and 20 ft/d, which gave an overall average of about 18 ft/d (Green and others, 2004). The areal distribution of hydraulic conductivity is shown in figure 6. No obvious spatial trend was visible, yet hydraulic conductivities indicated ground-water flow was unrestricted northwest across the detention basin and onward through the meadow.

Methods

Ground Water

Water levels were measured routinely in the wells using either an electric or a steel tape (Appendix B). Water levels generally were 3 ft or less below land surface in wells next to Cold Creek and more than 9 ft below land surface at wells cc03S and cc03D during summer and late fall. Water levels in monitoring wells for water year 2001 were published in Garcia and others (2002); water year 2002 were published in Berris and others (2003); and water year 2003 were published in Stockton and others (2004). All water-level information is available in the USGS, National Water Information System (NWIS) database <*http://waterdata.usgs.gov/nv/nwis/nwis*>.

During winter months, snow coverage inhibited access to the wells, measurements were halted until snowmelt allowed access. Several of the wells were still monitored with pressure transducers. Pressure transducers were installed in wells cc03S, cc03D, cc06S, cc06D, cc08S, cc08D, cc13S, cc13D, and cc14 (fig. 3). Water-level data from the pressure transducers were recorded every hour and the accuracy of recorded data were checked whenever manual water-level measurements were made in the wells. These data provided documentation of the 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 cc08S and cc08D but were moved to wells cc06S and cc06D following construction of the detention basin because of concerns that the water level in the pond could rise and cover wells cc08S and cc08D. In general, the direction of ground-water flow is from east to west across the detention basin and down through the meadow toward the west (fig. 6).

Cold Creek

A streamflow gage was established on Cold Creek upstream of the culvert beneath Pioneer Trail (fig. 3; USGS streamflow gage number 10336778). Mean daily discharge values for 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 pressure transducer was placed in Cold Creek below the future location of the detention basin adjacent to well cc14 (fig. 3) in June 2000. The transducer was installed to compare stream stage in relation to the ground-water elevation in well cc14.

Water-Quality Sampling Procedures

Cold Creek was sampled at two locations, next to well cc01 upstream of streamflow gage S1 at Pioneer Trail and near well cc14 at S2 (fig. 3). 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 to record field parameters (pH, specific conductance, temperature, and dissolved oxygen). After stabilization and measurement of the field parameters, the tubing was disconnected from the flow-through chamber, a 0.45 micrometer filter was attached, and samples were collected from November 2001 to October 2002. These samples were analyzed for nutrients, organic carbon, major ions, and trace elements.

Wells were sampled for dissolved nutrients (filtered through a 0.45 micrometer filter) during the spring, summer, and fall from January 2001 through June 2005. Twelve to 15 wells were sampled for dissolved organic carbon and major ions. Trace elements also were analyzed for samples collected from November 2001 to October 2002. Water samples were obtained from wells using a portable battery-operated peristaltic pump with C-flex tubing, following USGS

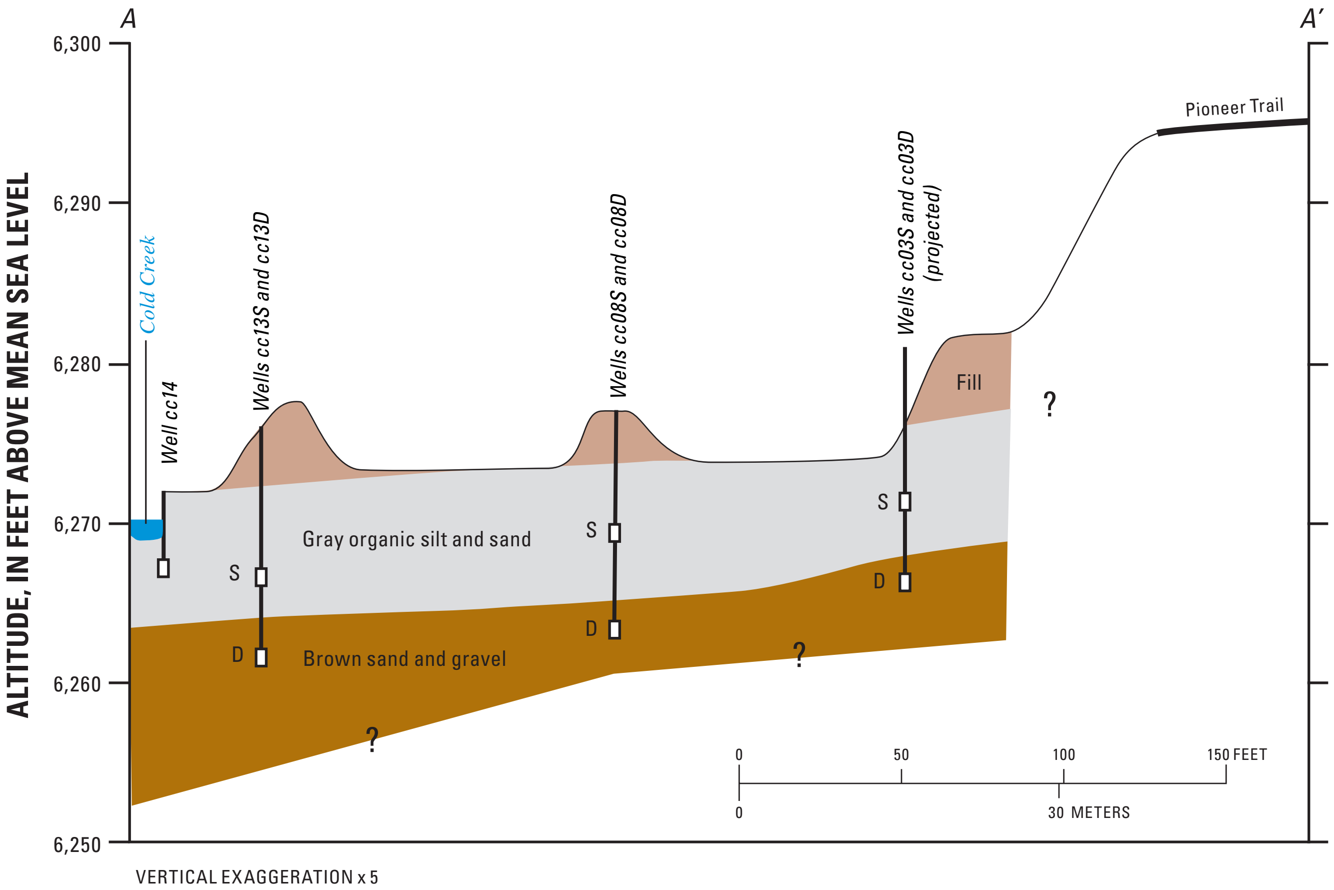


Figure 5. Vertical cross section through Cattlemans detention basin showing distribution of alluvial deposits, South Lake Tahoe, California.

procedures <*http://water.usgs.gov/owq/FieldManual/*>. Water was pumped into a flow-through chamber equipped with pH, specific conductance, temperature, and dissolved-oxygen sensors. Flow was maintained through the chamber until all parameters stabilized according to criteria listed in USGS procedures <*http://water.usgs.gov/owq/FieldManual/*>. Dissolved oxygen was not measured in wells where hydrogen sulfide odor was present because of potential damage to the dissolved-oxygen sensor. Further details of the sampling procedures are documented by Prudic, Sager, and others (2005). Results for analyses of these ground-water samples are listed in Appendix C.

Both culverts entering the basin and the weir at the outlet of the basin were instrumented with automatic samplers that were activated by a rise in the stage of the water at the site to collect runoff during storms. The samplers performed sporadically and thus did not collect samples during all runoff events. During several events, hand-dipped samples were collected when the automatic samplers did not function properly. When the samplers functioned properly, water collected during storms was collected by the automatic samplers into several bottles during the event and these bottles were combined to create a sample representative of the entire event. This combined sample was split into individual sample bottles for analysis at the laboratory.

Precipitation was collected in bulk collectors that were periodically emptied and the resultant unfiltered composite sample was analyzed in the laboratory.

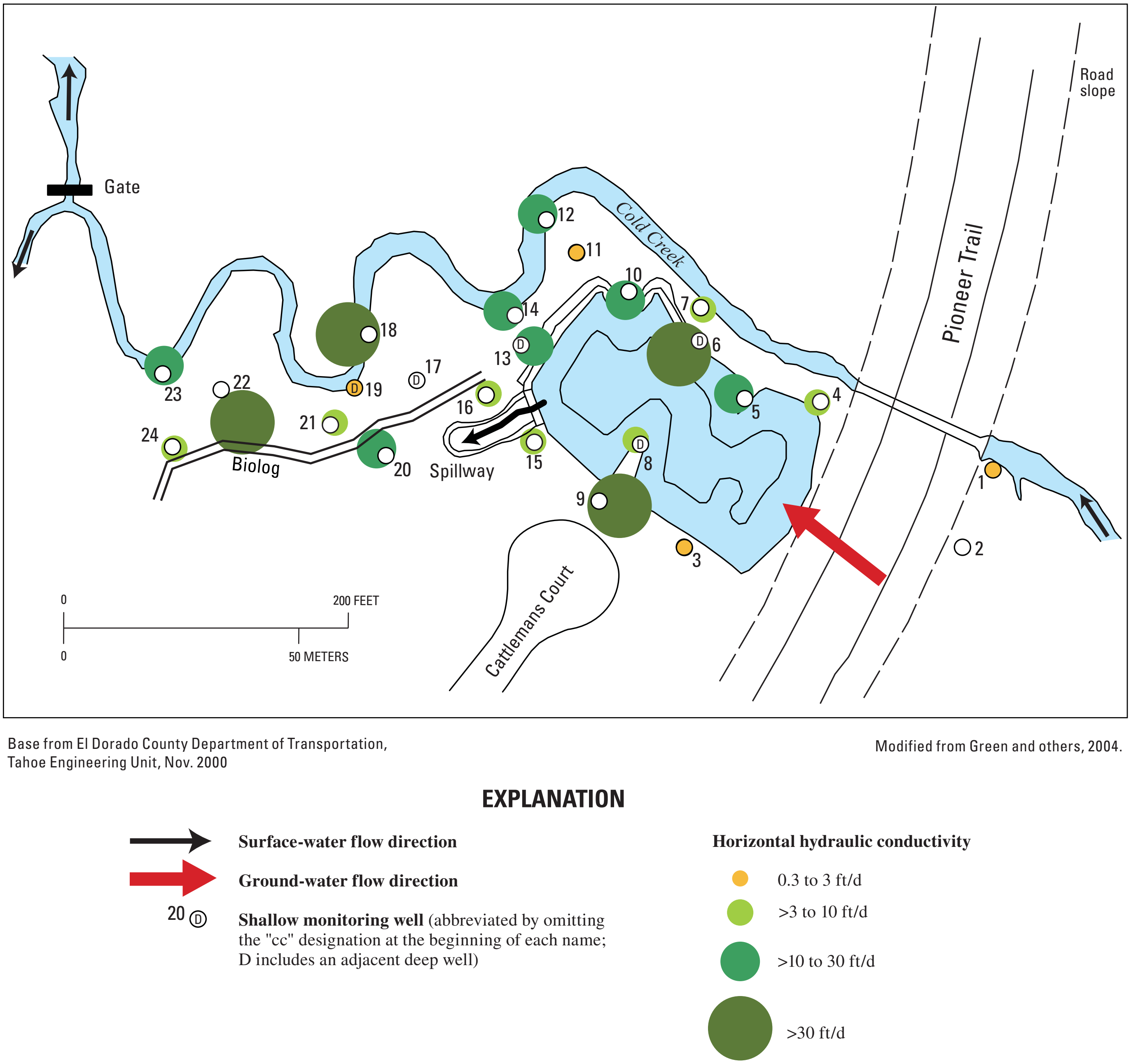
Analyses of Water Samples

Major ions, trace elements, and organic carbon samples were analyzed either by the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado or the University of California, Davis (UCD). Nutrient samples were analyzed by the Tahoe Research Group (TRG) Laboratories. Methods of analysis at the UCD and TRG laboratories have been documented by Lico (2004). The analytical procedures used by the NWQL can be found at <*http://nwql.cr.usgs.gov/usgs/catalog/index.cfm*>. Analytical results from all samples are stored in the NWIS database <*http://waterdata.usgs.gov/nv/nwis/nwis*>. Water-quality data collected for this project (both surface water and ground water) were published in Garcia and others (2002), Berris and others (2003), and Stockton and others (2004).

Quality of chemical data was documented by collecting a field blank during most sampling trips and by collecting replicate samples at some sites. Also, the UCD laboratory analyzed blind reference samples and duplicate aliquots of a sample for at least one nutrient per sample to assure laboratory procedures. The sample analyses completed by the NWQL have been quality assured by standard laboratory procedures and are documented by Pirkey and Glodt (1998) and Maloney (2005). The results of all quality-control samples combined indicate that no contamination or bias affected the concentrations reported for constituents in water samples.

Core Collection and Ground-Water Sampling

A total of 62 cores at two depth intervals from five locations were collected between 2001 and 2004 (table 2). Locations were sampled on successive years within 1 ft of each other. Three of the locations were selected to create a profile along the most direct path to Cold Creek: upper (CCMP3) and lower basin (CCMP2), and just downgradient from the basin (CCMP1; fig. 7). Two other locations, well away from the basin, were selected as control sites (CCMP4 and CCMP5). In each borehole, generally four samples were collected: two from a shallow depth (3.5–6 ft below land surface) and two from a deeper depth (7–10 ft below land surface). The shallow depth corresponds to the first permeable zone below the water table and the screened interval of most of the shallow wells drilled in the area of the detention basin. The deeper samples targeted the depth where the sediments changed color from gray to brown. Water in the boreholes generally rose to a depth of 2–3 ft below land surface.



Base from El Dorado County Department of Transportation, Tahoe Engineering Unit, Nov. 2000

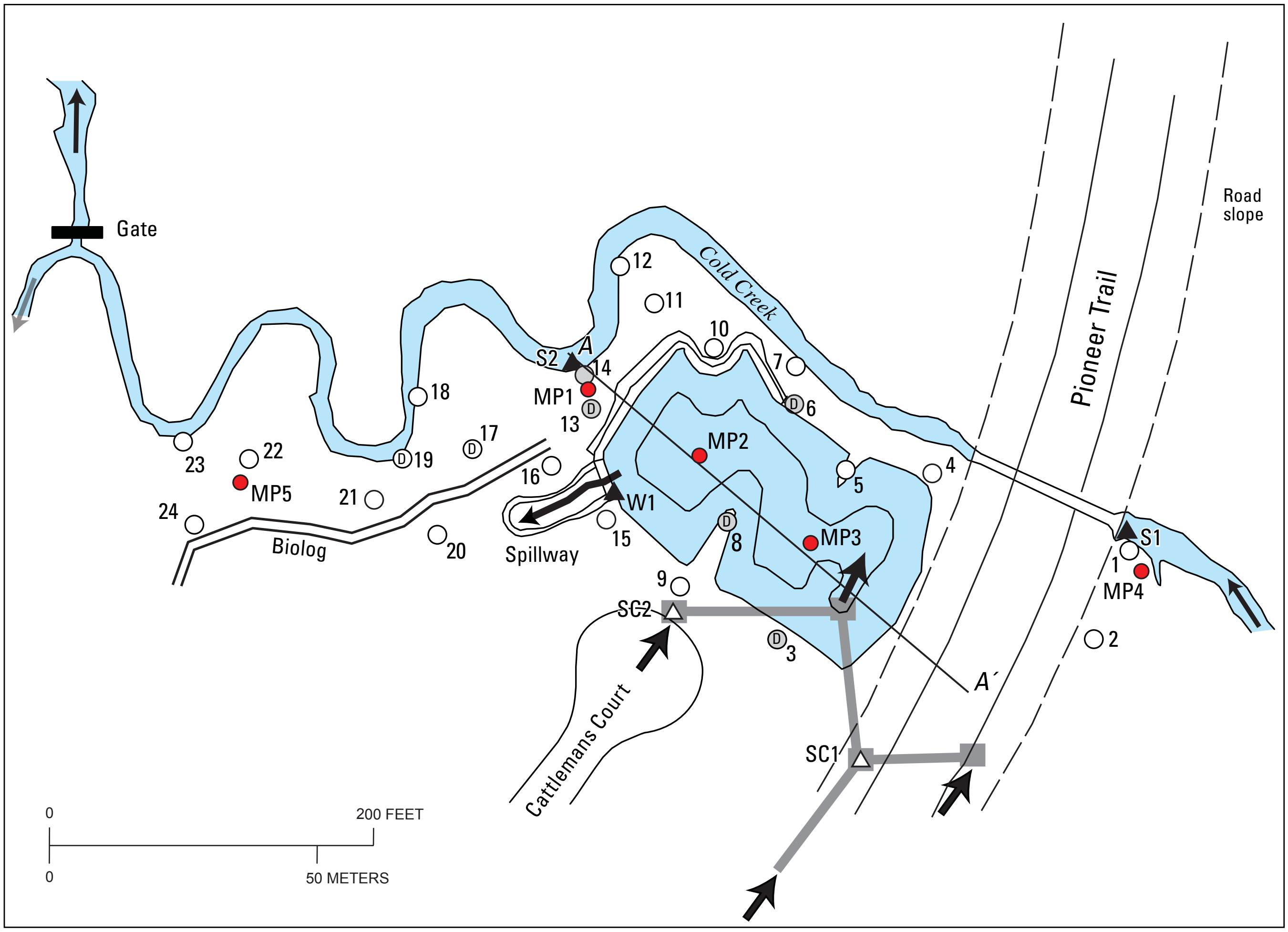
Modified from Green and others, 2004.

Figure 6. Distribution of horizontal hydraulic conductivity near Cattlemans detention basin, South Lake Tahoe, California.

During the core sampling, a borehole was first drilled 4–5 ft below land surface where water readily entered the hole. The auger was removed and a core was taken from the bottom of the borehole using a 2-in. diameter, 6-in. long split-tube stainless-steel-core barrel attached to the end of the auger flights. The core barrel was lined with a removable polycarbonate tube. The core was driven into the bottom of the hole using a fencepost driver. After retrieval, the polycarbonate tube was removed from the core barrel and immediately sealed with caps at the top and bottom, wrapped in plastic wrap followed by duct tape. A second core was taken immediately below the first.

Ground water was sampled from the borehole after collecting the second core sample. A drive point, nominal 3/8-in. stainless-steel tube, slotted over the last 6-in., was pushed into the sediment at the bottom of the borehole. Ground water was withdrawn from the stainless steel tube at a rate of about 0.1 gal/min using a peristaltic pump until specific conductance, temperature, and pH of the water stabilized. Usually, from 2 to 5 gal were pumped prior to sampling.

Temperature, specific conductance and pH were continuously monitored while water was pumped from the temporary drive point. A filtered 100 mL sample was collected following the purging of the drive point and alkalinity and bicarbonate



Base from El Dorado County Department of Transportation,
Tahoe Engineering Unit, Nov. 2000

Modified from Green and others, 2004.

EXPLANATION

→	**Surface-water flow direction**	Ⓓ 3	**Shallow monitoring well**—Abbreviated by omitting the "cc" designation at the beginning of each name; D includes an adjacent deep well
▬	**Stormwater drain**	○	**Ground-water level recorder**
A ——— A′	**Line of section shown in figure 8**	S1 ▲	**Surface-water level recorder and sampling site**
MP4 ●	**Microbial sampling site**	SC2 △	**Stormwater sampling site**

Figure 7. Locations of temporary microbial sampling sites at Cattlemans detention basin, South Lake Tahoe, California.

were measured in the field using the incremental acid titration method (Rounds and Wilde, 2001).

The borehole was advanced during the initial sampling in October 2001 using a hand auger until the depth of the hole approximated the depth of nearby wells. The open holes tended to collapse and there was concern that the cores might have some sediment from shallower depths. Consequently, sampling in subsequent years was done by over drilling the hole with a 4-in. diameter auger about 5 ft and collecting the first set of two cores. Then a 10-ft length of nominal 3-in. diameter PVC casing was inserted into the borehole until refusal. Sediment that entered the inside of the casing was removed using a 2.5-in. auger. The hole was advanced by alternately driving casing and cleaning sediment from inside the casing to a depth of 8–9 ft using a technique similar to that described by Prudic (1979). The third core was taken slightly above or at the top of the contact where the sediments changed color (fig. 8). The casing was advanced to the bottom of the third core and sediment removed from casing prior to collecting the fourth and last core. The third and fourth cores were taken using the same equipment and method as the first and second cores.

Ground water was again sampled from the borehole after collecting the fourth and final core. The same sampling procedures that were used to collect ground water after the second core were used to collect ground water from the borehole below the fourth core. Depths of all cores and water samples are summarized in table 2.

Microbial Sampling

Concentrations of aerobic, anaerobic heterotrophic, denitrifying, iron-reducing, sulfate-reducing, and methanogenic microorganisms were measured in both ground-water and sediment samples by a Most Probable Number (MPN) analysis. MPN analysis is a statistical method in which samples are diluted by factors of ten, and then used to inoculate selective media that encourages the growth of specific physiologic types of microbes. The concentrations of specific physiologic types of microorganisms in the original sample are determined from the growth patterns of the inoculated media. Five replicate analyses provide an estimate of 95-percent confidence intervals. The upper end of the 95-percent confidence interval corresponds to about three times the MPN and the lower end to one-third of the MPN (Meyall and Meyall, 1970). On a $\log_{10}$ scale this is plus or minus one-half log unit.

Suspended microorganisms in ground-water samples were ready for dilution and inoculation into media, but attached microorganisms on sediments had to be suspended prior to dilution. First, a few centimeters of the core

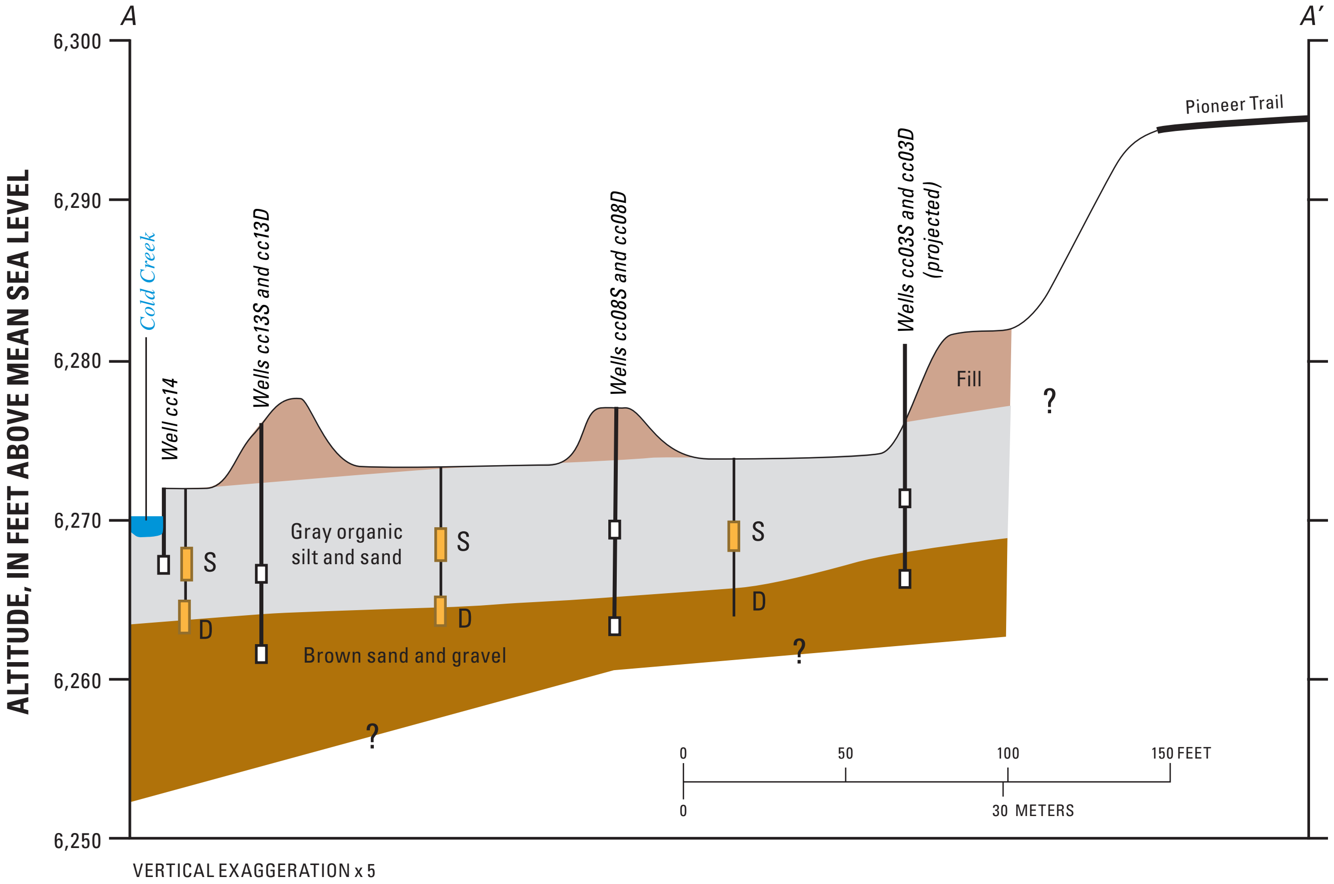


Figure 8. Cross section showing sampling intervals for temporary microbial sampling sites in relation to Cattlemans detention basin and nearby wells.

material from the bottom of the core were removed with a sterile spatula exposing an uncontaminated surface under a stream of oxygen-free nitrogen gas. Next, approximately 0.3 oz (10 g) of sediment from the center of the core was added to a 1 x 5.6 in. anaerobic isolation roll streak tube (Bellco Glass Inc., Vineland, N.J.) filled with 20.0 mL of a pre-reduced, anaerobic mineral salts solution.

The anaerobic mineral salts solution was prepared by adding the following salts and solutions to a liter of deionized water: 0.75 g of KH_2PO_4; 0.89 g of K_2HPO_4; 0.36 g of $MgCl_2{\cdot}6H_2O$; 0.9 g of NH_4Cl; 9.0 mL of trace metal solution (Zeikus, 1977); 5.0 mL of vitamin solution (Wolin and others, 1963) and 10 mg of Tween 80 (a nonionic surfactant added to remove microbes from the sediment as described by Yoon

Table 2. Sample dates, land-surface altitudes, depths of cores and water samples below land surface, and lithologic descriptions from temporary microbial sampling sites, Cattlemans detention basin, South Lake Tahoe, California.

[Locations of temporary microbial sampling sites are shown in figure 7]

Date	Depth interval in feet below land surface		Lithologic description
	Cores	Water sample	
	CCMP1S—Land-surface altitude 6,272.6 feet		
10/23/2001	3.6–4.6	4.7–5.2	Gray silt and sand
7/9/2002	3.7–4.7	5.2–5.7	Gray silt and sand
6/25/2003	3.8–4.8	5.2–5.7	Gray silt and sand
7/20/2004	3.9–4.9	5.3–5.8	Gray silt and sand
	CCMP1D—Land-surface altitude 6,272.6 feet		
10/23/2001	7.0–7.8	8.1-8.6	Greenish brown sand and gravel
7/9/2002	7.0–8.1	8.2–8.7	Greenish brown sand and gravel
6/25/2003	7.0–8.1	8.2–8.7	Greenish brown sand and gravel
7/21/2004	7.0–8.1	8.5–9.0	Greenish brown sand and gravel
	CCMP2S—Land-surface altitude 6,273.4 feet		
10/23/2001	3.5–4.4	4.5–5.0	Gray silt and sand
7/9/2002	3.6–4.6	4.9–5.4	Gray silt and sand
6/25/2003	3.5–4.5	5.2–5.7	Gray silt and sand
7/21/2004	3.6–5.0	5.3–5.8	Gray silt and sand
	CCMP2D—Land-surface altitude 6,273.4 feet		
10/23/2001	8.0–8.9	9.0-9.5	Greenish gray and brown coarse sand
7/10/2002	8.0–9.0	8.3–8.8	Greenish brown sand and gravel
6/26/2003	8.0–9.5	9.7–10.2	Greenish and yellowish brown sand and gravel
7/21/2004	8.0–9.1	8.6–9.1	Greenish and yellowish brown sand and gravel
	CCMP3S—Land-surface altitude 6,273.5 feet		
10/23/2001	4.2–5.1	5.2–5.7	Gray silt and sand
7/10/2002	4.0–5.3	5.5–6.0	Gray silt and sand
6/26/2003	4.2–5.2	5.3–5.8	Gray silt and sand
7/21/2004	4.0–5.1	5.3–5.8	Gray silt and sand
	CCMP3D—Land-surface altitude 6,273.5 feet		
10/24/2001	8.1–9.1	9.2–9.7	Greenish brown coarse sand
7/10/2002	8.0–9.0	9.2–9.7	Greenish brown sand and gravel
6/26/2003	8.4–9.5	9.7–10.2	Greenish and yellowish brown sand and gravel
7/22/2004	8.0–9.0	9.0–9.5	Greenish brown sand and gravel
	CCMP4S—Land-surface altitude 6,279 feet		
10/24/2001	6.0–6.9	7.0–7.5	Gray sand and gravel
	CCMP5S—Land-surface altitude 6,271.9 feet		
7/11/2002	4.2–5.3	5.3–5.8	Gray silt and sand
6/24/2003	4.1–5.0	5.2–5.7	Gray silt and sand
7/22/2004	4.0–5.0	5.1–5.6	Gray silt and sand
	CCMP5D—Land-surface altitude 6,271.9 feet		
7/11/2002	8.0–9.1	9.7–10.2	Gray sand and greenish brown sand and gravel
6/24/2003	8.1–9.1	9.3–9.8	Gray sand and greenish brown sand and gravel
7/22/2004	8.5–9.5	9.5–10.0	Greenish brown sand and gravel

and Rosson, 1990). The pH was adjusted to 7.0, and the solution was then boiled, cooled, and dispensed under a stream of oxygen-free nitrogen gas. The solution was sterilized at 121°C and 100 kPa for 15 minutes. Prior to use, a sterile solution of amorphous FeS (Brock and O'Dea, 1977) was added as a reducing agent to final concentration of one percent by volume.

Sterile, oxygen-free nitrogen gas was allowed to flow over the surface of the mineral salts solutions as the sediment sample was added. The tube was then sealed, mixed well, and allowed to stand for 2 hours to allow penetration of Tween 80 into the sample. The tubes were then opened and the microorganisms were dislodged from the sediment into the mineral salts solutions with an ultrasonic pulse using a Branson Sonifier, Model 200, with a sterilized microtip (Branson Ultrasonics Corporation, Danbury, Conn.) at 10 watts for 30 seconds (Yoon and Rosson, 1990) under a flow of sterile, oxygen-free nitrogen gas. The sediment samples in mineral salts solutions were stored for not more than 4 hours at 20°C before inoculation into growth media. The MPN of microbial concentrations on the sediments are referred herein as "attached numbers." Realistically, the attached numbers include a small proportion of the suspended population that was in the residual water on the sediments.

Samples were serially diluted by orders of magnitude into sterile, pre-reduced anaerobic mineral salts solutions as described by Holdeman and Moore (1972). Aliquots of the dilutions were inoculated into six different media designed to promote growth and enumeration of aerobic heterotrophic, anaerobic heterotrophic, denitrifying, iron-reducing, sulfate-reducing, and methanogenic microorganisms. Negative controls contained the same media, but were not inoculated. Microorganisms capable of aerobic heterotrophic growth were enumerated using Standard Methods Broth (BBL Microbiology Systems, Cockeysville, Md.). Tubes that showed visible growth after incubation at room temperature for 1 week were scored positive. Microorganisms capable of anaerobic heterotrophic growth or fermentation were enumerated using anaerobically-prepared Schaedler's Broth (Difco, Detroit, Mich.). Tubes that showed turbid growth or clumps of particulates after incubation at room temperature for 2 weeks were scored positive. Those microorganisms capable of denitrification were enumerated using the media described by Stanier and others (1966). The denitrifying media was dispensed into 0.6 x 3.9 in. screw cap test tubes that contained an inverted 0.25 x 2.0 in. test tube. The presence of denitrifying microorganisms was determined by the presence of nitrogen gas in the inverted tube and visible growth in the media after incubation for two weeks at room temperature.

Iron-reducing microorganisms were enumerated using anaerobically-prepared media consisting of 2.5 g of sodium acetate·$3H_2O$; 2.5 g of $NaHCO_3$; 0.1 g of $CaCl_2 \cdot 2H_2O$; 0.1 g of KCl; 1.5 g of NH_4Cl; 1.0 g of KH_2PO_4; 0.1 g of $MgCl_2 \cdot 6H_2O$; 0.1 g of $MgSO_4 \cdot 7H_2O$; 9.0 mL of trace metal solution (Zeikus, 1977); 5.0 mL of vitamin solution (Wolin and others, 1963); and 200 mL of 0.5 M Fe^{3+} dissolved in a liter of deionized water (Lovley and Phillips, 1986). The pH was adjusted to 7.0. The media was dispensed into 10 mL serum bottles and autoclaved at 121°C and 100 kPa for 15 minutes. After inoculation, the serum bottles were aseptically pressurized with a 30 percent carbon dioxide in molecular hydrogen mixture to 140 kPa. The serum bottles were allowed to incubate for a minimum of 10 weeks at room temperature. After incubation, 1 mL of a solution containing a 1:2 ratio of 2 g/L bipyridine and 350 g/L sodium acetate was injected into each of the serum bottles to determine the presence of reduced iron. Under these conditions, the presence of greater than 2 mg/L of reduced iron caused the clear solution to turn pink or red and was scored as a positive. The negative control also was treated with bipyridine and the resulting color was used as a no-growth standard.

Media for the enumeration of sulfate-reducing microorganisms consisted of anaerobic mineral salts media prepared by adding the following salts and solutions to a liter of deionized water: 3.0 g of Na_2SO_4; 0.2 g of KH_2PO_4; 0.3 g of NH_4Cl; 0.5 g of KCl; 0.15 g of $CaCl_2 \cdot 2H_2O$; 1.0 g of NaCl; 0.4 g of $MgCl_2 \cdot 6H_2O$; 2.8 g of sodium acetate·$3H_2O$; 9.0 mL of trace metal solution (Zeikus, 1977); and 5.0 mL of vitamin solution (Wolin and others, 1963). The pH was adjusted to 7.2. The media was dispensed into 10 mL serum bottles and autoclaved at 121°C and 100 kPa for 15 minutes. Just before use, 0.1 mL of sterile, CO_2-saturated, $NaHCO_3$ solution (84 g/L) was added to each of the serum bottles. After inoculation, the serum bottles were aseptically pressurized with a 30 percent carbon dioxide in molecular hydrogen mixture to 140 kPa. The serum bottles were allowed to incubate for a minimum of 10 weeks at room temperature. The presence of sulfide, and hence sulfate-reducing microorganisms, was measured by putting a drop of media on lead acetate paper (Fisher Scientific, Pittsburgh, Penn.). Any darkening of the paper, indicating a lead sulfide precipitate and a sulfide concentration greater than 0.25 mg/L, was scored as positive.

Microorganisms capable of methane production were enumerated using the same anaerobic mineral salts media prepared for dilution bottles. Mineral salts solutions with 4 mL/L of 250 mg/L resazurin solution, 2.5 g/L of sodium acetate·$3H_2O$ and 2.5 g/L sodium formate were dispensed into serum bottles. The bottles were pressurized aseptically after inoculation with a 30 percent carbon dioxide in molecular hydrogen mixture to 140 kPa. The serum bottles were allowed to incubate for a minimum of ten weeks at room temperature. The presence of methane in the head space was determined by gas chromatography with Flame Ionization Detection analysis (Godsy, 1980). Negative controls were used to establish a background methane concentration in the serum bottles.

Chemical Analyses

Water samples for dissolved gas analyses of methane and carbon dioxide were collected in 60 mL syringes from the peristaltic pump outlet and injected into evacuated, 30-mL serum bottles until atmospheric pressure was reached. The samples were preserved with 50 mg/L $HgCl_2$ as Hg and frozen. The headspace gas in each serum bottle was sampled at the research laboratory in Menlo Park, Calif., and analyzed for methane and total inorganic carbon using gas chromatography with a thermoconductivity detector and helium as a carrier gas (Godsy and others, 1992). Total inorganic carbon dissolved in water was calculated by converting the carbon dioxide concentration in the headspace gas using Henry's Law.

Initial water samples collected in October 2001 for dissolved iron(II) were passed through a 0.2 micrometer filter and analyzed using the bipyridine method (modified from Skougstad and others, 1979, p. 373) involving the addition of 0.5 mL/10 mL of 2 g/L bipyridine and 1.0 mL/10 mL of 250 g/L sodium acetate and measuring the absorbance on a spectrophotometer at 520 nanometers. Subsequent water samples for dissolved iron, as well as, all dissolved nutrient concentrations (nitrogen and phosphate) were collected following the same procedure used for sampling nutrients in the nearby wells (Prudic, Sager, and others, 2005).

Chloride and sulfate were analyzed using a Dionex ion chromatograph with hydroxide-selective, anion exchange columns (AS15 or AS18, Dionex) and suppressed conductivity as described in the Dionex manual. Calcium, cobalt, copper, iron, potassium, magnesium, manganese, nickel, silica, sodium, strontium, and zinc were measured by inductively coupled plasma atomic emission spectroscopy after filtration and acidification with 6 N hydrochloric acid to pH 2 (Coston and others, 1998; Savoie and others, 2004). The relative accuracy is within 5 percent for all the inorganic solutes except iron and magnesium.

Sediment ammonium-N, nitrate-N (Höfer, 2003; Knepel, 2003) and Olsen-phosphate (bioavailable, inorganic orthophosphate; Olsen and Sommers, 1982; Prokopy, 1995) were measured by the University of California, Davis, Division of Agriculture and Natural Resources Analytical Laboratory. Nitrogen was measured by equilibrium extraction of soil for nitrate and ammonium with potassium chloride and subsequent determination by flow-injection analyzer (method #312; Soil Nitrate and Extractable Ammonium—Flow Injection Analyzer Method). The method has a detection limit of approximately 0.1 mg/kg (on a soil basis) and is generally reproducible within 7 percent. Extractable phosphate was based on alkaline extraction with 0.5 N $NaHCO_3$ and ascorbic acid reduction of phosphomolybdate complex and measurement by flow injection analysis (method #340, Extractable Phosphorus–Olsen Method). The method has a detection limit of 1.0 mg/kg (soil basis) and is generally reproducible within 8 percent.

Cattlemans detention basin looking northwest. Photograph by James L. Wood.

Simulation of Ground-Water Flow

Jena M. Green and Keith J. Halford

Flow Model Description

Ground-water flow through the study area was simulated using MODFLOW, a three-dimensional, numerical (finite-difference) ground-water flow model (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). The model area was discretized into a grid of 12,950 rectangular model cells in 37 rows and 50 columns areally and 7 layers vertically (fig. 9). Each model cell was about 10-ft wide in the row and column dimensions and had variable thickness. About 11 percent of the model cells were inactive; the active model area of the top model layer covered about 179,000 ft^2. The model grid was oriented north to south (fig. 2, outlined area). The eastern boundary was placed just west of Pioneer Trail in order to exclude the earthen work and compaction of Pioneer Trail, which would have added uncertainty to hydraulic properties. Placement of the western boundary was just west of well cc23, because no data were collected farther down-basin. The northern boundary of the model is just north of Cold Creek. The southern boundary was placed where Cattlemans Court enters the study area and the bedrock becomes very shallow.

Aquifer thickness was interpolated across the model from column 1 to 50 decreasing in thickness uniformly to the eastern boundary. The 10-ft thick eastern edge resulted from an estimate based on bedrock contact during drilling of monitoring well cc02. Depth to bedrock was estimated with a seismic refraction survey along column 18 south of Cold Creek. Contacts between layers were determined by assigning a percentage of the total model thickness to each layer, which resulted in layer thickness ranging from 1 to 27 ft (table 3). The upper model layers were thinner because the detention basin affected flow less than 20 ft below the water table. Lithologic layers had similar hydraulic conductivities and were not differentiated in the model.

Table 3. Percentage of the total thickness assigned to each ground-water model layer.

Model layer number	Layer thickness
1	1 foot
2	5%
3	10%
4	15%
5	20%
6	25%
7	25%

Creation of the detention basin and seasonal effects on ground-water flow were simulated with a transient-flow model. The basin-fill system was simulated between January 1, 1996 and August 31, 2004. Water levels were not observed prior to September 1, 2001, but the more than 5-year period from January 1, 1996 to September 1, 2001, was simulated to minimize the effects of initial heads. Simulated river stages prior to September 1, 2001 were assigned monthly average stages measured between September 1, 2001 and August 31, 2004. Each month represented a stress period, therefore producing 104 stress periods that were each divided into 5 time steps.

Boundary Conditions

The alluvial aquifer is unconfined and the water table represents the upper model boundary. Transmissivity was simulated independently because the water-table fluctuated less than 2 ft which is less than 5 percent of the aquifer thickness. The storage coefficient of layer 1 was assigned a value representative of specific yield for the unconfined aquifer.

Bedrock underlies layer seven and represents the basal boundary of the model. Along the southern model boundary bedrock is very shallow. Because bedrock permeability is very small compared to the permeability of basin-fill deposits the basal and southern model boundaries were simulated as no-flow. The northern boundary is parallel to the direction of ground-water flow; therefore the northern boundary also was simulated as no-flow (fig. 9).

Potential flow beneath Pioneer Trail was simulated with a general head boundary along the eastern edge of the study area. A hydraulic gradient of 0.013 existed beneath Pioneer Trail from well cc02 to cc03S based on water-level data (fig. 3). A water-level altitude of 6,276 ft, the average head in well cc02 from 2001–04, was assigned to all general head boundary cells along the eastern boundary.

The western boundary was simulated as a specified flux boundary. Discharge was specified on the western boundary to match observed gradients. An average horizontal gradient of 0.007 was measured at the water table between wells cc20 and cc23 (fig. 3). Horizontal gradients were assumed to decrease linearly with depth and ranged between 0.001 near the bedrock in layer 7 to 0.007 at the water table in layer 1. Uniform horizontal gradients were assigned for each model layer. Specified discharges were revised iteratively during model calibration so assigned gradients were maintained as hydraulic conductivity estimates were revised.

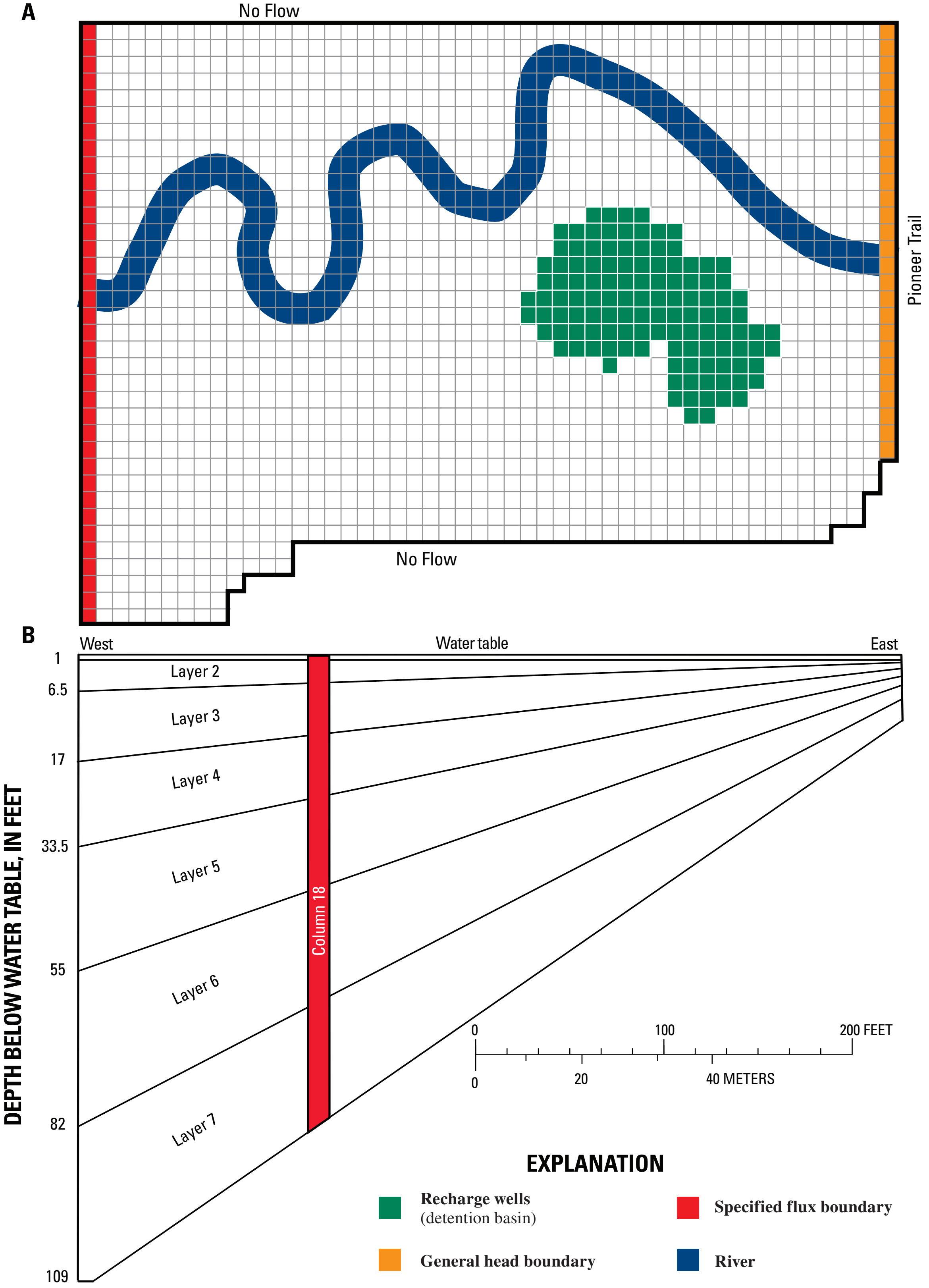


Figure 9. Schematic depicting **A**, ground-water model layer one with boundary conditions; **B**, ground-water model vertical discretization.

Initial Conditions

A uniform hydraulic conductivity was estimated through model calibration which was initially estimated to be 10 ft/d (fig. 6). Vertical anisotropy could not be estimated and a uniform value of 0.3 was assigned (Heath, 1983). A specific yield of 0.25 was assigned to layer 1 (Cohen, 1965). Storage coefficients in layers 2 through 7 were calculated as aquifer thickness times a specific storage of 1.5 x 10^{-6} ft^{-1}. Total aquifer thickness averaged 100 ft and the average storage coefficient was 1.5 x 10^{-4}.

Areal recharge and evapotranspiration were simulated as a uniform, net flux from the study area. Temporal changes in recharge were estimated from SNOTEL data collected at Heavenly Valley, California, from 2000–2004 (NRCS, 2005). The months of June, July and August were assigned negative values because evapotranspiration exceeded precipitation (fig.10C). Remaining months were grouped seasonally, with a few exceptions where a specific year had abnormally high or low precipitation. Recharge for grouped months was estimated as a single parameter (table 4, 12 groups).

Table 4. Grouping of recharge parameters as observed by SNOTEL data.

Grouped recharge parameters
January, February (2001, 2002)
January, February 2003
January, February 2004
March, April (2001, 2004)
March, April 2002
March, April 2003
May (2001-2004)
June, July, August (2001-2004)
September, October (2001-2004)
November, December (2001, 2004)
November, December 2002
November, December 2003

Evaporation rates for open water were not included as part of the calculated detention basin recharge because these rates were within the 10–15 percent uncertainty of the measurements (Stannard and Weaver, 1995). Dome evaporation rates for open water were estimated in June 2004 at the study site (Stannard, 1988). The average rate was 0.011 ft/d, which is less than 3 ft/yr, as the detention basin was dry during at least seven months per year (table 5).

The stage of standing water in the detention basin was estimated using continuously recorded water-levels in well cc03S (fig. 3). The altitude of the detention-basin bottom is 6,273.1 ft. When the water level in well cc03S exceeded this altitude, it was assumed that there was standing water in the detention basin. Data were collected from September 2001, when construction of the detention basin was complete, to August 2004.

Recharge from the detention basin was determined by two methods, both using well cc03S as a surrogate for stage. The first method used the hydrograph from cc03S for periods when the water level exceeded 6,273.1 ft. A negative slope was measured for periods after stormwater runoff additions to the basin had ceased (fig. 10). The slope is the rate of decline of water in the basin, or the infiltration rate. It was assumed that at any time water is present in the basin, the infiltration rate will decline at this same rate. Slopes taken on different infiltration events throughout the dataset had very similar infiltration rates. Infiltration through the detention basin averaged 10 ft/yr where water-level declines were 18 ft/yr and the basin was wet 566 days during the three-year period.

The second method to determine the rate of infiltration from the detention basin was to directly add up the cumulative height of water rise in the basin during each precipitation event. A threshold when water would remain in the basin, which is included in each rise, was determined to be 0.020 ft of water. This number has an error of about 33 percent and therefore is rather sensitive to the calculated feet of water. It was chosen because 0.020 ft is a reasonable number and allows the total height of water to be about 30 ft, which is consistent with the slope of the water decline method.

Table 5. Average daily evapotranspiration rates in the vicinity of Cattlemans detention basin, South Lake Tahoe, California.

	Average daily evapotranspiration rates in feet per day		
	9/23/2004	6/16/2004	12/13/2004
Detention grass south	0.016	0.026	
Detention grass north	0.012	0.035	
Detention soil east	0.013	0.012	
Detention soil west	0.009	0.015	
Creek (short) grass west	0.022	0.027	
Creek willow (& short grass)	0.020	0.026	
Creek (tall) grass east	0.017	0.027	
Creek in creek	0.005	0.011	
Snow site 3			0.003
Snow site 4			0.002
Snow site 5			0.002
Snow site 6			0.003

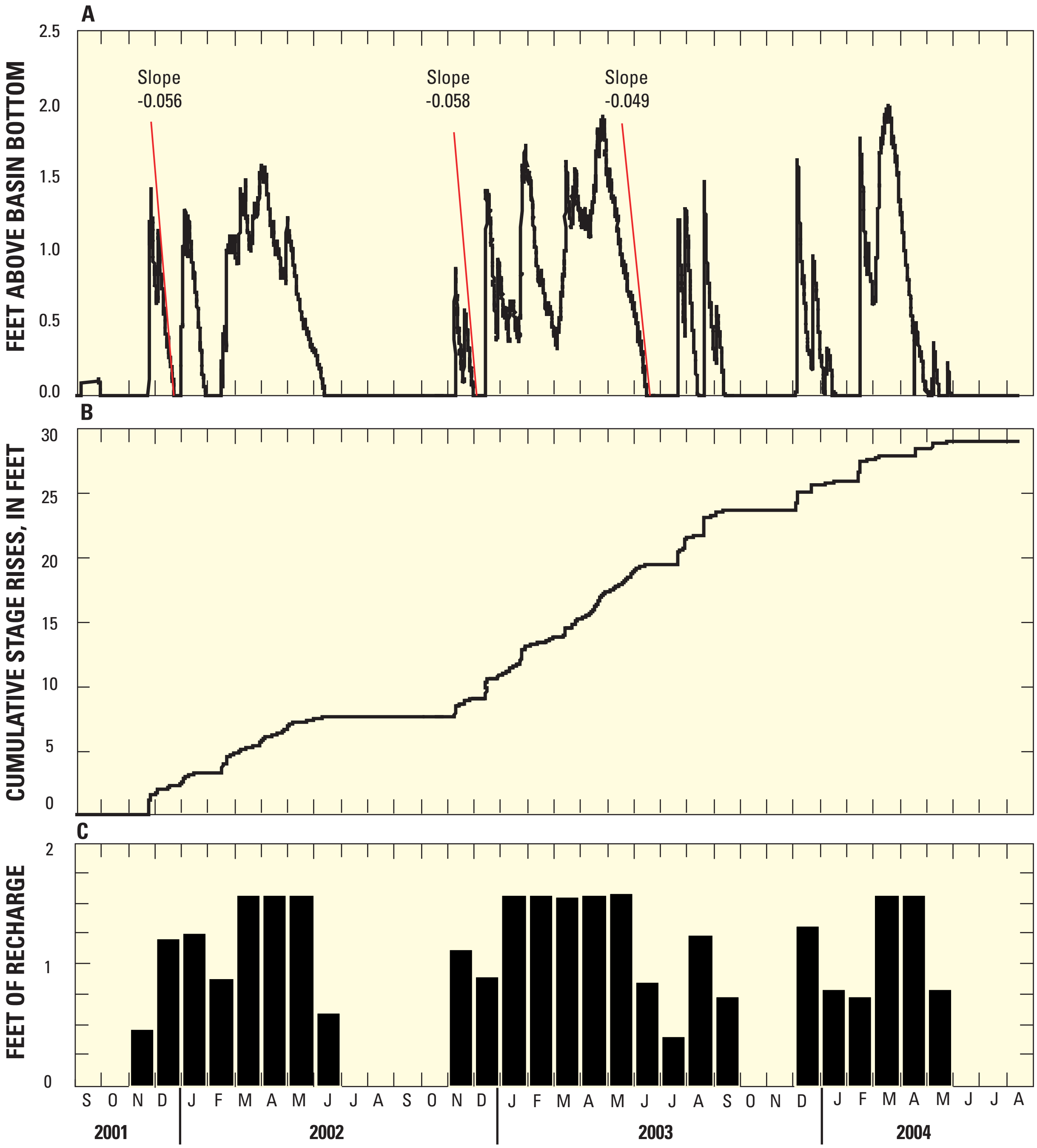


Figure 10. Graph depicting **A**, slope analysis of cc03S hydrograph method; **B**, cumulative stage rises from precipitation events method; and **C**, feet of calculated monthly recharge based on cumulative stage rises method.

Both methods of determining the amount of water entering the basin provide approximately the same number, for calculation simplicity the second method was used to determine monthly recharge rates from the detention basin.

The construction of Cattlemans detention basin in August 2001 corresponds to stress period 69. This stress period marks a disruption in the evenly applied recharge from precipitation due to the focused recharge beneath the detention basin. Therefore, 120 model cells representing the detention basin were excluded from the natural recharge and replaced at stress period 69 with specified flow cells that represent the runoff entering the detention basin (fig. 9, recharge wells). Calculated values of detention basin recharge were assigned to each cell based on the monthly rates determined by the sum of water rise method.

Ground-water/surface-water interactions were simulated between Cold Creek, a perennial stream, and the shallow aquifer using the MODFLOW river package (McDonald and Harbaugh, 1988). River cells were selected visually from an aerial photograph and assigned stages. The stages were taken from a series of field-surveyed points that were interpolated and then correlated to a Cold Creek hydrograph.

Model Calibration

Calibration is the attempt to reduce the difference between model results and measured data by adjusting model parameters. The improvement of the calibration is based on minimizing the differences between simulated and measured ground-water levels. Simulated water levels from a calibrated, deterministic ground-water model commonly depart from measured water levels despite diligent calibration efforts. The discrepancy between model results and measurements (residuals) commonly is in part the cumulative result of simplification of the conceptual model, the model grid, and the scarcity of sufficient measurements to account for the spatial variation in hydraulic properties and recharge throughout the study area.

The ground-water flow model was calibrated to 1,046 water-level measurements in 28 wells. Discharges were not included in the objective function because specified flow from the detention basin was used to constrain the model. Calibration minimized a sum-of-squares (*SS*) error, although the root-mean-square (*RMS*) error is reported instead. This is because *RMS* error is more directly comparable to actual values and serves as a composite of the average and the standard deviation of a set. *RMS* error is related to *SS* error by:

$$RMS = \sqrt{SS \Big/ \sum_{i=1}^{nobs} w_i^{\,2}} \qquad (1)$$

where

nobs is the number of simulated and measured observations that are compared

w_i is the i^{th} weight

Because measured water levels rarely coincide with the center of a cell, simulated water levels were interpolated to the measurement point from the centers of surrounding cells. Plots of measured versus simulated heads are shown in figure 11 for three wells that represent good and poor matches to measured heads.

Model calibration was further facilitated by a parameter estimation program (Halford, 2006). The parameter estimation process was initialized by using the model to establish the initial differences between simulated and measured observations or residuals, which were minimized by the parameter estimation program. Parameter changes were estimated with a quasi-Newton procedure (Gill and others, 1981) that uses sensitivity coefficients and residuals from the initial model. Sensitivity coefficients were derivatives of simulated water-level change with respect to parameter change and were calculated by the influence coefficient method (Yeh, 1986). Each parameter was changed a small amount and MODFLOW was used to compute new water levels for each perturbed parameter. Parameter changes were incorporated in the model, which created a new model with different residuals. Parameters were estimated, new models were created, and new residuals were calculated iteratively until residual change could not be improved. Fourteen parameters were used to calibrate this model: hydraulic conductivity, 12 monthly recharge groups and conductance of the general head boundary. Parameters were used as global multipliers to change hydraulic properties and recharge rates by a fixed amount.

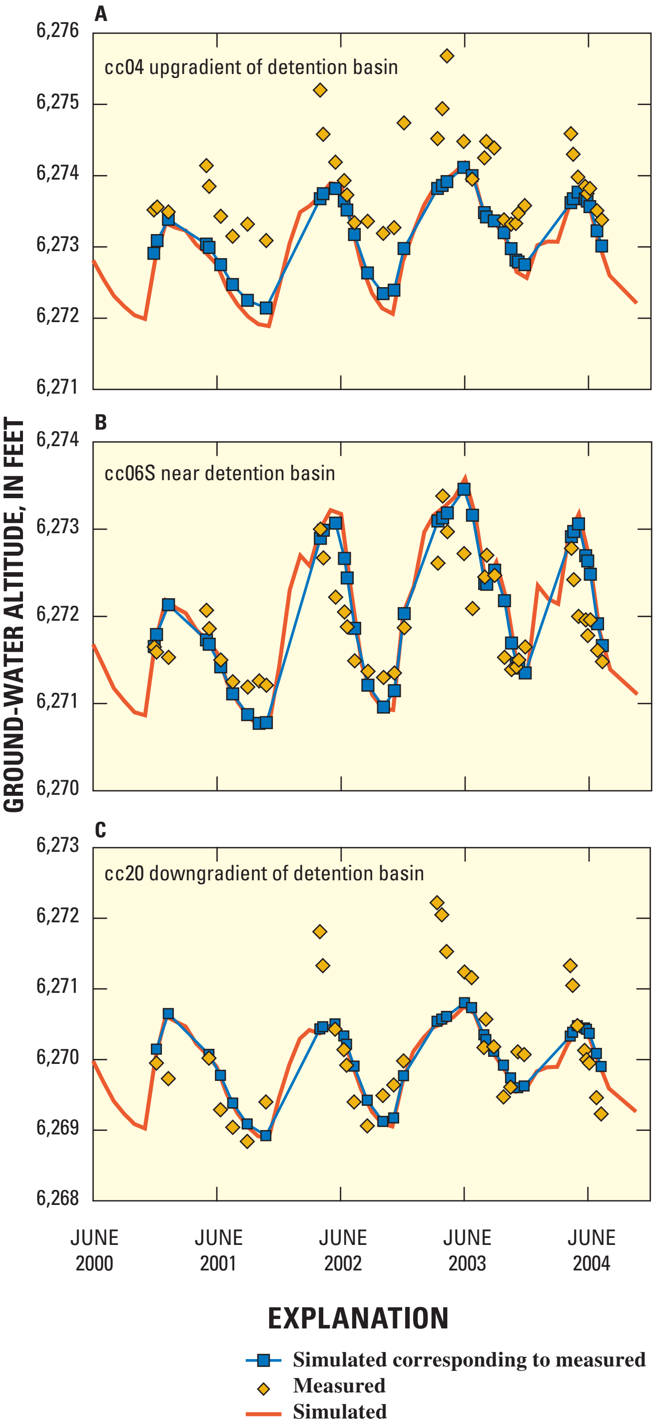


Figure 11. Hydrographs showing examples of simulated head values that **A**, underestimate; **B**, fit well with; and **C**, underestimate peaks with measured head values.

The calibrated model was a good fit to the observed data (fig. 12). Deviations from the observed data were mostly in wells located upgradient of Cattlemans detention basin (cc03 and cc04) where the general head boundary may not have accurately represented ground-water flux under Pioneer Trail (figs. 12 and 13). Simulated water-levels typically predicted lower than observed water-levels. Wells nearest Cattlemans detention basin and those downgradient of it display a good fit, although those downgradient tend to underestimate the peaks (fig. 11).

Model Results

The final estimated value of horizontal hydraulic conductivity was 2.6 ft/d. This is reasonable as it falls into the 0.5–70 ft/d range of values estimated from slug tests (Green and others, 2004; table 6). Recharge estimates appeared realistic at about 1.3 ft/yr. Grouped parameters show recharge occurring generally during expected months (table 6).

Simulated ground-water contours of the Cattlemans detention basin study area were compared throughout a single year, as well as, between a dry (2002) and wet (2003) year (fig. 14). Early in the year, the gradient was altered as a result of water infiltration from the detention basin, although Cold Creek is still the dominant hydraulic process. By August and November, when the detention basin is dry, Cold Creek is the only surficial influence on subsurface flow. The time of year does not affect the direction of flow. The pattern and direction of ground-water flow does not change during the study period, although during 2003 the gradient increased due to more precipitation and recharge.

Ground-water modeling has shown that the contribution of ground-water discharge from Cattlemans detention basin is extremely small when compared to the flow in Cold Creek. Flow in Cold Creek and ground-water flux through the model was calculated over two years from August 2002 to August 2004. During this period Cold Creek had an average flow of 8.9 ft^3/s and the simulated ground-water flux was 0.011 ft^3/s. In order to determine what fraction of this flux through the model discharges to separate reaches of Cold Creek or flows out the western boundary, flow paths were calculated by particle tracking using MODPATH (Pollock, 1994). One particle per model cell within the detention basin was tracked, 120 in all. Particles were placed in the center of each cell at the beginning of stress period 69, which corresponds to the completion of the detention basin construction in September 2001. River boundary cells were separated from the rest of the model into a single zone to determine the number of particles reaching Cold Creek.

A modified model was created to allow ground water originating in the detention basin enough time to flow through the entire study area. The number of stress periods was increased to 250, corresponding to October 2016, although it was a more than sufficient number of stress periods. Five time steps were assigned per stress period through the end of August 2004 and reduced to 2 time steps beyond this date to minimize calculation time. Extraneous stress periods were assigned two typical years of repeating data.

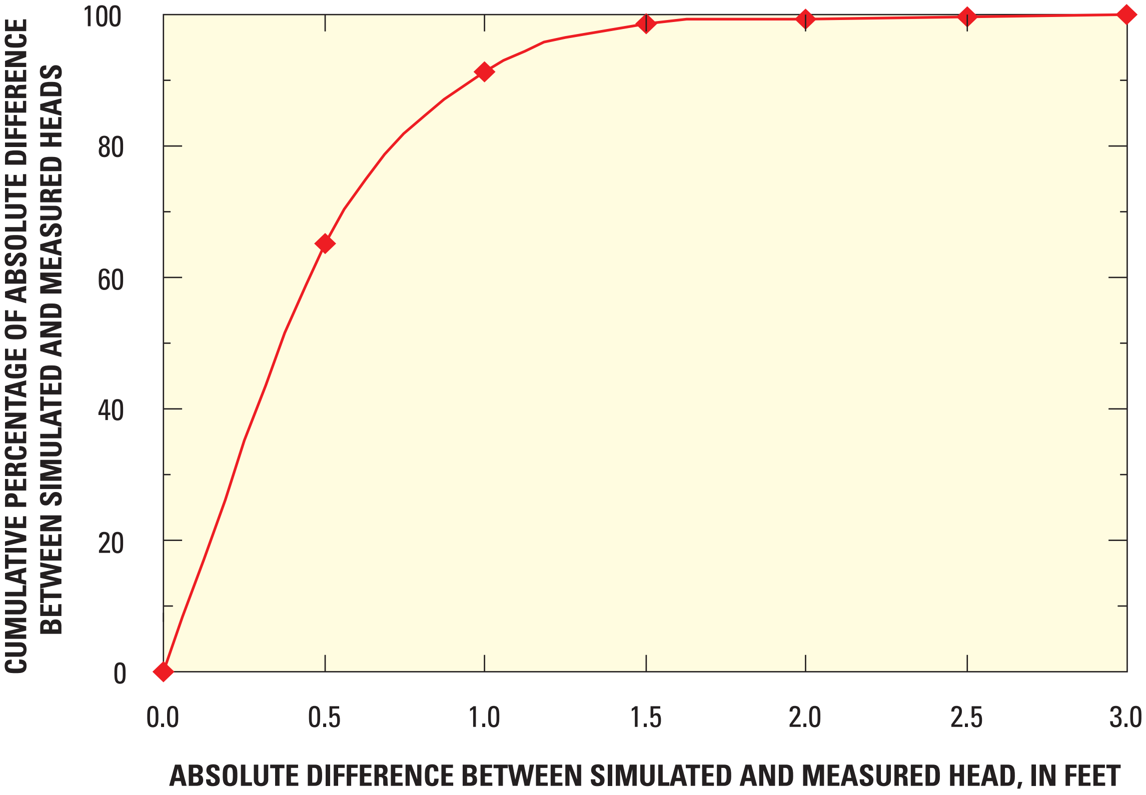


Figure 12. Graph of cumulative percent of absolute difference versus absolute difference between simulated and measured water-level measurements.

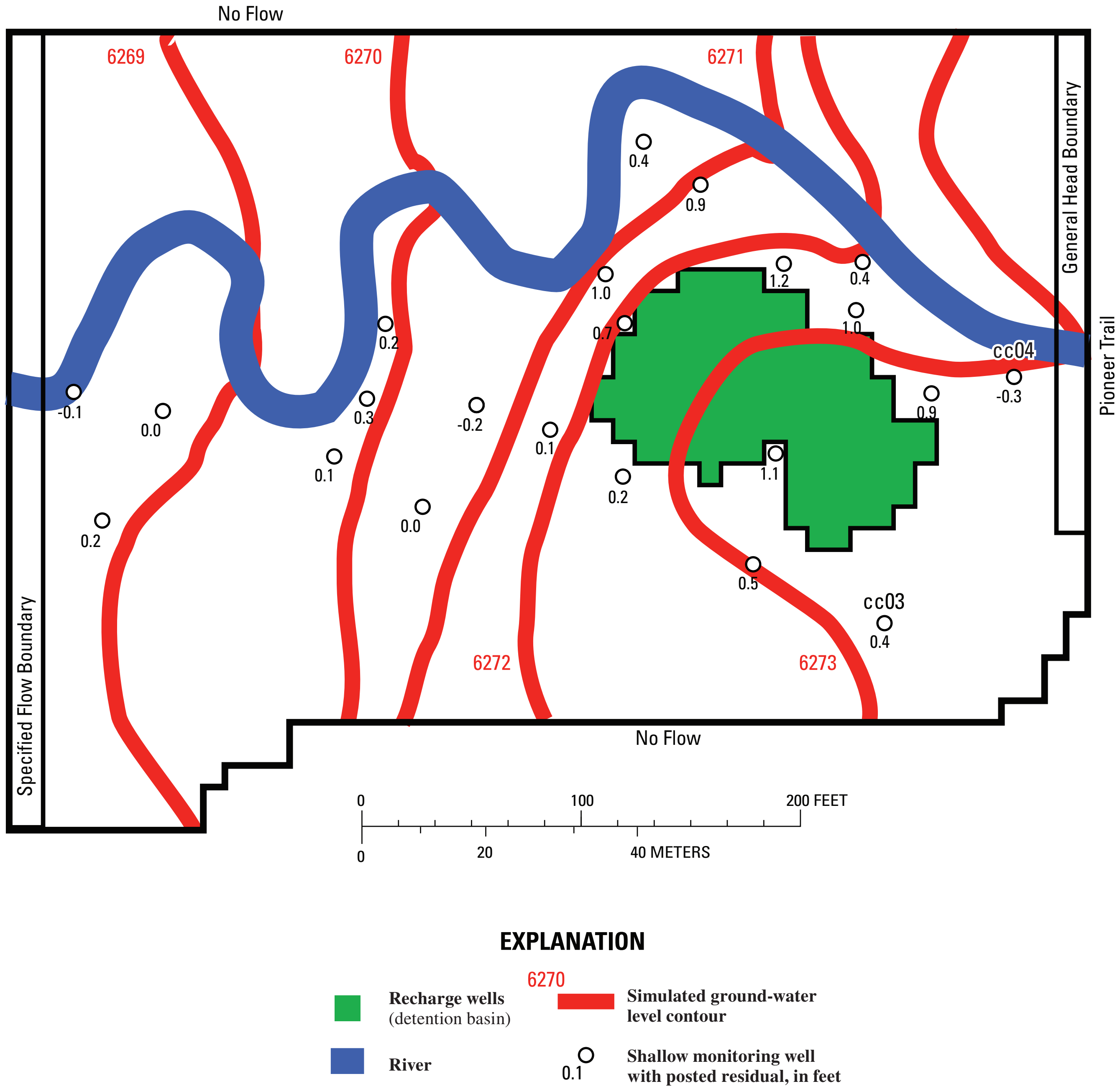


Figure 13. Plots of simulated ground-water levels in the vicinity of Cattlemans detention basin, South Lake Tahoe, California.

About 34 percent, or 0.004 ft^3/s, of the total ground water within the model area originates from the detention basin. Particle tracking results suggest that of the 0.004 ft^3/s, 45 percent, or 0.0018 ft^3/s, actually discharges to Cold Creek (table 7). Remaining ground water discharges through the downgradient western boundary. The ground water that does not discharge to Cold Creek within set model boundaries may or may not enter into Cold Creek at a location further downstream outside the model domain. Other possibilities include ground water discharging as ET or directly into Lake Tahoe. For the scope of this model, it can only be stated that 45 percent of ground water discharging from the detention basin reaches Cold Creek. Of this 45 percent, ground water entering directly downstream of the detention basin makes up about 9 percent, whereas about 36 percent enters slightly more downgradient (table 7).

Model Sensitivity

To determine how model parameters affected simulation results, each estimated parameter was varied independently from 0.2 to 5 times their calibrated value. This range was greater than the uncertainties associated with the parameters, but provided a more complete perspective on parameter

Table 6. Simulated ground-water flow model parameters and corresponding estimates.

Recharge parameters	Parameter estimate (inches)	Relative sensitivity
January, February (2001, 2002)	3.93	5
January, February 2003	2.36	8
January, February 2004	1.22	11
March, April (2001, 2004)	2.23	4
March, April 2002	2	6
March, April 2003	1.98	9
May (2001-2004)	0.75	10
June, July, August (2001-2004)	0.04	13
September, October (2001-2004)	0.06	14
November, December (2001, 2004)	1.91	2
November, December 2002	0.89	7
November, December 2003	0.44	12
Other parameters	**(feet per day)**	
Horizontal hydraulic conductivity	2.6	1
General head boundary	2.6	3

sensitivity. Model sensitivity was described in terms of weighted *RMS* error. The sensitivity of model results to changing one parameter while all others are held at their calibrated values is shown in figure 15. Residuals were determined to be most sensitive to changes in horizontal hydraulic conductivity of the aquifer. The model was least sensitive to changes in the effective recharge rate from precipitation during the grouped months of October and November (fig. 15).

Model sensitivity to specified boundary conditions and hydraulic properties was investigated with alternative models (table 8). Each alternative model was calibrated after changing selected boundary conditions and hydraulic properties from original model values. The original model was considered the preferred model for which other model runs are compared to determine the effects of parameter changes. Hydraulic conductivity estimates in the alternative models differed most from estimates in the original model and ranged between 1.6 and 6.6 ft/d. Model error remained 40 percent greater than the original model when the stage of Cold Creek was decreased 1 ft (table 9). The lowest *RMS* error was calculated when the detention basin recharge was reduced by 50 percent. Even though the error is lower, it does not seem reasonable to have less than 1 ft/yr recharge due to the documented precipitation and the amount of lush vegetation present in the study area.

The analysis of model sensitivity and application of alternative models showed that the calibrated model is not necessarily unique. Different recharge rates could be simulated that also provide a balance to the water budget and an acceptable match to observed water levels, even though grouping months together attempted to limit this. However, this calibrated model provides a reasonable representation of the relative distribution of inflow and outflow through the study area using the available parameter estimates based on field measurements.

Model and Data Limitations

The flow model reasonably describes local ground-water flow beneath Cattlemans detention basin, but it cannot exactly mimic the true system. Simulated values often are similar to, but do not precisely match, measured values. The ground-water flow model is a numerical approximation of the flow system, and is limited by simplifications in the conceptual model, discretization effects, and the scarcity of measurements to account for the spatial variation in hydraulic properties throughout the study area.

Inherent in the conceptual model is the assumption that all sources of flow and stresses on the natural system are represented in the numerical model. Because measurements of water levels used to constrain the model calibration were made over a short time period and measurements of streamflow are very limited, it is not known how completely or how accurately the numerical model simulates the natural system.

Areal discretization of the study area into a rectangular grid of cells and vertical discretization into layers forced an averaging of hydraulic properties. Each model cell represents an averaged block of the aquifer system. Due to this averaging, the model cannot simulate the local effects on flow caused by aquifer heterogeneity. Further simplification of the heterogeneous aquifer system occurred in the methods used to describe the distribution of the hydraulic conductivity. The lack of sufficient measurements to account for the spatial variations in hydraulic properties necessitated the uniform assignment of hydraulic properties across the study area. Simplifying the model to this degree does not invalidate the model results, but should be considered when interpreting the results.

The timing of recharge application within a stress period was not a good representation of natural recharge. Recharge for the entire stress period was applied in the first time step. Although this gives the model the appropriate amount of recharge, if it were applied more evenly throughout the stress period the flow could be altered slightly.

Table 7. MODPATH results showing the percentage of ground water from Cattlemans detention basin that discharges to Cold Creek

Flow system component	Percent
Upper reach	9
Middle reach	7
Lower reach	29
Total	45
Western boundary	53

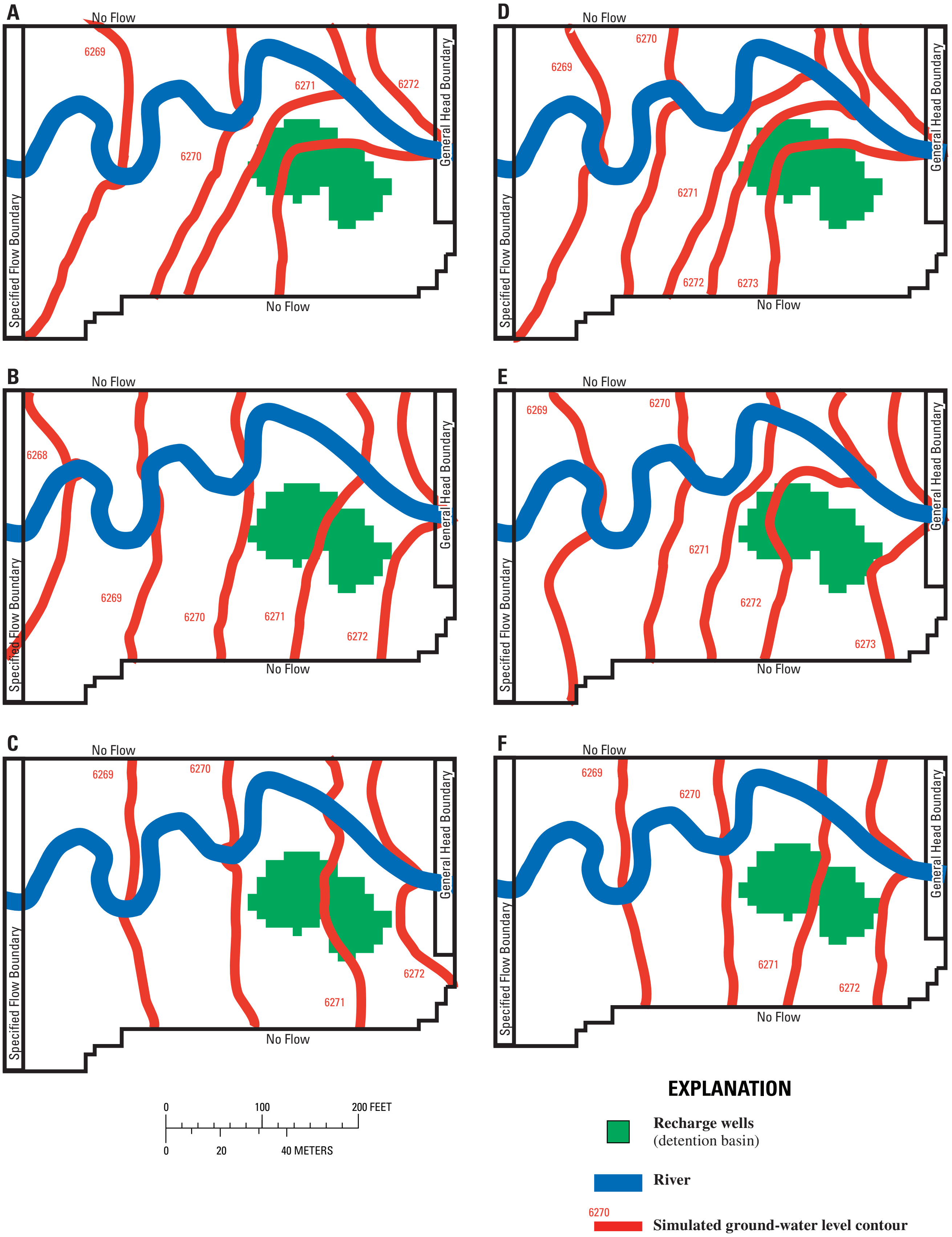


Figure 14. Graphs showing simulated ground-water level contour comparison of 2002 (dry) and 2003 (wet). **A**, March 2002, stress period 75; **B**, August 2002, stress period 80; **C**, November 2002, stress period 83; **D**, March 2003, stress period 87; **E**, August 2003, stress period 92; and **F**, November 2003, stress period 95.

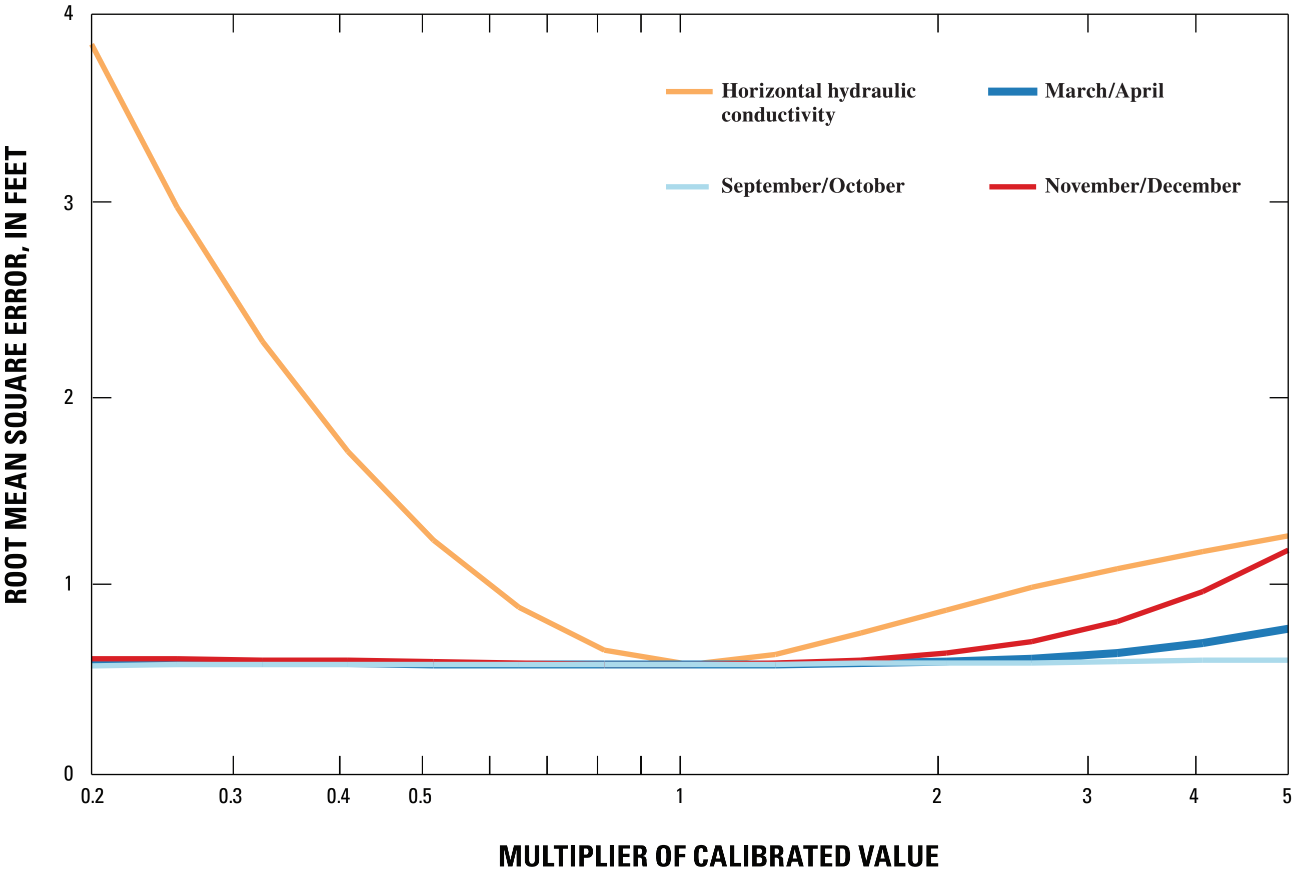


Figure 15. Model sensitivity to independent changes in selected calibration parameters.

Table 8. Alternative ground-water flow models.

[Abbreviations: ft/d, feet per day]

Alternative model	Explanation	Modification
Western boundary 1	Specified flow boundary is constant with depth	Specified flow = 0.007 ft/d
Western boundary 2	Specified flow boundary is constant with depth and vertical hydraulic conductivity is reduced	Specified flow = 0.007 ft/d and vertical hydraulic conductivity = 0.1 ft/d
River stage 1	Increased river stage	+ 1 foot stage
River stage 2	Decreased river stage	- 1 foot stage
Basin recharge 1	Increased recharge	+ 50% recharge wells
Basin recharge 2	Decreased recharge	- 50% recharge wells

The reliability of ground-water flow models is affected by the choice and accurate representation of boundary conditions and aquifer representation. Simulated water levels near model boundaries may be less reliable than simulated water levels that are distant from boundaries. Boundary effects are most notable when there are nearby stresses. The western specified flow boundary of this model was not located as far as it could have been from the detention basin. Interactions of the detention basin and this boundary were not investigated specifically, although no noticeable influences were detected. For purposes of simplification, the upper model boundary (the water table) was simulated as a confined system. The variations in transmissivity with respect to water-level change were trivial and limited error was introduced as a result of this simplification.

Table 9. Ground-water model results from selected simulations as compared to the preferred run.

[Abbreviations: ft^3/s, cubic feet per second; ft, foot; ft/d, foot per day]

	Model Run		
	Preferred	Basin recharge 2	River Stage 2
Ground-water flux through model, ft^3/s	0.011	0.009	0.014
Root mean square error, ft	0.17	0.15	0.24
Horizontal hydraulic conductivity estimate, ft/d	2.6	1.6	1.7

Water Quality in and near Cattlemans Detention Basin

Michael S. Lico

Chemical Composition of Water

Cold Creek

Cold Creek carries water that originates mostly from melting snow in the surrounding mountains. This water is made up of a fairly constant ionic composition dominated by calcium, sodium, and bicarbonate (fig. 16). The water typically is very dilute, with specific conductance values ranging from 24 to 74 µS/cm (fig. 17). These values are similar to those reported for six South Lake Tahoe area streams (between 24 and 47 µS/cm) by Rowe and others (2002). Other characteristics measured in the field are typical of streams in the Lake Tahoe Basin. Dissolved oxygen is near saturation and pH ranges from 5.2 to 7.5. Chloride and sulfate concentrations generally are low and have median concentrations of 0.5 and 1.6 mg/L, respectively. Chemical analyses and other information for samples from Cold Creek are listed in Appendix C.

In general, nutrient concentrations in Cold Creek are low. Total nitrogen (ammonia, organic nitrogen, nitrite, and nitrate) concentrations in samples collected from Cold Creek during this study range from 0.092 to 0.44 mg/L as N (median value of 0.31 mg/L as N). Rowe and others (2002) found median concentrations of total nitrogen to be between 0.11 and 0.19 mg/L as N in six streams in the South Lake Tahoe area. Dissolved (filtered through a 0.45 micrometer filter) phosphorus concentrations in samples from Cold Creek during this study ranged from 0.01 to 0.024 mg/L as P and had a median concentration of 0.016 mg/L as P (table 10). Total phosphorus (unfiltered samples) concentrations in samples from Cold Creek during this study ranged from 0.016 to 0.042 mg/L as P and had a median concentration of 0.025 mg/L as P. Median concentrations of total phosphorus in six streams in the South Lake Tahoe area were between 0.21 and 0.40 mg/L as P as reported by Rowe and others (2002). The concentrations of total phosphorus found in Cold Creek during this study are an order of magnitude less than those reported by Rowe and others (2002). Total suspended sediment in Cold Creek ranged between 6 and 34 mg/L.

Ground Water

Ground water beneath and near the detention basin has a variable ionic composition, shown in figure 16. The most common cations present include calcium, sodium, and iron. Dominant anions typically are bicarbonate and chloride (fig. 16). Sulfate concentrations generally are low (median concentration of 0.2 mg/L). On the whole, major-ion concentrations in water from the shallow aquifer do not differ substantially from that in the deeper aquifer. Iron is sometimes the most abundant cation (in equivalents per liter) present in ground water. Specific conductance values for ground water measured in the study area ranged from 31 to 673 µS/cm and had a median value of 230 µS/cm (fig. 17). The water with high iron concentrations typically had no measurable dissolved oxygen and high concentrations of dissolved organic carbon and ammonia.

Generally, nutrient concentrations in ground water within the shallow meadow deposits are higher than those within the deeper sand and gravel aquifer. In the shallow meadow deposits, ammonia typically is the most abundant nitrogen species and concentrations range from 0.001 to 18.4 mg/L as N with a median concentration of 0.26 mg/L as N (table 10). In the deeper sand and gravel deposits, the water tends to be more oxic with ammonia concentrations ranging from 0.006 to 0.641 mg/L as N with a median concentration of 0.086 mg/L as N. Nitrate concentrations in the shallow and deeper aquifer are similar with median concentrations of 0.043 and 0.042 mg/L as N, respectively. Phosphorus concentrations in the shallow meadow deposits (median of 0.107 mg/L as P) generally are higher than those in the deeper sand and gravel aquifer (median of 0.0325 mg/L as P). Orthophosphate (soluble reactive phosphorus) makes up a small percentage of the total dissolved phosphorus in most water samples (table 10 and Appendix C).

Stormwater

Stormwater generally is from two sources; summer thunderstorms and other rain events, and spring snowmelt. Two culverts funnel water from the surrounding terrain to the Cattlemans detention basin. Stormwater has a variable ionic composition with dominant cations being either calcium or sodium and dominant anions being bicarbonate or chloride (fig. 16). The composition is dependent on the source; calcium bicarbonate type water is from rain events and sodium chloride type water is from spring snowmelt (fig. 18). Sulfate concentrations generally are low (median concentration of 1.1 mg/L). Specific conductance values ranged from 35 to 421 µS/cm and had a median value of 70 µS/cm (fig. 17).

Average total nitrogen concentration of samples collected from storm drains flowing into the detention basin was 0.54 mg/L as N during spring snowmelt and 0.80 mg/L as N during rain events. The average nitrogen concentrations during spring snowmelt and rain events was 0.63 mg/L as N. Average total phosphorus concentrations of samples collected from storm drains was 0.16 mg/L as P during spring snowmelt and 0.12 mg/L as P during rain events.

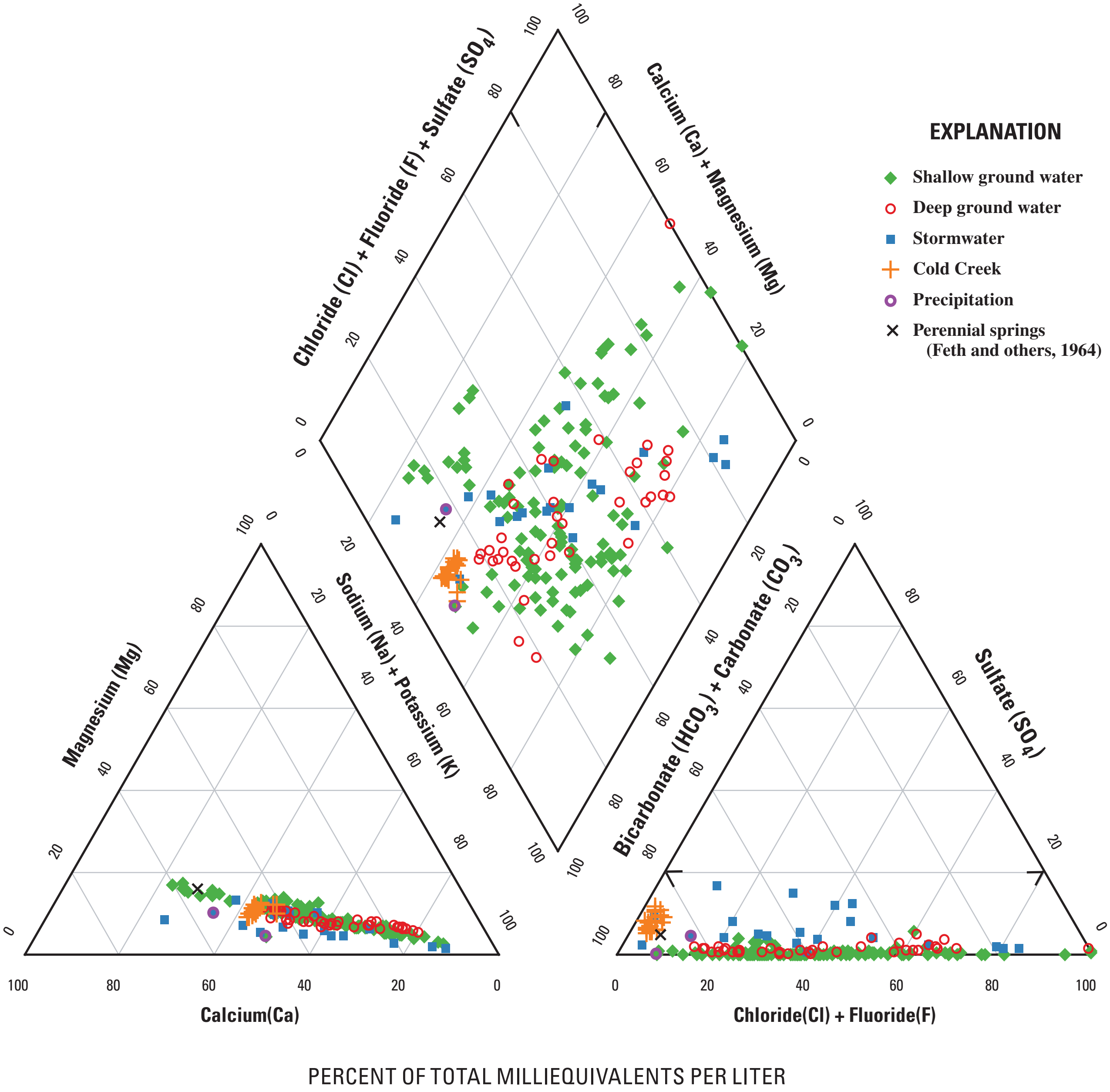


Figure 16. Equivalents diagram showing the ionic composition of ground water, stormwater, water in Cold Creek, and precipitation in samples collected from Cattlemans detention basin study area, South Lake Tahoe, California.

Precipitation

Precipitation generally is very dilute (dissolved solids less than 10 mg/L) with calcium, sodium, and bicarbonate as the major ionic components (fig. 16). Ammonia was the most prevalent nitrogen species and ranged in concentration from 0.01 to about 6 mg/L as N. Phosphorus concentrations ranged from 0.006 to 1.2 mg/L as P.

Effect of Detention Basin on Water Quality

General Chemical Composition

Prudic, Wood, and others (2005) describe, in detail, changes in the water chemistry beneath and near the detention basin, utilizing data through November 2003. Additional data collected between April 2004 and June 2005 further support

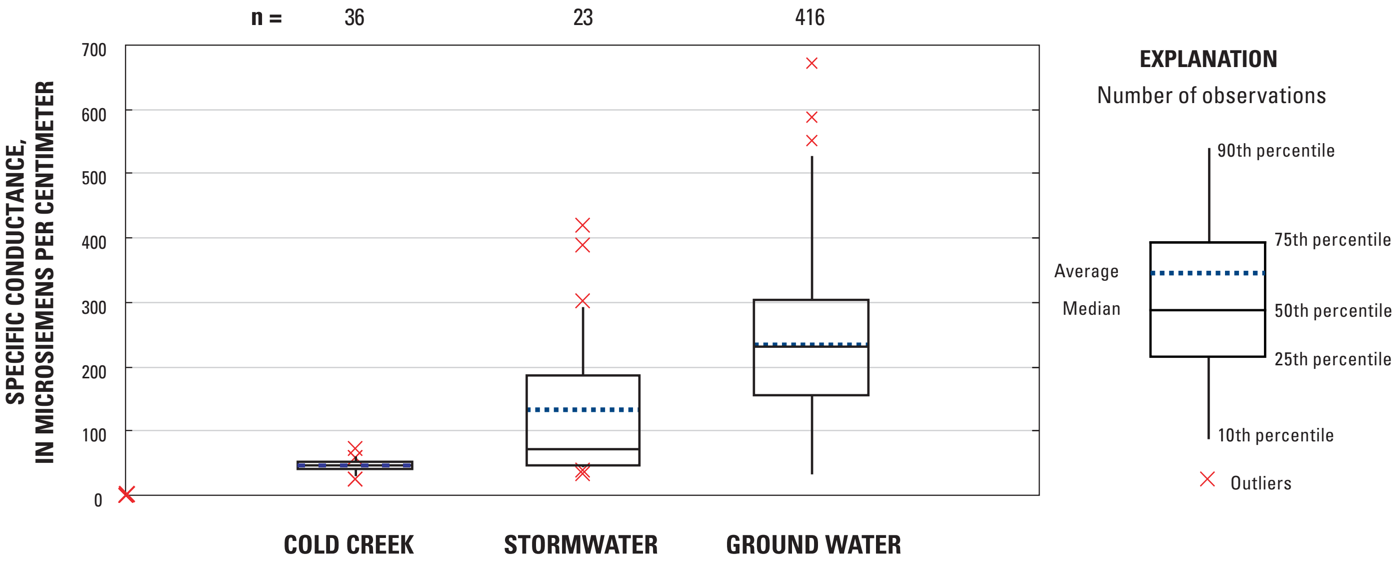


Figure 17. Boxplot showing the distribution of specific conductance values in Cold Creek, stormwater and ground-water samples from Cattlemans detention basin study area, South Lake Tahoe, California.

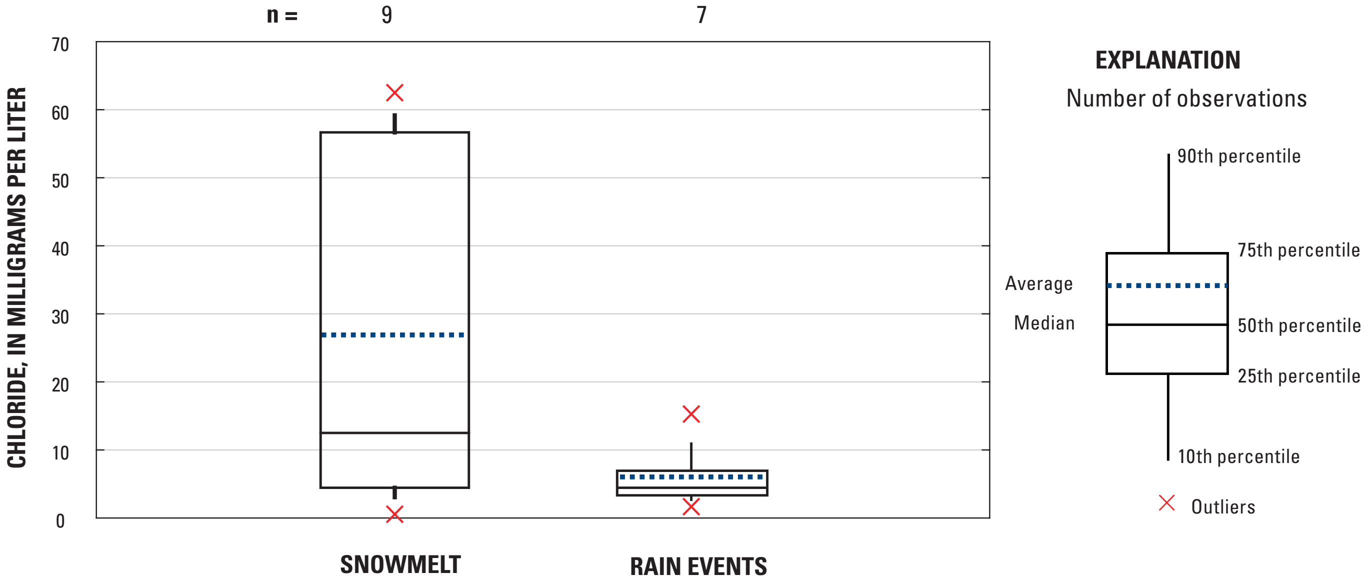


Figure 18. Boxplot showing chloride concentrations in runoff to Cattlemans detention basin, South Lake Tahoe, California. Snowmelt concentrations represent samples during winter snow events and spring runoff (March–June). Rain events typically are during July through November.

their conclusions. In summary, the chemical composition of ground water in the area of the detention basin did not change substantially after construction as compared to analyses of samples collected prior to the detention basin. The similarity in concentrations before and after construction of the basin can be seen in a qualitative sense in several figures in Prudic, Wood, and others (2005). Water collected from deeper wells in the brown sand and gravel had a similar chemical composition to water from shallow wells in the organic silt deposits except sulfate concentrations generally were higher and dissolved iron concentrations were about one half of those from the organic silt deposits (fig. 19). The principal dissolved (filtered) cations remained sodium, iron, and calcium, and the principal dissolved anions were bicarbonate and chloride in both the shallow and deeper wells. Concentrations of the trace elements did not change following construction of the detention basin and most were below laboratory reporting limits (see Appendix C).

Nutrient concentrations in ground water from the meadow deposits did not change substantially after construction of the detention basin. Dissolved ammonia was the most common form of nitrogen both before and after

Table 10. Median concentrations, range of concentrations, and number of observations of nutrients in the study area, 2001–05.

[Listed in each cell are the median (in milligrams per liter as N or P), range in concentration, and the number of observations (n); Symbols: --, no data available; <, less than]

	Ammonia, filtered	Ammonia plus Organic N, filtered	Ammonia plus Organic N, total	Nitrate plus Nitrite, filtered	Phosphorus, filtered	Phosphorus, total	Ortho-phosphate, filtered
Cold Creek	0.004	0.11	0.3	0.011	0.016	0.025	0.007
	<0.001-0.025	0.07-0.76	0.09-0.41	0.001-0.065	0.01-0.024	0.016-0.042	0.004-0.011
	n = 22	n = 20	n = 9	n = 18	n = 22	n = 9	n = 22
Shallow ground water	0.26	0.5		0.043	0.107		0.05
	0.001-18.4	0.01-19	--	0.001-0.554	0.005-0.408	--	0.001-0.382
	n = 305	n = 331		n = 328	n = 329		n = 327
Deep ground water	0.086	0.26		0.042	0.033		0.01
	0.006-0.641	0.005-1.8	--	0.002-0.461	0.02-0.336	--	0.001-0.398
	n = 94	n = 93		n = 94	n = 94		n = 94
Stormwater runoff	0.03	0.485	0.79	0.044	0.066	0.19	0.04
	0.001-1.1	0.1-3.1	0.22-21	0.004-0.425	0.021-1.12	0.068-3.09	0.008-1.1
	n = 39	n = 38	n = 39	n = 40	n = 40	n = 37	n = 40
Precipitation	0.035a	0.23	0.28	0.043	0.062	0.031	0.06
	0.01-15.2	0.15-0.31	0.06-6	--	0.027-0.096	0.006-1.24	0.031-0.089
	n = 13	n = 2	n = 13	n = 1	n = 2	n = 12	n = 2

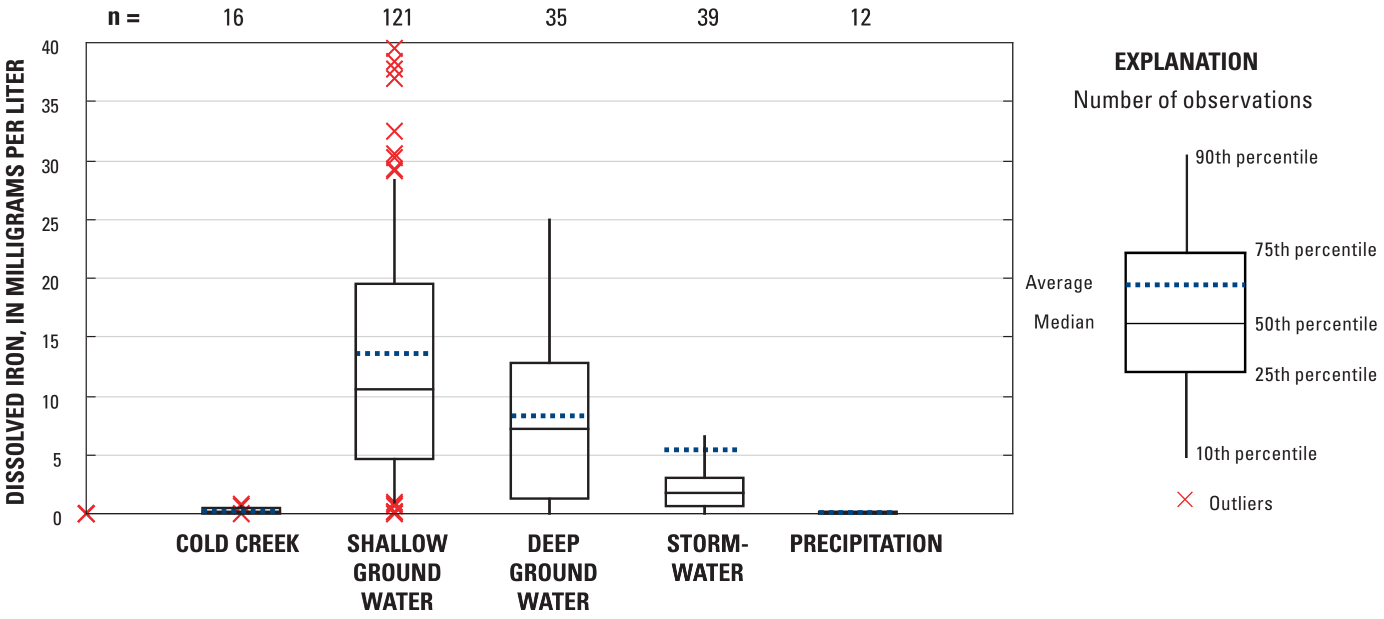


Figure 19. Boxplot showing dissolved iron concentrations in water samples collected from Cattlemans detention basin, South Lake Tahoe, California.

construction of the detention basin. Concentrations ranged from 0.004 to 18.4 mg/L prior to construction and 0.001 to 15 mg/L after construction. Dissolved nitrate plus nitrite concentrations remained substantially the same and were always less than 0.55 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.

Spatial Changes in Water Quality

To evaluate spatial changes in water quality in the study area, Prudic, Wood, and others (2005) divided the monitoring wells into three groups as follows (fig. 3): wells near the detention basin (wells cc03S, cc04, cc05, cc06S, cc08S, cc09, cc10, cc13S, cc15, and cc16); wells near Cold Creek (wells cc01, cc07, cc12, cc14, cc18, cc19S, and cc23); and wells in the meadow (wells cc17S, cc20, cc21, cc22, and cc24). Patterns of major-ion and nutrient concentrations had no noticeable change due to the construction of the basin. Total dissolved nitrogen concentrations were highest in the area of the detention basin prior to its construction and remained high after construction. Near the detention basin, the total nitrogen concentrations slightly decrease in time, but still are much higher than in other parts of the study area. Total dissolved nitrogen concentrations generally were the same before and after construction near Cold Creek and beneath the meadow (Prudic, Wood, and others, 2005).

Dissolved phosphorus concentrations generally were higher in wells near Cold Creek than in the area of the detention basin or in the meadow (Prudic, Sager, and others, 2005). Except for the anomalously high dissolved iron concentrations at well cc08S in the middle of the detention basin, iron concentrations were similar in all three groups. The relatively high iron concentrations of ground water in the shallow organic silt deposits are consistent with anoxic conditions.

In general, mean and median concentrations of dissolved nitrogen, phosphorus, and organic carbon in the deeper sand and gravel increased slightly, 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 construction of the detention basin.

Temporal Changes in Water Quality

Several wells show seasonal variations in the chemical composition of ground water with patterns dependent on location of the well with respect to the detention basin (fig. 20). Peak concentrations of bicarbonate, chloride, sodium, and iron in ground water from organic silt deposits at well cc03S generally occurred in April and May of each year, whereas peak concentrations at well cc08S generally occurred later during June and July. Concentrations of most constituents did not change substantially from 2001 to 2005, except for bicarbonate concentrations at well cc08S. At well cc08S, Prudic, Wood, and others (2005) reported bicarbonate concentrations slowly decreased during the two years after construction of the detention basin in August and September 2001 (fig. 20). This trend continued to the end of data collection (June 2005). The decrease in bicarbonate concentrations at well cc08S may be related to a change in microbial activity in the organic silt deposits beneath the detention basin.

Peak concentrations for most dissolved constituents in ground water from well cc13S occurred in July (similar to the timing of peak concentrations at well cc08S). The chloride concentration peaked each year in July with a relatively large peak in July of 2002. The timing of the chloride peaks was right after the spring snowmelt (fig. 18). The most likely source of the chloride peaks was from road salt, which was applied to Pioneer Trail during snow events. Most recently, during the winter of 2004–05, the salt application was changed from solid sodium chloride to a brine solution that was applied to the roadway prior to the snowfall (Jennifer Quickel, El Dorado County Department of Transportation, oral commun., 2005). The effect of the brine application to rates of chloride infiltration into the ground-water system is unknown. The lag in peak chloride concentration may be due to travel-time of the ground water between infiltration and well cc13S.

Dissolved nitrate plus nitrite concentrations are consistently low in all water samples from wells near the detention basin and make up a small part of the total nitrogen in the ground water. Even though the concentrations are low, a seasonal variation is present at most wells with higher concentrations occurring during the late spring and summer (fig. 21). Seasonal increases in dissolved Kjeldahl nitrogen (DKN, ammonia plus organic nitrogen) concentrations occur each year during the summer and fall at most wells in the area. The magnitude of the seasonal changes in DKN concentrations has decreased from 2001 to 2005 in many of the wells (fig. 21; wells cc03S and cc16 for example). Near the detention basin (wells cc03S, cc08S, and cc13S), the dissolved orthophosphate (DOP) concentrations mirrored the dissolved phosphorus (DP) concentrations until the spring of 2004 (fig. 21). At that time, DOP concentrations fell to near the laboratory reporting limit (0.001 mg/L as P) while DP remained at concentrations similar to those reported previously until its concentration fell in the spring of 2005. Because DP concentrations at these wells were low during only one sampling since construction of the basin (spring of 2005), it is unknown whether these low concentrations will persist.

Suspended sediment concentrations were less in water within the basin compared to water entering the basin. The concentrations of suspended sediment entering the basin from two storm drains (32 samples) ranged from 0 to 1,540 mg/L and had mean and median values of 165 and 74 mg/L, respectively (Appendix C). The concentrations of suspended sediment in water collected (6 samples) near the weir, that allows water to flow out of the basin, ranged from 9 to 45 mg/L and had mean and median values of 26 and

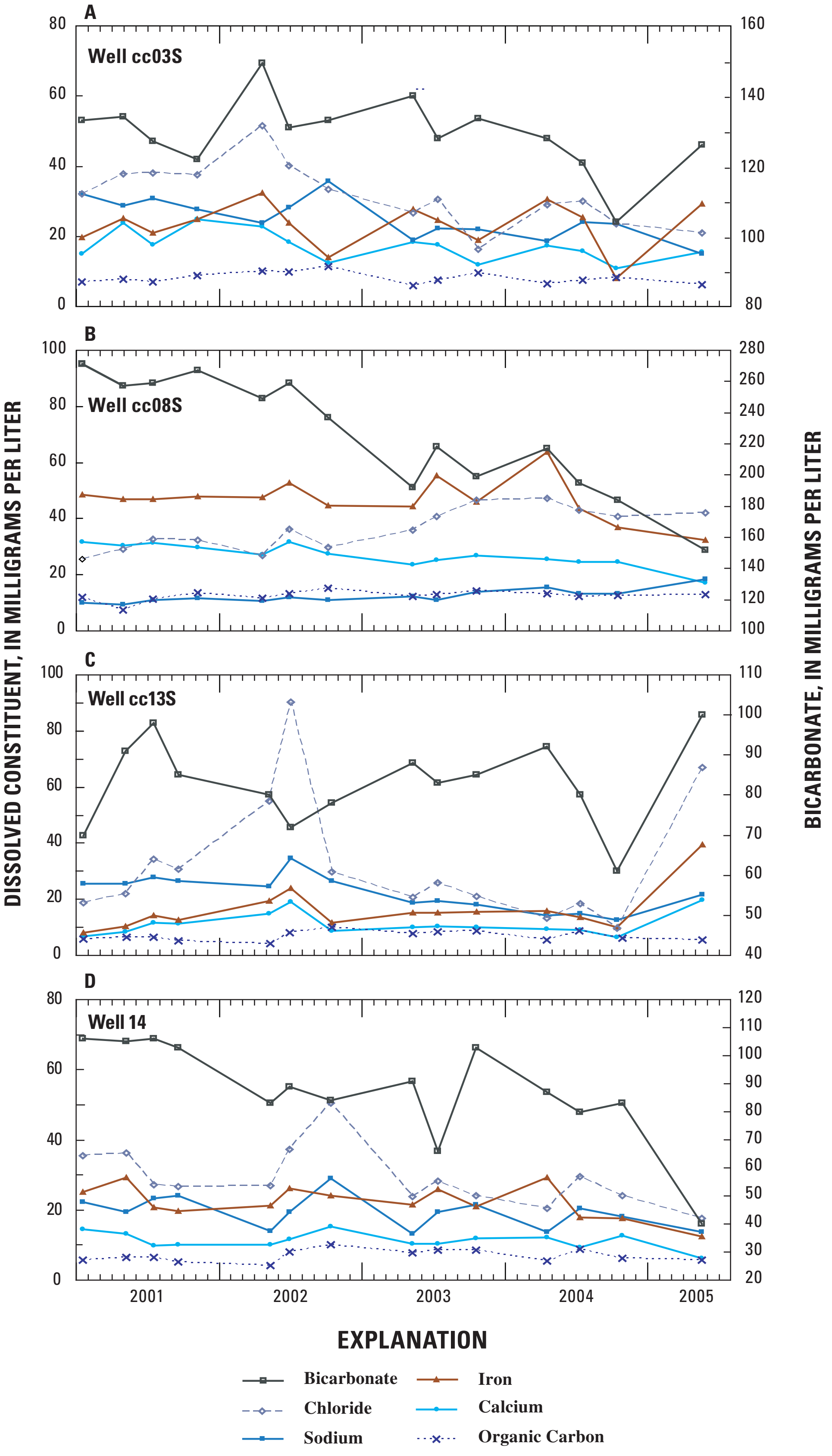


Figure 20. Concentrations of major ions, iron, and dissolved organic carbon in ground-water samples collected from January 2001 to June 2005 from wells in Cattlemans detention basin study area, South Lake Tahoe, California.

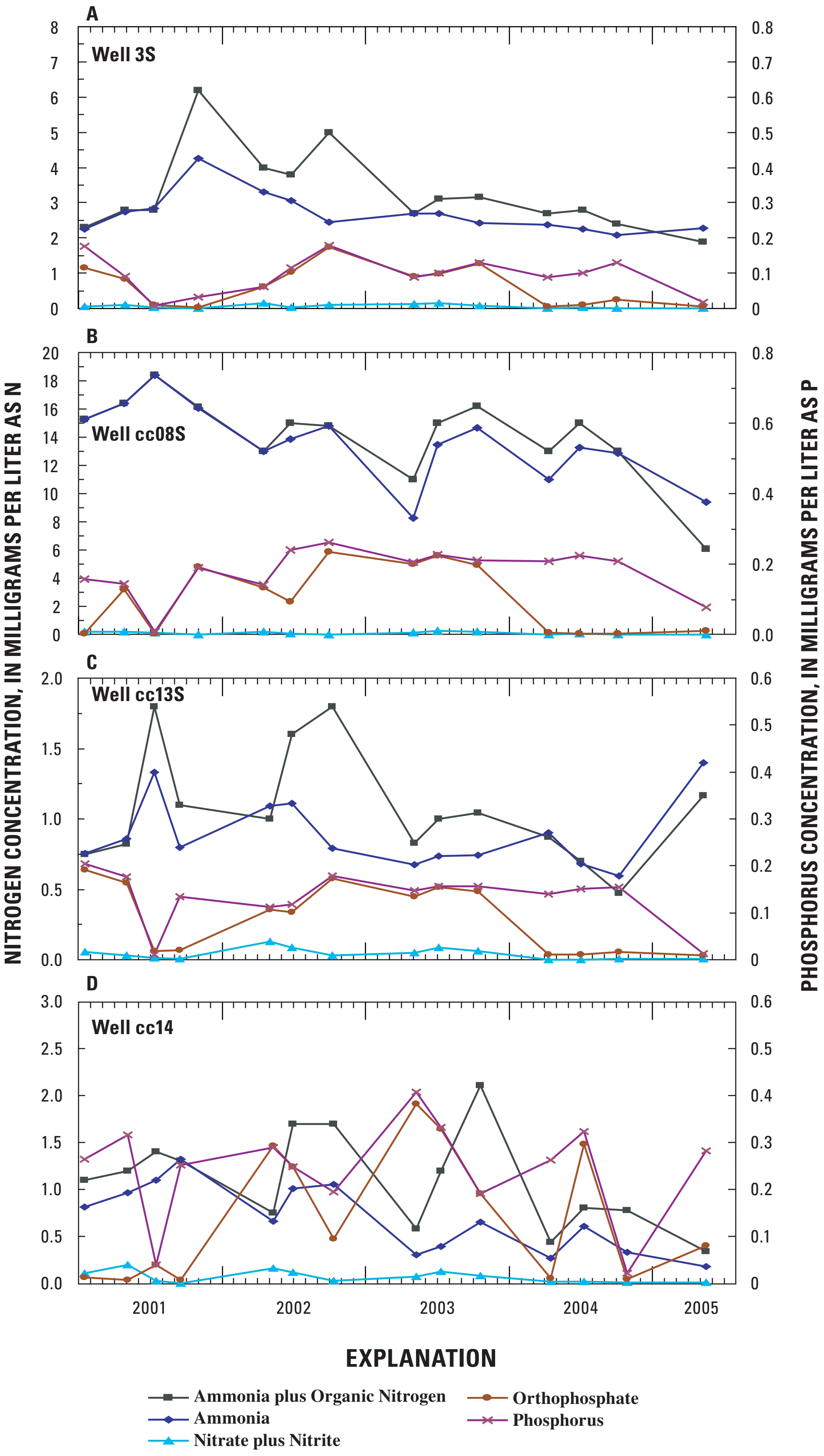


Figure 21. Concentrations of nutrients in ground-water samples collected from January 2001 to June 2005 from wells in Cattlemans detention basin study area, South Lake Tahoe, California.

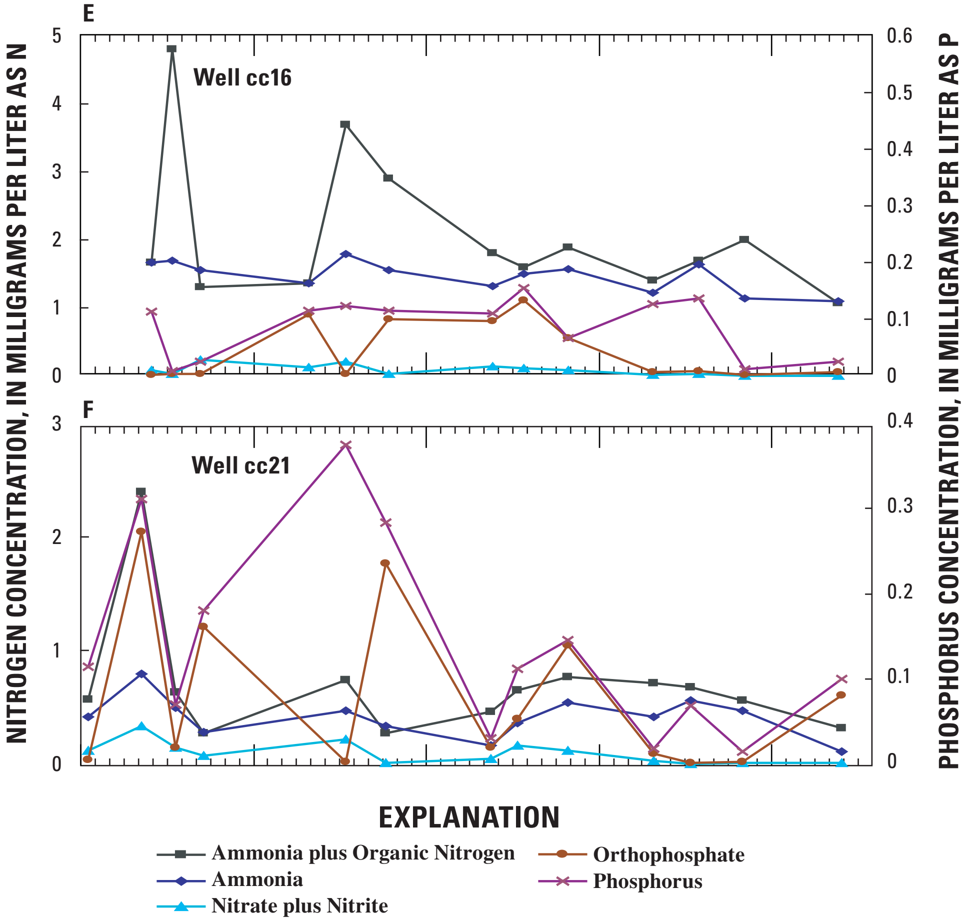


Figure 21. Concentrations of nutrients in ground-water samples collected from January 2001 to June 2005 from wells in Cattlemans detention basin study area, South Lake Tahoe, California—Continued.

23 mg/L, respectively (Appendix C). However, as previously stated, little flow was observed leaving the pond over the weir during the study period. Concentrations of suspended sediment are reduced as a result of settling of sediment in the basin.

Processes Affecting Water Quality near the Detention Basin

The chemical characteristics of ground water in the Cold Creek area are derived from the reaction of ground water with the local granitic rocks and sediment derived from these rocks. The ionic composition of the water is similar to those reported by Feth and others (1964) with calcium, sodium, and bicarbonate being the dominant ions. Imprinted on this common water type, derived from Sierra Nevada granitic rock, are the effects of several other geochemical processes. Typically, recently recharged ground water in the Sierra Nevada has measurable dissolved oxygen because there is little reactive material, such as organic carbon, to remove oxygen from the water. Ground water in the upgradient part of the study area (wells cc01 and cc02) had measurable amounts of dissolved oxygen (between 1.8 and 4.2 mg/L). Most of the ground water beneath the detention basin was anoxic (<0.1 mg/L dissolved oxygen). The dissolved oxygen was consumed by the oxidation of abundant sedimentary organic matter in the shallow meadow deposits. Observations made during drilling of monitoring wells indicated that decomposing meadow grass was present beneath the layer of fill in the detention basin area (Prudic, Sager, and others, 2005). This would provide a large source of organic matter that could react with oxygen and form carbon dioxide. The general reaction controlling the consumption of oxygen is:

$$(CH_2O) + O_2 = CO_2 + H_2O \qquad (2)$$

Organic matter, represented in equation 2 as CH_2O, could be either dissolved organic carbon (as humic or fulvic acids) or sedimentary organic matter. In this case it represents buried meadow grass and its organic-rich soil. Natural organic matter does not contain only carbon and oxygen as depicted in equation 2, but typically also contains many other elements, including nitrogen and phosphorus. Average values of nitrogen in soil humic substances have been reported to be

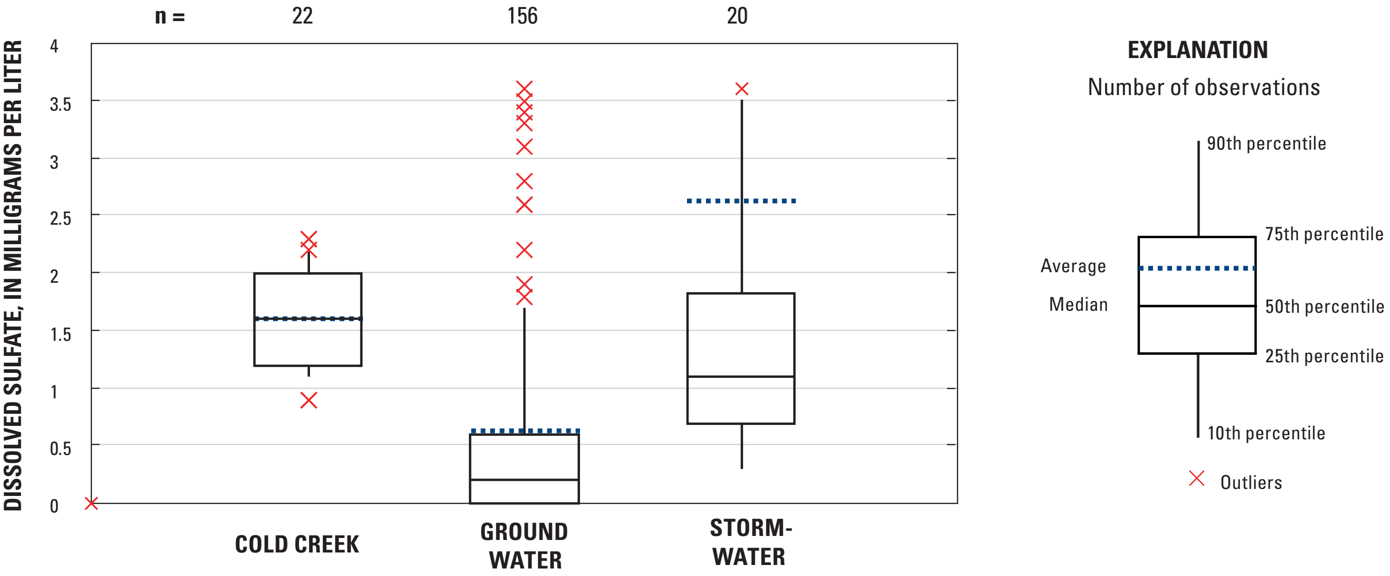


Figure 22. Boxplot of dissolved sulfate concentrations in water samples from the Cattlemans detention basin, South Lake Tahoe, California.

between 0.8 and 4.3 percent (Drever, 1988). Thurman (1986) reports nitrogen content of fulvic and humic acids in ground water as 0.9 and 2.0 percent, respectively. Nitrogen content of terrestrial plant material (angiosperms and gymnosperms) was reported as 3.1 percent by Lerman (1979). Phosphorus concentrations in fulvic and humic acids are less than nitrogen concentrations and are reported by Thurman (1986) to be about 0.3 and 0.46 percent. Phosphorus content of terrestrial plant material (angiosperms and gymnosperms) was reported to be between 0.2 and 0.3 percent by Lerman (1979).

As organic matter is oxidized, the complex fulvic and humic acid fractions are broken down into simpler organic compounds that can be further utilized as an energy source by bacteria present in the ground water. As a result, some of the nitrogen and phosphorus present in the dissolved organic carbon is released into the ground water as ammonia, organic nitrogen compounds, and dissolved phosphorus. This process most likely is the reason total nitrogen (mostly ammonia) concentrations increase greatly in ground water beneath the basin (as high as 18 mg/L as N in well cc08S) as compared to the concentrations upgradient (usually less than 1 mg/L as N in wells cc01 and cc02). An increase in phosphorus concentrations was not found in the area where oxidation of organic matter occurred.

Another process that affects the water quality near the detention basin is sulfate reduction. This process occurs when all of the available dissolved oxygen has been consumed. Ground water beneath the study area had lower sulfate concentrations than potential recharge sources in the immediate vicinity of the basin (Cold Creek and stormwater) indicating some process is consuming dissolved sulfate (fig. 22). The reaction controlling reduction of sulfate typically is mediated by microbes and can be represented by:

$$2(CH_2O) + SO_4^{2-} = 2HCO_3^{-} + H_2S \qquad (3)$$

Hydrogen sulfide, a product of sulfate reduction, was detected during the sampling of several wells in the area. The highest observed bicarbonate concentrations in the study area were in samples from well cc08S, which was directly beneath the detention basin (Appendix C). This well also had high concentrations (18 mg/L as N) of total nitrogen (mostly ammonia), high concentrations of dissolved iron (34 to 55 mg/L), high concentrations of dissolved organic carbon (8 to 14 mg/L), low concentrations of dissolved oxygen (less than 1 mg/L), and low concentrations of nitrate (less than 0.3 mg/L as N). The above observations are indicative of a reducing environment where sulfate reduction is taking place.

Cold Creek in the Cattlemans detention basin study area. Photograph by James L. Wood.

Changes in Microbial Activity

By Ean Warren, David E. Prudic, and E. Michael Godsy

Concentrations of Microbial Populations

The concentrations of six physiological classes of microorganisms were measured each year using the MPN method at each of the temporary borehole sites located within one foot of each other in the shallow gray silt and sand and in the deeper, more oxidized brown sand and gravel. Concentrations of aerobic-respiring microorganisms attached to the sediment varied from 45 to 77,000 MPN per gram dry sediment from 2001–04 (table 11). Concentrations on sediments from the shallow gray silt and sand were relatively stable with time, although concentrations spiked in 2002 at the lower basin (CCMP2) site and in 2003 at the upper basin (CCMP3) and background (CCMP4/CCMP5) sites (fig. 23). For the shallow depth, concentrations at the downgradient (CCMP1) site were consistently less than those at the lower and upper basin sites. Concentrations on sediments from the deeper brown sand and gravel varied over several orders of magnitude, with 2004 samples having at least an order of magnitude fewer microorganisms than the same locations in 2003. Suspended aerobic microorganisms showed a general trend of decreasing concentration between 2002 and 2004. In addition, there were lower concentrations of suspended microorganisms than attached. Also, the samples from the deeper locations had lower concentrations than those from the shallow depths. The exceptions are the samples from the upper basin, which also had greater concentrations of attached bacteria than at other deep locations.

Few denitrifying microorganisms were found at the site (table 12); the concentrations of most samples lie within two standard deviations (2σ) of each other. The two exceptions were on sediments from the shallow gray silt and sand collected at the lower basin site in 2004 and from the deeper brown sand and gravel collected at the background site in 2003 (fig. 24). All samples with attached concentrations above the detection limit (30 microorganisms per gram of sediment) had significantly lower suspended concentrations.

Concentrations of attached heterotrophic fermenting microorganisms remained high in the shallow samples for each year sampled (table 13). Attached populations in the deep samples were generally lower than the shallow. Concentrations suspended in the ground water were relatively low and decreased with depth. Again the deep sample at the upper basin site had elevated suspended numbers. The attached and suspended concentrations in the shallow samples remained relatively constant with time. The deeper samples either were consistently low or decreased with time to approach detection limits (fig. 25; 2 microorganisms per milliliter of porewater or 70 microorganisms per gram of sediment). Unfortunately, samples from 2001 were not successfully determined because the microorganisms did not grow in the media.

The first year following completion of the detention basin, 2002, showed a large increase in the concentrations of attached, iron-reducing microorganisms. The increase occurred at both the background and basin sites in the shallow attached population (table 14; fig. 26). The highest numbers occurred at the shallow lower basin site and the deep upper basin site for both the attached and suspended populations. After 2002 concentrations decreased to below detection limits (2 microorganisms per milliliter of porewater or between 6 and 300 microorganisms per gram of sediment).

Concentrations of sulfate-reducing microorganisms were initially high on the sediment and in the ground water at both the background and basin sites (table 15). However, concentrations after the first year decreased to or below the detection limit (fig. 27; 2 microorganisms per milliliter of porewater or between 4 and 30 microorganisms per gram of sediment). Methanogens were frequently detected but in low numbers at or near the detection limit (table 16; fig. 28; 2 microorganisms per milliliter of porewater or between 4 and 30 microorganisms per gram sediment).

Microbial Populations and Redox Conditions

The chemical and microbial samples taken in 2001, before stormwater filled Cattlemans detention basin, indicate that both the shallow gray silt and sand and the deeper brown sand and gravel were predominantly sulfate-reducing with some methanogenic activity. Under sulfate-reducing conditions, concentrations of sulfate-reducing microorganisms, dissolved ammonium, and reduced iron are expected to be high, whereas methanogens, methane, sulfate, nitrate, and dissolved oxygen concentrations are expected to be low. Nitrate (less than 0.3 mg/L) and dissolved oxygen concentrations measured in nearby wells (median value of less than 0.3 mg/L) were low prior to the filling of the detention basin (Prudic, Sager, and others, 2005).

Sulfate-reducing microbial populations were relatively high in all samples (fig. 27). Methanogenic microorganisms were present, albeit in low concentrations (fig. 28). However, not many methanogenic microorganisms need to be present to have a significant impact (Bekins and others, 1999). Sulfate concentrations in water sampled from the temporary holes were low compared with the background sites (table 17), indicating an active sulfate-reducing microbial community. Methane concentrations were low but detectable (table 18). Reduced iron concentrations were not very high, but that may be due to precipitation along with the sulfide produced. Sediments had relatively high concentrations of extractable ammonium, whereas nitrate concentrations were consistently below detection (table 19). These data suggest that the aquifer was

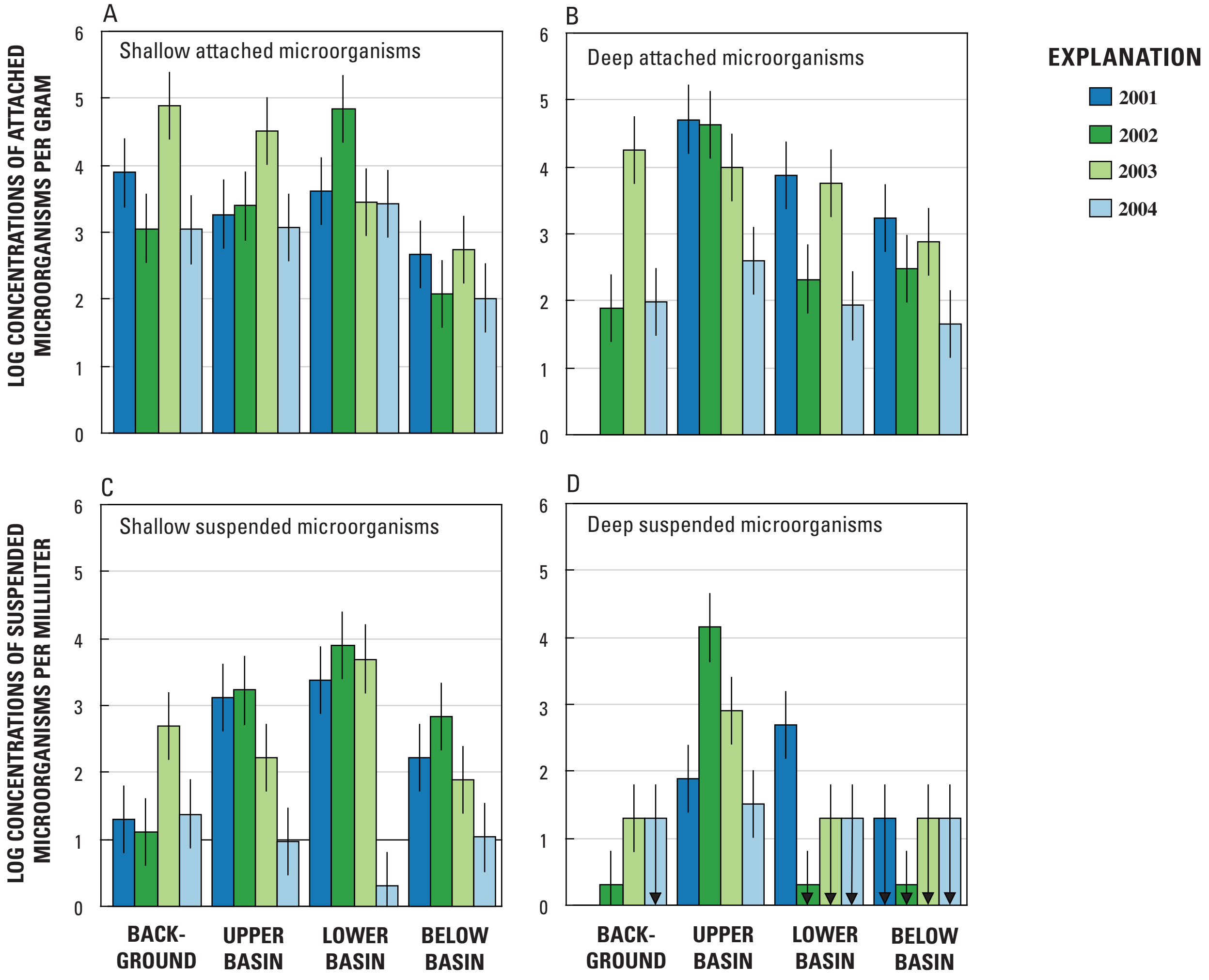
Table 11. Concentrations of attached and suspended aerobic microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (numbers per gram of dry sediment)				Suspended microorganisms (numbers per milliliter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
				Shallow				
CCMP1S	470	120	550	100	170	690	80	11
CCMP2S	4,200	70,000	2,900	2,600	2,400	7,900	4,900	2
CCMP3S	1,900	2,500	33,000	1,200	1,300	1,700	170	9
CCMP4S/5S[2]	7,700	1,100	77,000	1,100	20	13	490	24
				Deep				
CCMP1D	1,800	310	770	45	<20	<2	<20	<20
CCMP2D	7,600	210	5,700	85	490	2	<20	<20
CCMP3D	51,000	42,000	9,700	400	79	14,000	790	33
CCMP5D[2]	--	78	18,000	96	--	2	20	<20

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. "Background" contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 23. Graphs showing concentrations of attached and suspended aerobic microorganisms on log scale.

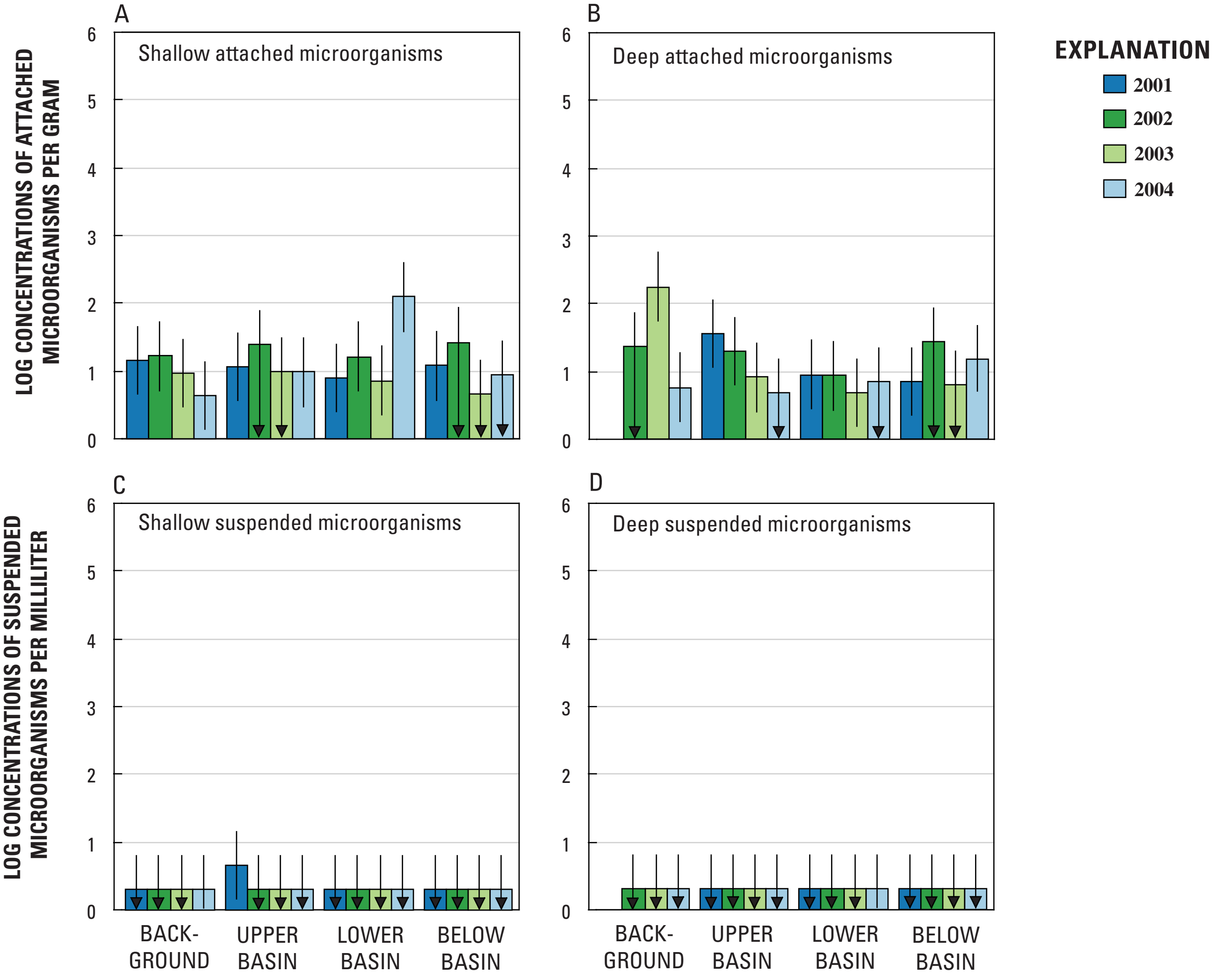
Table 12. Concentrations of attached and suspended denitrifying microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Acronym: MPN, Most Probable Number. Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (concentration in MPN per gram of sediment)				Suspended microorganisms (concentrations in MPN per liter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
				Shallow				
CCMP1S	12	<27	<5	<9	<2	<2	<2	<2
CCMP2S	8	16	7	120	<2	<2	<2	<2
CCMP3S	11	<25	<10	10	5	<2	<2	<2
CCMP4S/5S[2]	15	17	9	4	<2	<2	<2	2
				Deep				
CCMP1D	7	<27	<6	15	<2	<2	<2	<2
CCMP2D	9	9	5	<7	<2	<2	<2	<2
CCMP3D	36	20	8	<5	<2	<2	<2	2
CCMP5D[2]	--	<23	180	6	--	<2	<2	<2

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. "Background" contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 24. Graphs showing concentrations of attached and suspended denitrifying microorganisms on log scale.

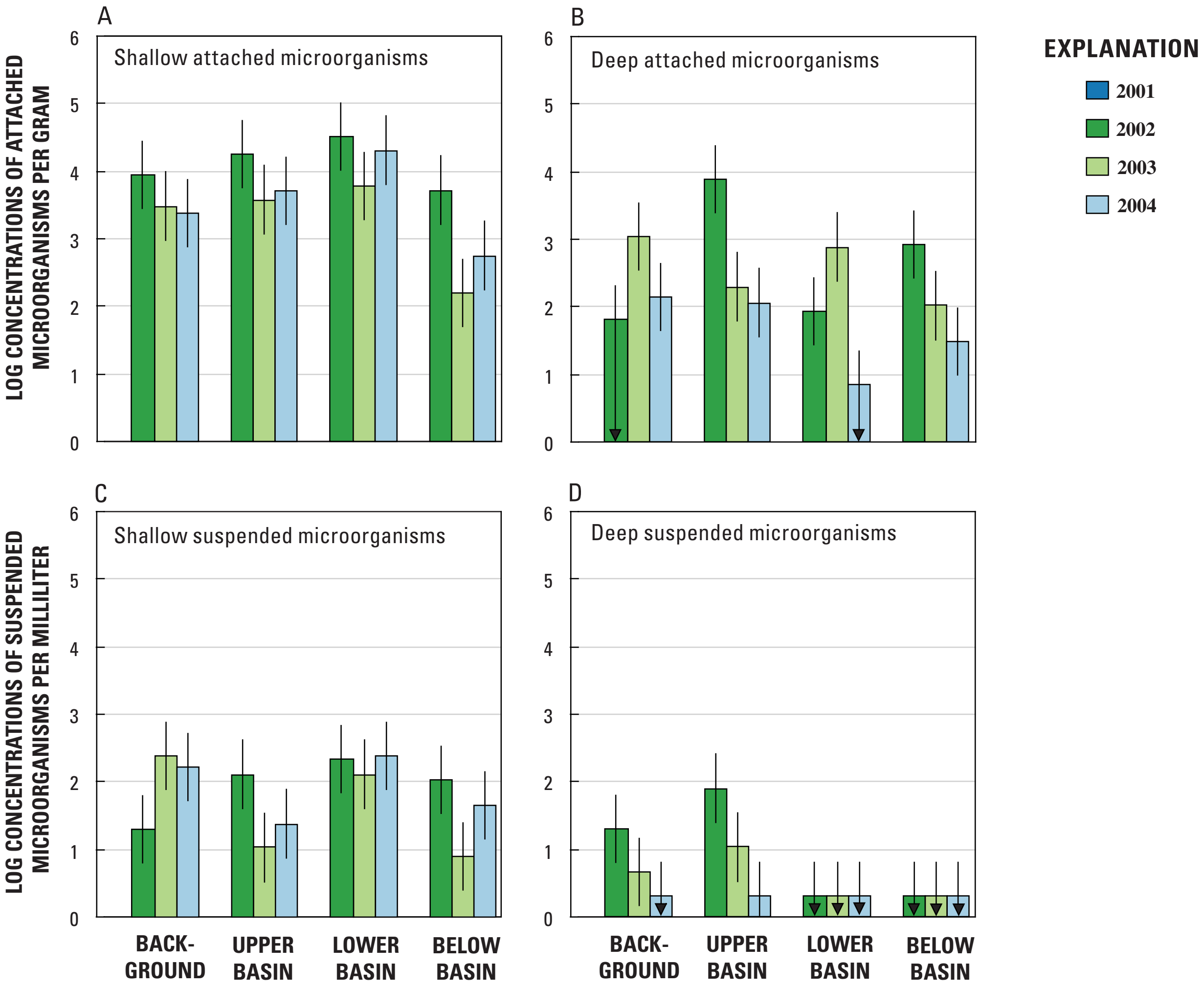
Table 13. Concentrations of attached and suspended fermenting microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Abbreviations: ND, concentrations not successfully determined. Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (numbers per gram of dry sediment)				Suspended microorganisms (numbers per milliliter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
Shallow								
CCMP1S	ND	5,200	160	560	ND	110	8	45
CCMP2S	ND	32,000	6,100	20,000	ND	220	130	240
CCMP3S	ND	18,000	3,800	5,200	ND	130	11	24
CCMP4S/5S[2]	ND	8,800	3,000	2,400	ND	20	240	170
Deep								
CCMP1D	ND	840	110	31	ND	<2	<2	<2
CCMP2D	ND	86	780	<7	ND	<2	<2	<2
CCMP3D	ND	7,800	200	120	ND	79	11	2
CCMP5D[2]	--	<65	1,100	140	--	20	5	<2

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were samples in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. “Background” contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 25. Graphs showing concentrations of attached and suspended fermenting microorganisms on log scale.

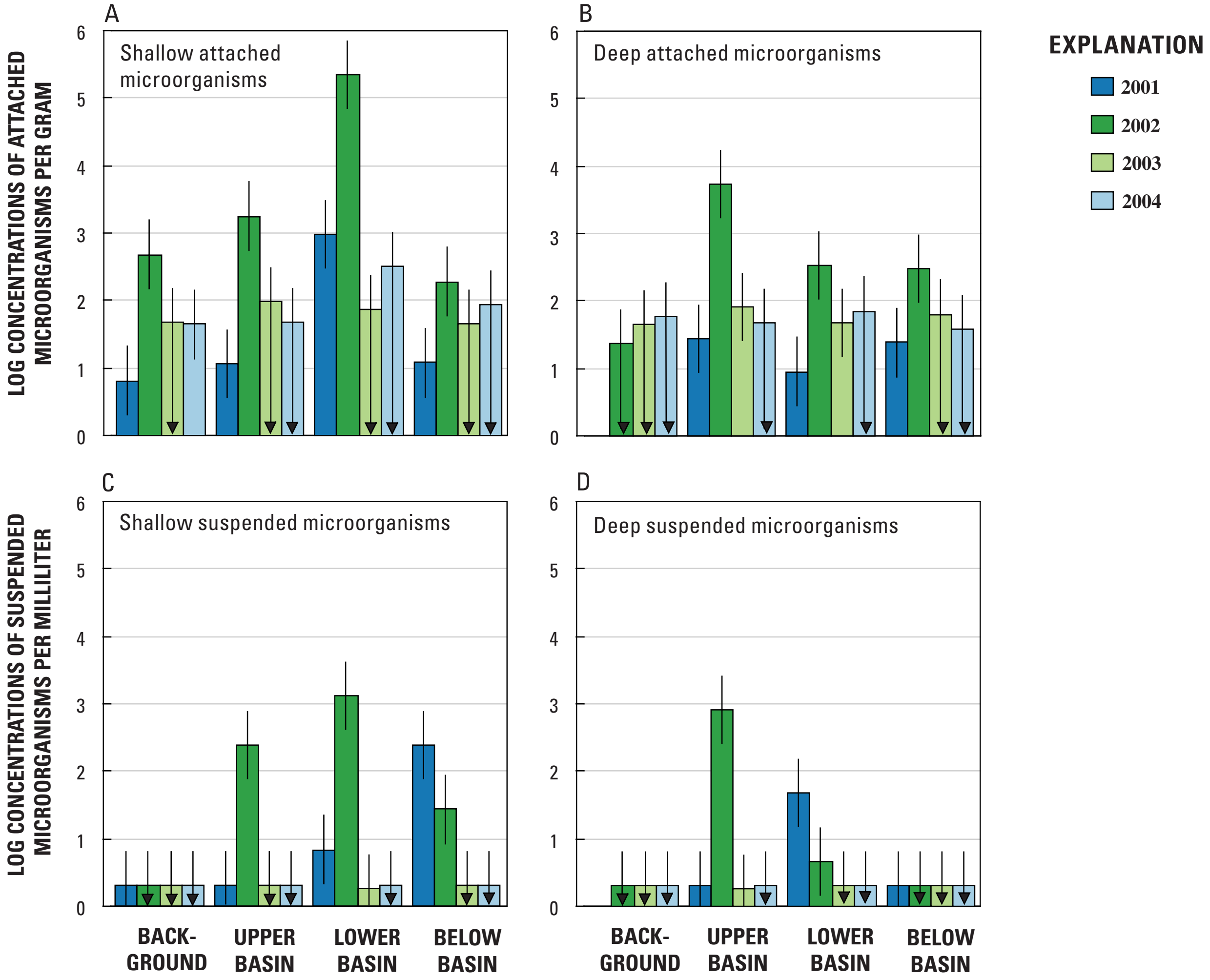
Table 14. Concentrations of attached and suspended iron-reducing microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (numbers per gram of dry sediment)				Suspended microorganisms (numbers per milliliter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
				Shallow				
CCMP1S	12	190	<46	<87	240	27	<2	<2
CCMP2S	930	220,000	<72	<320	7	1,300	2	<2
CCMP3S	<11	1,800	<96	<48	<2	240	<2	<2
CCMP4S/5S[2]	<6	480	<47	44	2	<2	<2	<2
				Deep				
CCMP1D	24	310	<64	<38	<2	<2	<2	<2
CCMP2D	<9	340	48	71	48	5	<2	<2
CCMP3D	28	5,500	81	<47	<2	790	2	<2
CCMP5D[2]	--	<23	<46	<58	--	<2	<2	<2

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. "Background" contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 26. Graphs showing concentrations of attached and suspended iron-reducing microorganisms on log scale.

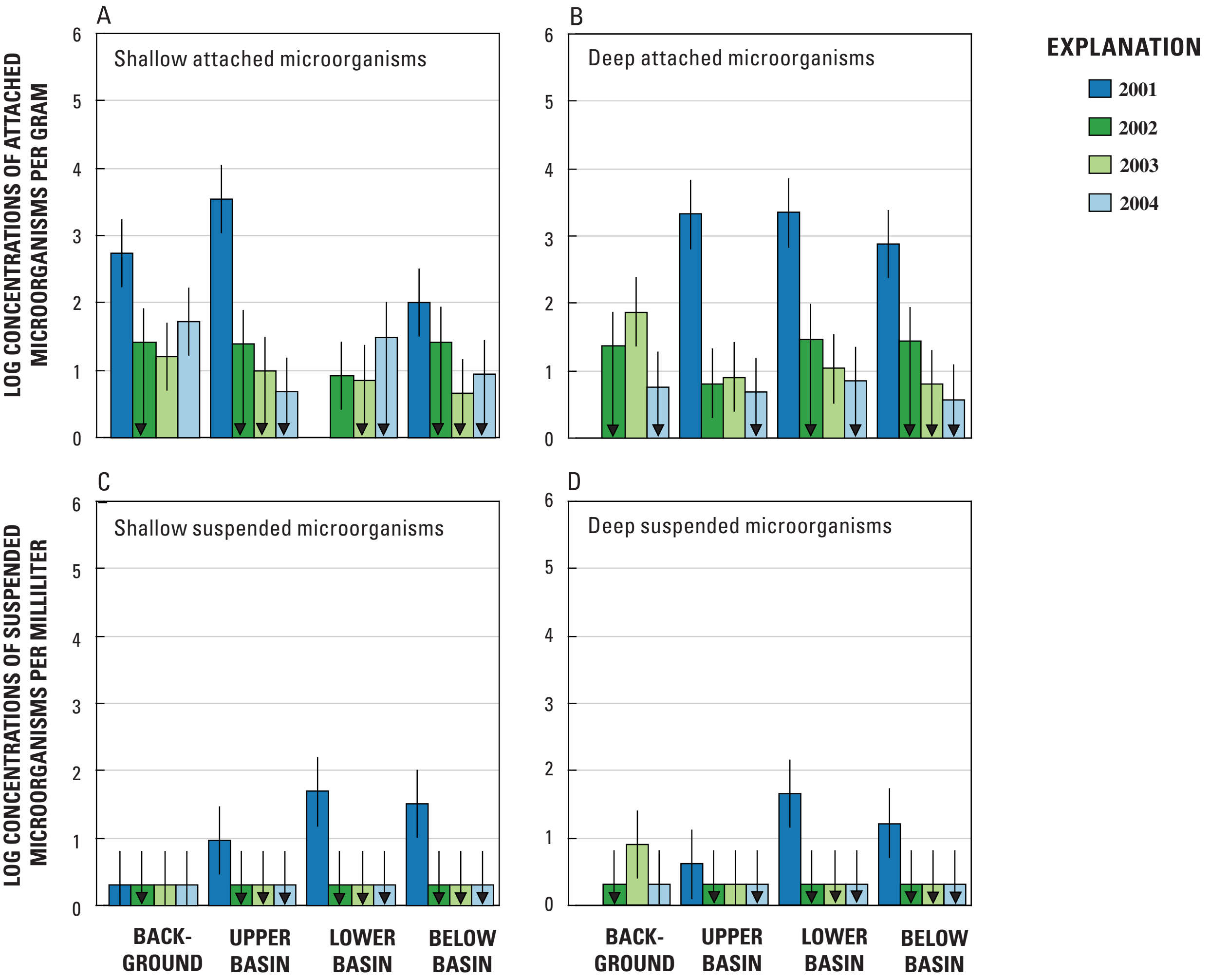
Table 15. Concentrations of attached and suspended sulfate-reducing microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Abbreviations: ND, concentrations not successfully determined. Acronym: MPN, Most Probable Number. Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (concentrations in MPN per gram of sediment)				Suspended microorganisms (concentrations in MPN per liter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
				Shallow				
CCMP1S	100	<27	<5	<9	33	<2	<2	<2
CCMP2S	ND	8	<7	<31	49	<2	<2	<2
CCMP3S	3,500	<25	<10	<5	9	<2	<2	<2
CCMP4S/5S[2]	550	<26	16	53	2	<2	2	<2
				Deep				
CCMP1D	770	<27	<6	<4	16	<2	<2	<2
CCMP2D	2,200	<30	11	<7	45	<2	<2	<2
CCMP3D	2,100	7	8	<5	4	<2	2	<2
CCMP5D[2]	--	<23	75	<6	--	<2	8	<2

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. "Background" contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 27. Graphs showing concentrations of attached and suspended sulfate-reducing microorganisms on log scale.

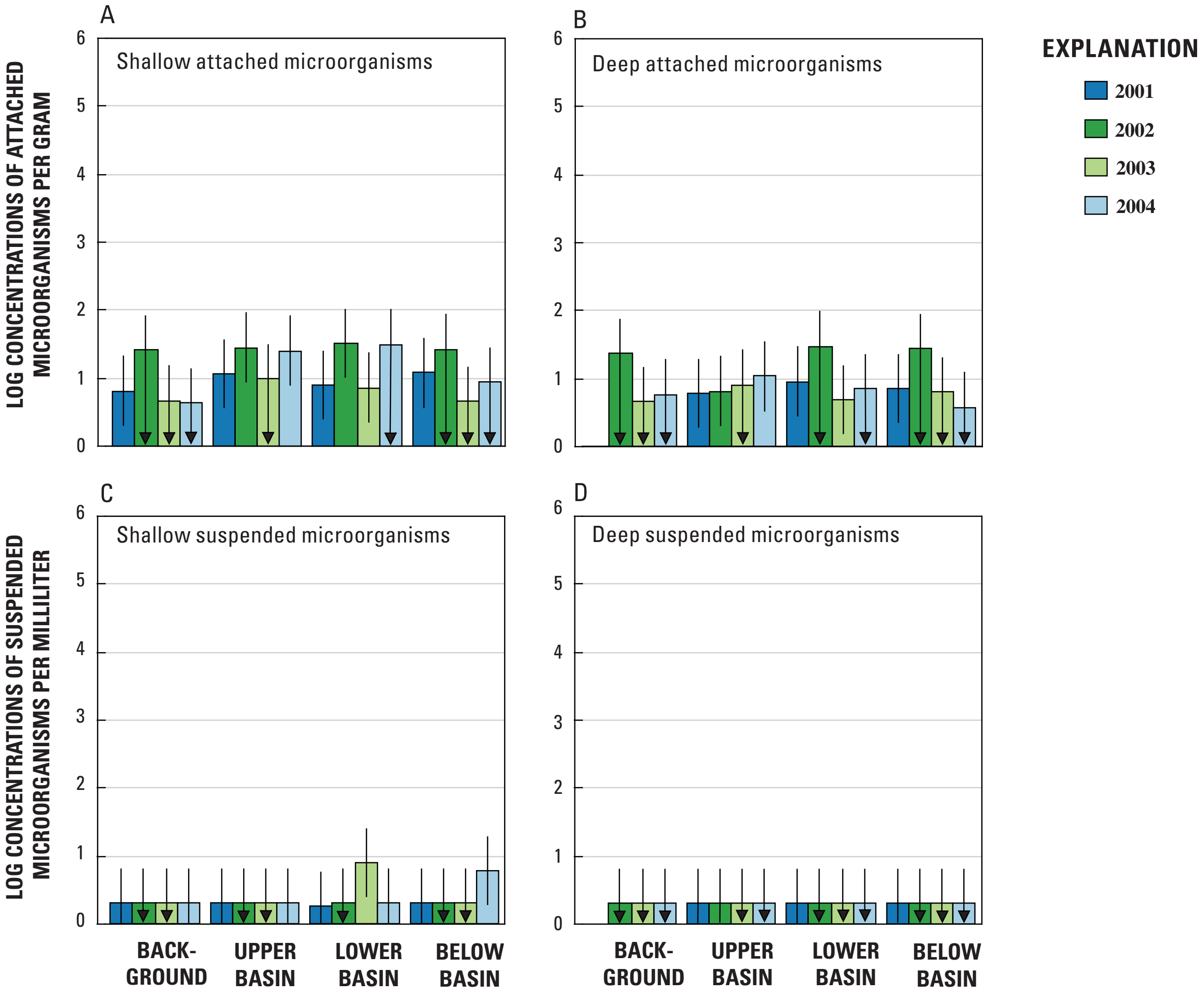
Table 16. Concentrations of attached and suspended methanogenic microorganisms from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Acronym: MPN, Most Probable Number. Symbols: <, less than; --, not sampled]

Location[1]	Attached microorganisms (concentrations in MPN per gram of sediment)				Suspended microorganisms (concentrations in MPN per liter of water)			
	2001	2002	2003	2004	2001	2002	2003	2004
				Shallow				
CCMP1S	12	<27	<5	<9	2	<2	<2	6
CCMP2S	7	32	7	<31	2	<2	8	2
CCMP3S	11	28	<10	25	2	<2	<2	2
CCMP4S/5S[2]	6	<26	<5	<4	2	<2	<2	2
				Deep				
CCMP1D	7	<27	<6	<4	2	<2	<2	<2
CCMP2D	9	<30	5	<7	2	<2	<2	<2
CCMP3D	6	7	<8	11	2	2	<2	<2
CCMP5D[2]	--	<23	<5	<6	--	<2	<2	<2

[1] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[2] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.



Bars represent 95 percent confidence interval. "Background" contains data from sites CCMP4S, CCMP5S, and CCMP5D. Absence of data bar indicates concentration not measured at that site in that year. Arrows indicate that concentration was below method detection limit.

Figure 28. Graphs showing concentrations of attached and suspended methanogenic microorganisms on log scale.

Table 17. Concentrations of dissolved inorganic constituents in water samples collected from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Symbol: --, not determined]

Date	Temperature	pH	Dissolved constituent in milligrams per liter[1]					
	degrees Celsius		Calcium	Sodium	Iron	Bicarbonate	Chloride	Sulfate
CCMP1S[2]								
10/23/2001	11	6.4	7.95	25.4	18.9	106	31.5	0.76
7/9/2002	12	6.4	--	--	32	99	35	1.02
6/25/2003	10	6.6	14.9	22.7	25	117	22.6	1.02
7/20/2004	14	6	--	--	22.2	110	20.5	0.09
CCMP1D								
10/23/2001	11	6.7	15.4	23.6	7.76	80	40.8	0.29
7/9/2002	11	6.6	--	--	2	81	19.5	0.72
6/25/2003	10	6.6	12.4	21.61	4.6	71	16.7	1.04
7/21/2004	12	6.2	--	--	0.84	67	18	0.22
CCMP2S								
10/23/2001	12	6.3	15.2	13.2	31.5	169	23	0.23
7/9/2002	15	6.4	--	--	19	120	--	--
6/25/2003	14	6.4	18.9	29.4	30	105	67	1.03
7/21/2004	16	6.2	--	--	17.2	84	30.7	0.1
CCMP2D								
10/23/2001	11	6.7	24.5	19.3	3.07	87	47.7	0.41
7/10/2002	12	7.5	--	--	0.07	72	28	0.95
6/26/2003	11	6.5	13.9	17.2	0.05	58	14.8	1.07
7/21/2004	14	6.1	--	--	9.69	68	23.4	0.28
CCMP3S								
10/23/2001	10	6.6	2.67	15.9	9.57	62	9.37	0.28
7/10/2002	14	6.4	--	--	7.5	60	12.3	--
6/26/2003	12	6.4	9.2	25.5	18	76	33	1.01
7/21/2004	11	6.3	--	--	9.69	59	9.5	0.06
CCMP3D								
10/24/2001	8	6.7	3.09	12.6	7.42	63	5.63	0.9
7/10/2002	11	6.8	--	--	5.3	70	15.7	0.97
6/26/2003	10	6.5	7.58	20.1	12	64	15.8	1.94
7/22/2004	11	6.4	--	--	10.6	63	7.14	0.91
CCMP4S[3]								
10/24/2001	9	6.8	4.66	5.59	0	27	0.46	2.45
CCMP5S[3]								
7/11/2002	14	6.2	--	--	16	42	52.8	5.71
6/24/2003	10	5.8	16.1	26.2	2	25	119	5.73
7/22/2004	11	5.9	--	--	0.79	33	71.3	1.61
CCMP5D[3]								
7/11/2002	12	6.4	--	--	33	71	54.8	1.84
6/24/2003	9	6.5	12.9	24.7	24	61	54.3	3.83
7/22/2004	11	6.4	--	--	15.5	56	47.6	4.7

[1] Methods to determine concentrations of dissolved inorganic constituents are discussed in the section titled "Chemical Analyses."

[2] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[3] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.

Table 18. Concentrations of dissolved nitrogen, phosphorus, and carbon compounds in water samples collected from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Symbol: --, not determined]

Date	In milligrams per liter as nitrogen[1]			In milligrams per liter as phosphorus[1]		In milligrams per liter[1]		
	Ammonia + Organic nitrogen	Ammonia (NH_3)	Nitrate (NO_3) + nitrite (NO_2)	Phosphorus	Ortho-phosphate	Total inorganic carbon, as carbon dioxide	Methane	Organic carbon
				CCMP1S[2]				
10/23/2001	7.4	3.05	0.003	0.23	0.26	259	1.93	5.9
7/9/2002	1.5	1.14	0.14	0.22	0.01	259	1.45	6.3
6/25/2003	0.95	0.77	0.13	0.19	0.18	289	2.07	4.1
7/20/2004	1.01	0.83	0.13	0.17	0.015	476	2.96	3.2
				CCMP1D				
10/23/2001	0.4	0.41	0.008	0.039	0.028	121	2.52	1.9
7/9/2002	0.25	0.16	0.025	0.031	0.023	93	0	1.3
6/25/2003	0.32	0.24	0.019	0.065	0.062	129	0	1.1
7/21/2004	0.28	0.16	0.001	0.018	0.012	102	0.09	0.9
				CCMP2S				
10/23/2001	19	9.27	0.009	0.11	0.18	488	0.97	10
7/9/2002	--	5.37	0.12	0.16	0.07	255	0.36	5.1
6/25/2003	6.9	6.91	0.16	0.16	0.15	384	6.02	15.1
7/21/2004	2.35	2.16	0.003	0.17	0.012	79	2.59	3.7
				CCMP2D				
10/23/2001	0.14	0.14	0.007	0.007	0.043	108	0	1.2
7/10/2002	0.12	0.14	0.004	0.026	0.015	101	0	0.7
6/26/2003	0.2	0.14	0.003	0.012	0.01	158	0	0.8
7/21/2004	0.36	0.18	0.009	0.023	0.001	46	0.02	0.9
				CCMP3S				
10/23/2001	0.4	0.43	0.004	0.15	0.14	115	0	1.8
7/10/2002	0.28	0.18	0.049	0.14	0.009	112	0	1.6
6/26/2003	1.1	0.34	0.088	0.098	0.097	233	1.73	2.3
7/21/2004	0.3	0.016	0.003	0.11	0.001	45	0.25	0.9
				CCMP3D				
10/24/2001	0.11	0.11	0.007	0.19	0.2	102	0	1.4
7/10/2002	0.31	0.1	0.059	0.27	0.26	60	0	2.9
6/26/2003	0.2	0.12	0.057	0.14	0.14	151	0	1
7/22/2004	0.16	0.072	0.001	0.14	0.004	48	0.05	0.7
				CCMP4S[3]				
10/24/2001	0.11	0.004	0.012	0.011	0.008	61	0	0.5
				CCMP5S[3]				
7/11/2002	0.44	0.17	0.11	0.16	0.15	153	0	4.3
6/24/2003	0.29	0.016	0.024	0.019	0.017	211	0	5.8
7/22/2004	0.3	0.016	0.003	0.029	0.016	104	0.06	3.3
				CCMP5D[3]				
7/11/2002	0.5	0.37	0.2	0.15	0.006	175	0	3
6/24/2003	0.47	0.22	0.14	0.22	0.2	198	0	4.1
7/22/2004	0.57	0.26	0.005	0.13	0.025	165	0.11	2.9

[1] Methods to determine dissolved nitrogen, phosphorus, and carbon compounds are discussed in section titled "Chemical Analyses."

[2] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

[3] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.

Table 19. Concentrations of ammonium, nitrate, and Olsen phosphorus attached to sediments collected from temporary sampling sites at Cattlemans detention basin, South Lake Tahoe, California, 2001–04.

[Symbol: <, less than]

Date	Concentration of nutrient attached to sediments in parts per million (microgram per gram of sediment)[1]		
	Ammonium (NH_4) as nitrogen	Nitrate (NO_3) as nitrogen	Olsen phosphorus as phosphorus
CCMP1S[2]			
10/23/2001	15.7	<0.1	15.8
7/9/2002	2.1	<0.1	3.7
6/25/2003	1.9	<0.1	4.3
7/20/2004	1.9	<0.1	5.3
CCMP1D			
10/23/2001	2	<0.1	2.9
7/9/2002	2	<0.1	4.4
6/25/2003	1.7	<0.1	2
7/21/2004	0.9	<0.1	1.7
CCMP2S			
10/23/2001	7.3	<0.1	2.6
7/9/2002	19	<0.1	11.1
6/25/2003	4.3	<0.1	3.8
7/21/2004	5.1	<0.1	4.5
CCMP2D			
10/23/2001	7.8	<0.1	6.5
7/10/2002	0.4	<0.1	2.4
6/26/2003	6.6	<0.1	7.5
7/21/2004	4.1	<0.1	4.4
CCMP3S			
10/23/2001	11.7	<0.1	7.4
7/10/2002	14.4	<0.1	9.9
6/26/2003	14.9	<0.1	14.6
7/21/2004	11.3	<0.1	10.2
CCMP3D			
10/24/2001	4.5	<0.1	5.2
7/10/2002	0.9	<0.1	2.3
6/26/2003	5.9	<0.1	6.5
7/22/2004	7.2	<0.1	8.7
CCMP4S[3]			
10/24/2001	5	<0.1	14.5
CCMP5S[3]			
7/11/2002	1.3	<0.1	6.9
6/24/2003	1.9	<0.1	6.7
7/22/2004	1.3	<0.1	8.9
CCMP5D[3]			
7/11/2002	12.2	<0.1	6.5
6/24/2003	1.3	<0.1	6.5
7/22/2004	0.6	<0.1	2.8

[1] Methods to determine concentrations of ammonium, nitrate, and Olsen phosphorus attached to sediments are discussed in the section titled "Chemical Analyses."

[2] Locations of temporary microbial sampling sites are shown in figure 7 and depths are listed in table 2.

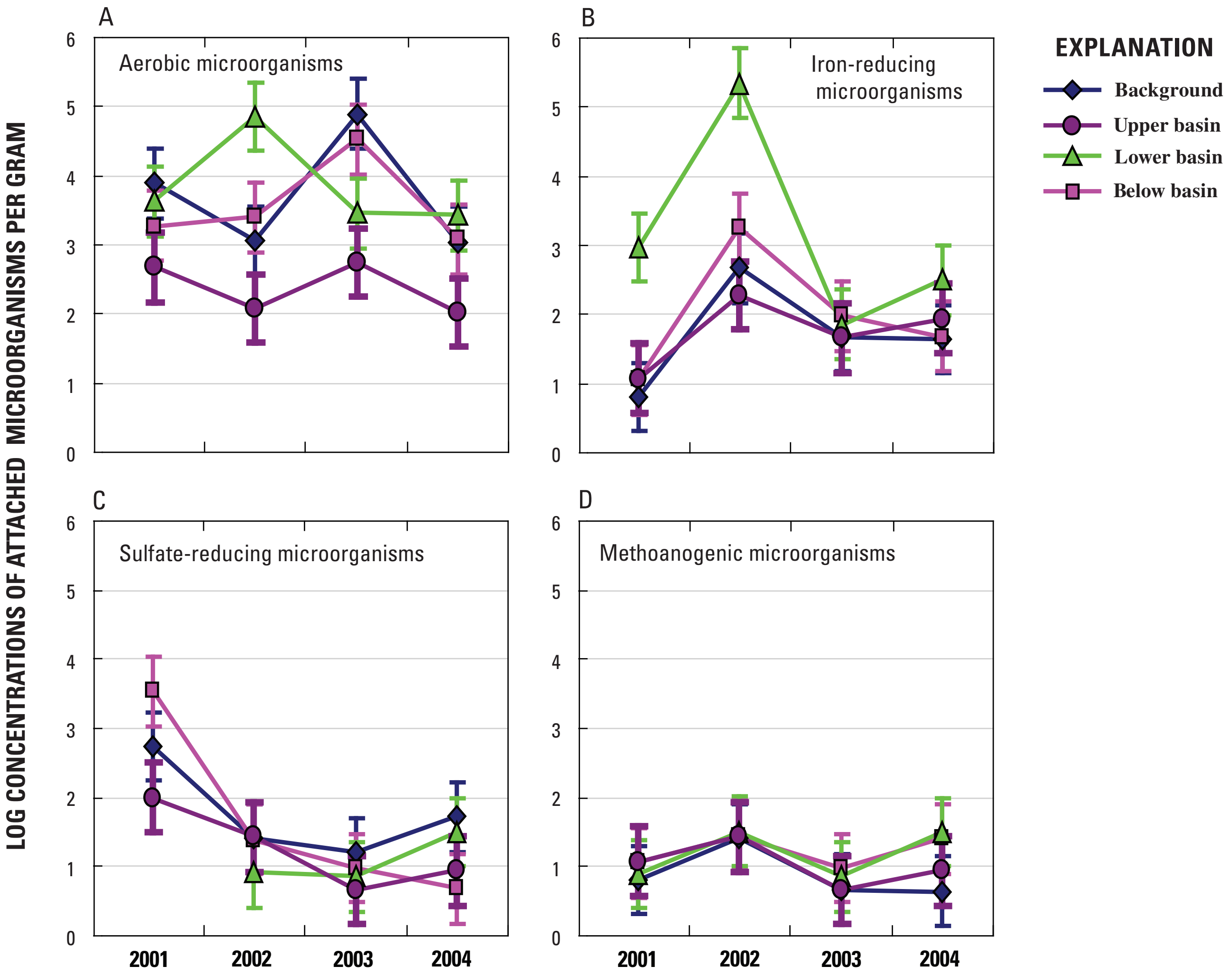
[3] Site CCMP4S, considered a background site, was sampled in 2001; CCMP5S and CCMP5D, also background sites, were sampled in 2002, 2003, and 2004.

initially sulfate-reducing with some methanogenesis and iron reduction occurring. Cozzarelli and others (1999) found simultaneous sulfate and iron reduction at Galloway, New Jersey. Precipitation of iron sulfides kept iron and sulfide concentrations low. Additionally, phosphate concentrations were high on the sediments and may be a source for much of the phosphate in the ground water.

In 2002, analyses indicated that both the shallow gray silt and sand and the deeper brown sand and gravel were predominantly iron-reducing. Under iron-reducing conditions, concentrations of iron-reducing microorganisms, reduced iron, sulfate, and ammonium are expected to be high and concentrations of sulfate-reducing microorganisms, methanogens, nitrate and dissolved oxygen are expected to be low. Methane concentrations may be low.

In 2002, iron-reducing microorganisms increased in concentration (fig. 26), whereas the sulfate-reducing microorganisms decreased in concentrations (fig. 27). Concentrations of methanogenic microorganisms continued to be above the method detection limit in the shallow gray silt and sand beneath the basin (fig. 28). Methane concentrations remained low but measurable (table 18). Sulfate concentrations increased in wells after 2001 and fluctuated with peaks in the spring (fig. 29). Dissolved iron concentrations increased in downgradient wells (fig. 30) in the spring of 2002, possibly due to transport of the reduced product, but this seemed to occur every spring since the basin was constructed, with the dissolved iron concentrations returning to its original concentrations by summer. Ammonium concentrations on the sediments (table 19) and ammonia in the water were unchanged (fig. 31).

In the years 2003 and 2004, microbial concentrations of iron-reducing, sulfate-reducing and methanogenic microorganisms were all low (figs. 26–28). In 2003, there was an increase in the attached, aerobic bacteria concentrations in all sites except the shallow, lower basin and the deep, upper and below basin sites (fig. 32). The increase implies that these sites became more aerobic at that time. By 2004, the aerobic bacteria concentration decreased to 2002 values while iron-reducing, sulfate-reducing and methanogenic microorganisms remained constant (fig. 32). Thus, the specific redox condition cannot be inferred from the microbial ecology. Concentrations of dissolved sulfate and iron in nearby wells were highest in the spring (figs. 29 and 30). The subsequent decrease over time and distance may indicate sulfate and iron reduction or natural dispersion. The general trend of increasing methane concentrations in the temporary test holes suggests methanogenesis may be occurring, but the data are inconclusive.



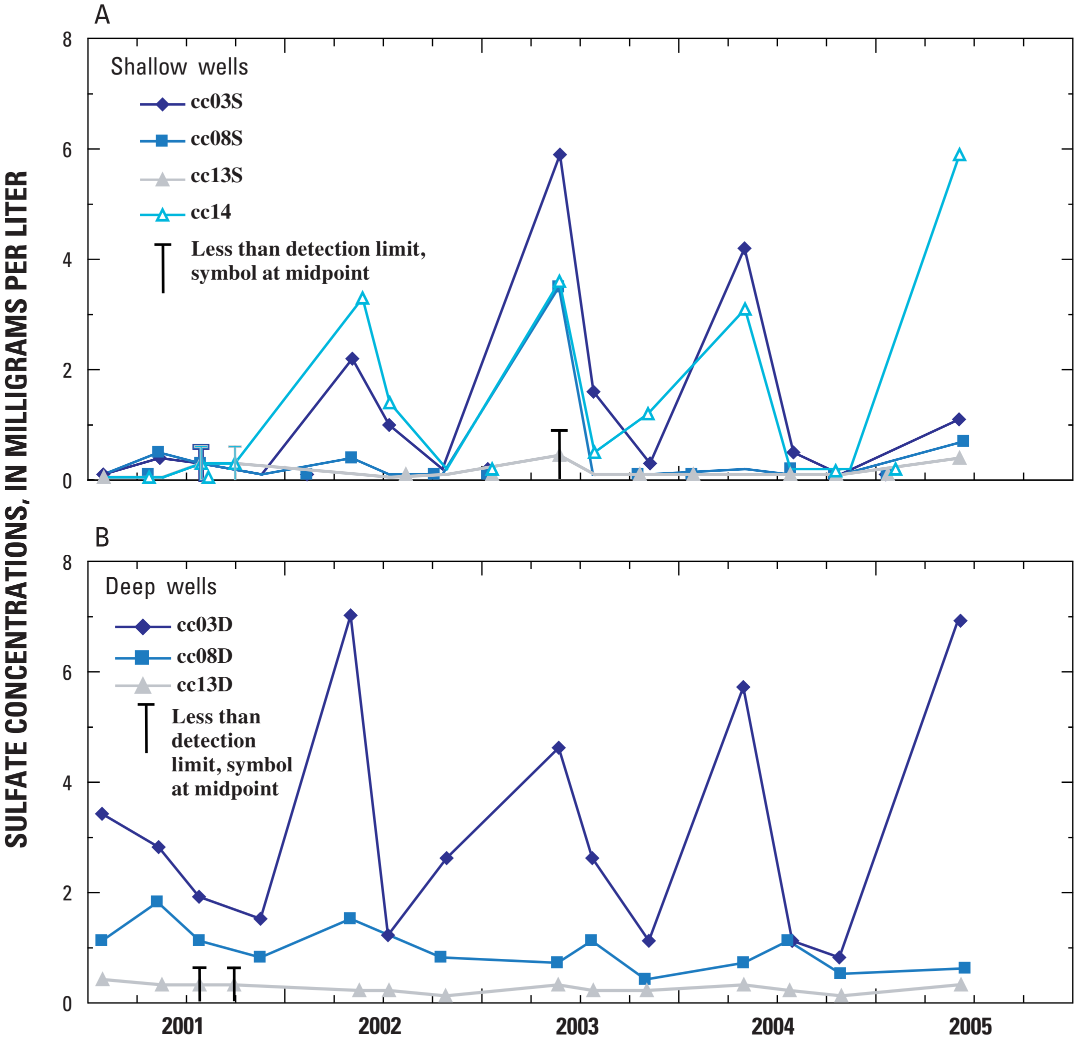
Vertical lines represent 95 percent confidence interval. "Background" contains data from sites CCMP4S and CCMP5S. The upper basin site includes data from CCMP3S; lower basin site from CCMP2S; and below basin site from CCMP1S. Absence of data point indicates concentration not measured at that site in that year.

Figure 29. Concentrations on log scale of attached microorganisms on shallow sediments over the course of the study.

Effects of Stormwater Infiltration on Microbial Populations

The infiltration of stormwater in Cattlemans detention basin has not affected the aerobic microbes on the basis of MPN determinations of the obligate respiratory aerobes and on the basis of changes in ground-water chemistry. Oxygen concentrations remained low in nearby wells through 2004 (Appendix C). Nitrogen, when present, was in the reduced form: either ammonia or organic nitrogen (Prudic, Wood, and others, 2005). Dissolved iron was frequently detected, some times in high concentrations (well cc08S in fig. 30), but did not change through 2003 in wells near the detention basin (Prudic, Wood, and others, 2005). Sulfate concentrations typically increased at the upgradient wells in the spring and subsequently decreased during the summer and fall (fig. 29). Sulfate concentrations from well cc08S and cc08D near the middle of the basin showed attenuated sulfate spikes, whereas the wells downgradient from the basin at both depths (wells cc13S and 13D) had very little sulfate. Methane concentrations at the shallow depths in the temporary test holes (table 18) increased relative to the initial values in October 2001, suggesting some methanogenic activity may be occurring.

Dissolved oxygen from infiltration of surface runoff into the basin, along with reduced carbon, are quickly used in aerobic respiration. The low concentrations of denitrifying microorganisms in the shallow gray silt and sand and in the deeper brown sand and gravel are consistent with the low nitrate and nitrite concentrations (Prudic, Wood, and others, 2005). Iron-reducing microorganisms are present in significant numbers, but they seem to be decreasing with time after an initial spike in 2002 following completion of the detention basin. Sulfate-reducing microorganisms were initially high in concentration



Wells along transect A–A´ are shown on figure 8. Symbol plotted at midpoint when below detection limit. Detection limit was generally at or below 0.2 milligram per liter and detection limit delineation was within well symbol.

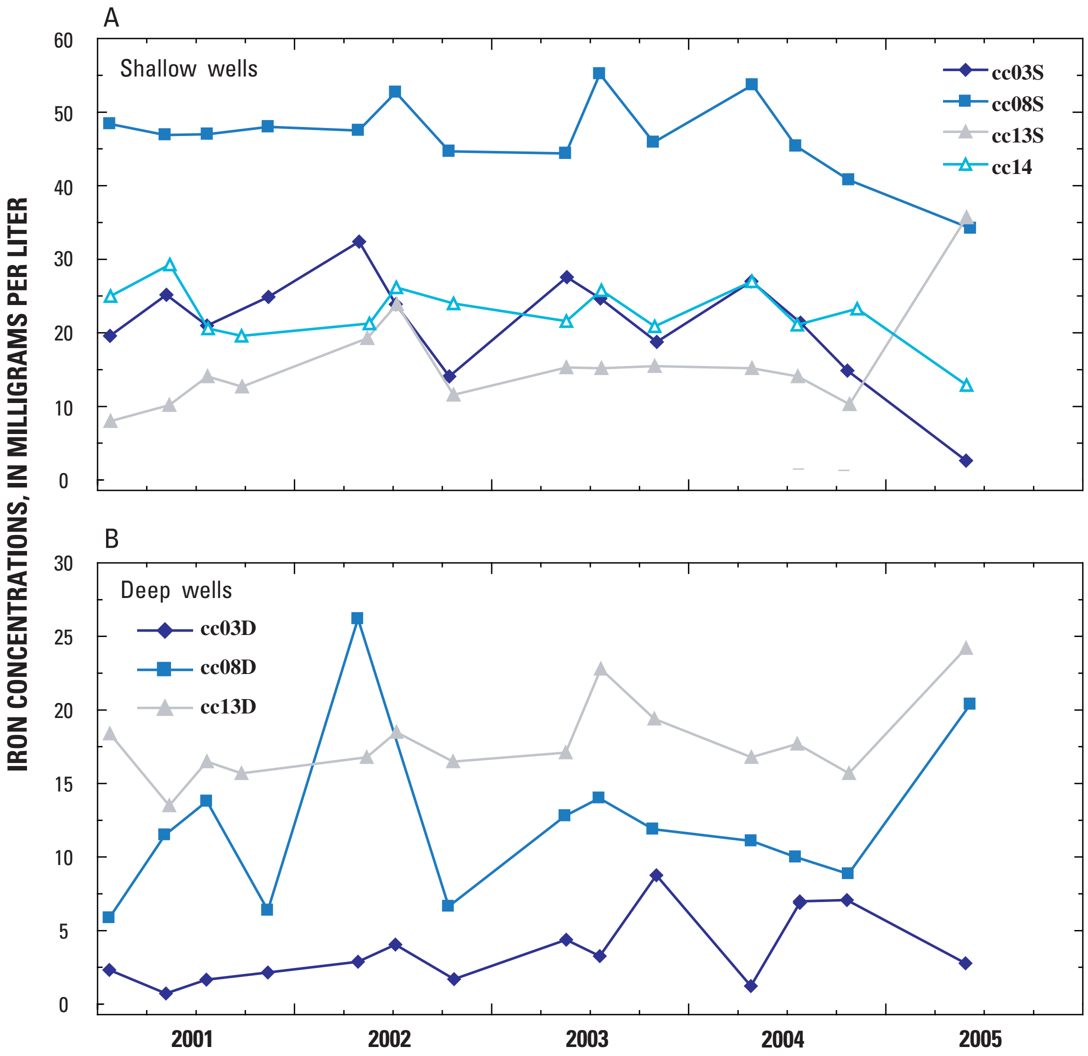
Figure 30. Graphs showing trends in sulfate concentrations in water sampled from wells along transect A—A´.

and also decreased with time, despite the presence of dissolved sulfate in the infiltration of stormwater in the detention basin. Finally, methanogenic microorganisms, though in low numbers, are contributing to measurable concentrations of methane.

Summary and Conclusions

Detention basins are used in the Lake Tahoe Basin to reduce sediment and nutrient loads from urban runoff before reaching Lake Tahoe. Ground water beneath detention basins may provide avenues for transport of dissolved nutrients to nearby streams and to Lake Tahoe. A study began in November 2000, in cooperation with the El Dorado County Department of Transportation, Tahoe Engineering Unit and the California Tahoe Conservancy to determine if nutrients in a detention basin are transported by ground water to a nearby stream. Cattlemans detention basin is the study area, which was constructed in a meadow adjacent to Cold Creek in South Lake Tahoe, California. This report describes the numerical model used to evaluate ground-water flow and discharge to Cold Creek, as well as, the chemistry of ground water and microbial activity beneath the detention basin.

A three-dimensional, numerical, transient ground-water flow model of the Cattlemans detention basin study area was constructed using MODFLOW. The model was calibrated to water-level measurements in 28 wells from September 2001 to August 2004. Results of the ground-water modeling show there is little annual change in seasonal ground-water flow under and in the vicinity of Cattlemans detention basin. While allowing the gradient to change with fluctuations in the amount of ground water present, the flow patterns and direction remain similar from year to year.



Wells along transect A–A´ are shown on figure 8.

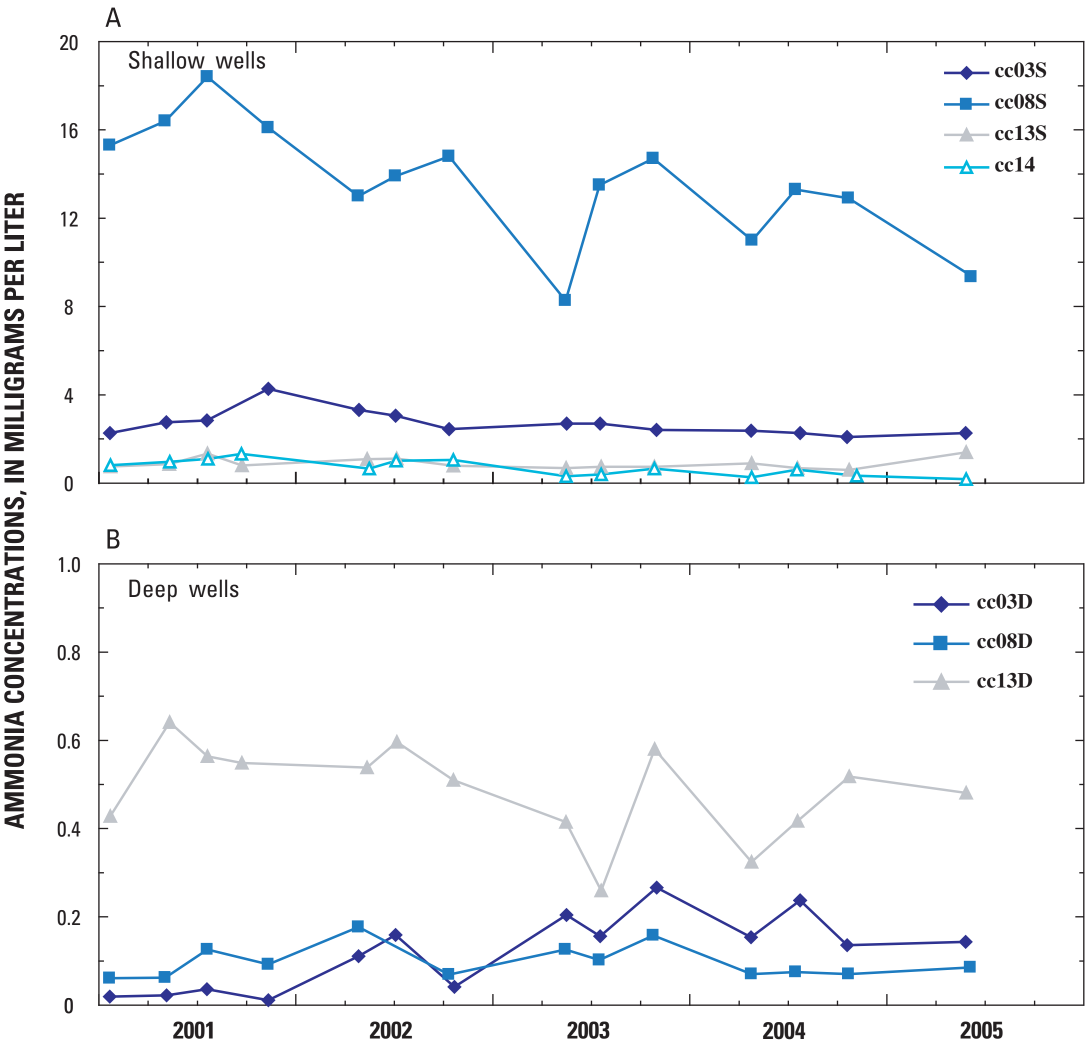
Figure 31. Graphs showing trends in iron concentrations in water sampled from wells along transect A—A´.

The contribution of ground water to Cold Creek from Cattlemans detention basin is extremely small when compared to the flux in Cold Creek. Average Cold Creek flow was 8.9 ft^3/s, whereas total ground-water flux moving through the modeled system was 0.011 ft^3/s. Ground water originating in the detention basin makes up about 34 percent, or 0.004 ft^3/s, of the total ground water moving through the system. Particle tracking in MODPATH was used to calculate flow paths in order to determine where stormwater entering to the detention basin would discharge. Results show that of the 0.004 ft^3/s, 45 percent, or 0.0018 ft^3/s, actually discharges to Cold Creek in the modeled area as compared to Cold Creek's 8.9 ft^3/s.

Water quality beneath Cattlemans detention basin is typical of Sierra Nevada ground water but has some differences. Water in the aquifers beneath the basin was reducing, containing abundant organic carbon (sedimentary and dissolved), ammonia, iron, and low concentrations of dissolved oxygen and nitrate.

The combination of chemical and microbial concentrations suggests that both shallow (3.5–6 ft) and deep (7–10 ft) depths were initially under sulfate-reducing conditions. In 2002, the entire aquifer, including under the detention basin, seemed to have switched to iron-reducing redox conditions with a resulting spike of reduced iron, sulfate and iron-reducing microorganisms. In 2003, the aquifer seemed to be more aerobic. Redox conditions in 2004 cannot be determined from the data. The effect of the basin on the microbial ecology seems to be minimal: the redox conditions in the aquifer are similar to that under the basin. The microbial analyses suggest that the aquifer continues to be anoxic and thus may reduce nitrate. However, ammonium would remain present in the aquifer and would eventually discharge into Cold Creek.

The construction of the detention basin did not substantially change the water quality or the geochemical processes that are occurring near the basin. However, the increase in recharge of oxygenated water to the ground-water system



Wells along transect A-A´ are shown on figure 8.

Figure 32. Graphs showing trends in ammonia concentrations in water sampled from wells along transect A-A´.

beneath the basin may eventually redistribute nutrients due to increased oxidation of dissolved and sedimentary organic matter. Also, the increased amount of water could speed up the transport of dissolved nutrients from the ground-water system to Cold Creek. Suspended sediment concentrations have been reduced in water leaving the basin compared to water entering the basin.

Cattlemans detention basin is functioning as designed. The detention basin is effective in removing sediment from stormwater. Sediment concentrations in stormwater discharged to the basin by two culverts have been greatly reduced and loads to Cold Creek are less than before the basin was constructed. Nutrient loads to Cold Creek also are reduced, although nitrogen and phosphorus concentrations in outflow from the basin are unknown. However, the volume of water leaving the basin is substantially less than that entering the basin; therefore the mass of nitrogen and phosphorus leaving the basin in surface water is far less than what flowed into Cold Creek prior to construction of the basin.

A few factors in the detention basin efficiency remain uncertain. It is unsure if the dissolved nutrients are being removed from the ground water or simply cycling by a different flow path. The possibility remains that the increase in water recharged by the basin will over time increase the nutrient flow to Cold Creek through ground-water discharge. Continued ground-water monitoring and water quality sampling may be able to answer this question. Also unknown is whether the increase in focused recharge of oxygenated water in the detention basin will release more nutrients to the ground water by increased oxidation of nitrogen- and phosphorus-bearing organic matter in the aquifer.

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Appendix A

Description of deposits from boreholes drilled in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, November-December 2000

USGS Standard identification: The standard identification number consists of 15 digits and is based on the grid system of latitude and longitude. The first six digits denote degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits (assigned sequentially) identify sites within a 1-second grid. For example, site 385432119574001 is at 38°54'32" latitude and 119°57'40" longitude, and it is the first site recorded in that 1-second grid. The assigned number is retained as a permanent identifier even if a more precise latitude and longitude are later determined.

[Abbreviations: ft, feet; in., inches]

Well cc01

Date: December 7, 2000

USGS Standard identification number: 385432119574001

Latitude: 385432.26

Longitude: 1195739.88

Altitude (accuracy 0.01 ft): 6,279.84

Depth below land surface, in feet		Lithologic description
From	To	
0	0.2	Frozen dark brown soil (loam)
0.2	1.8	Dark brown clayey silt with numerous roots—moist yet crumbly
1.8	2.6	Dark brown micaceous clayey silt, roots less common—moist and tacky
2.6	3.4	Dark brown micaceous clayey silt, wet
3.4	4	Dark grayish brown sandy silt, saturated; strong organic smell
4	5.5	Grayish brown micaceous sandy silt; saturated
5.5	5.6	Brownish gray silty sand, micaeous. Unconsolidated. End of hole.

Well cc02

Date: December 7, 2000

USGS Standard identification number: 385432119574002

Latitude: 385431.66

Longitude: 1195740.07

Altitude (accuracy 0.01 ft): 6,281.57

Depth below land surface, in feet		Lithologic Description
From	To	
0	2.8	Dark brown clayey sandy silt with lots of roots. Dry and crumbly.
2.8	3.5	Dark brown sandy silt. Less clay and fewer roots. Moist yet crumbly.
3.5		Large rock—could only continue by reducing bucket to 2 in.
3.5	4.5	Dark brown sandy silt—very micaceous
4.5	5	Reddish brown sand with streaks of dark red next to roots: water at 5 ft
5	5.8	Grayish brown silty sand—wet
5.8	6.8	Brownish gray sand—suspect removing weathered granite as augering is difficult and hole remains open. Auger is grinding on rock. Reached granite bedrock at 6.8 ft.

Well cc03S

Date: November 22, 2000

USGS Standard identification number: 385432119574301

Latitude: 385431.63

Longitude: 1195742.55

Altitude (accuracy 0.01 ft): 6,281.23

Depth below land surface, in feet		Lithologic Description
From	To	
0	4.5	Dark reddish brown gravelly, sandy loam. Gravels pea size to 0.5 in.
4.5	8	Gray, very silty, very fine sandy clay, minor organics.
8	10	Dark brown, moist, sandy clay loam.
		Top water table 7 to 7.5 ft
		Static water level: 9.99
		1.7
		8.59 ft below land surface
		Completion
		#3 Aquarium Sand 7.9 – 10 ft
		Silica Flour 7.2 – 7.9 ft
		Native Cuttings 2.5 – 7.2 ft
		Neat Cement Seal 0 – 2.5 ft
		Core from 8.0 to 9.33 ft

Well cc03D

Date: November 21, 2000

USGS Standard identification number: 385432119574302

Latitude: 385431.63

Longitude: 1195742.55

Depth below land surface, in feet		Lithologic Description
From	To	
0	4.5	Dark reddish brown gravelly, sandy loam – Gravels 0.5 to 1.5 in.
4.5	8	Gray very silty, very fine sandy clay, minor organics.
8	12.5	Dark brown, sand ~ 16 mesh, sandy clay loam
12.5	15	Red, oxidized, sandy silt
		Top water table @ approx 7.5 ft. Cored 13 ft to 14 ft
		Static water level: 10.00
		-1.51
		8.49 ft below land surface

Well cc04

Date: November 27, 2000

USGS Standard identification number: 385433119574201

Latitude: 385432.6

Longitude: 1195741.51

Altitude (accuracy 0.01 ft): 6,279.12

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Frozen surface soil and gravel
0.5	3	Dark reddish brown sandy
3	4	Brown (slightly moist) fine sandy loam
4	5.5	Brown, silty, fine sandy loam. Pea size gravels
5.5	8	Dark black silty (moist), fine #16 mesh sand
8	9	Top water table
		Black silty fine sand
9	10	Black, gravelly, silty fine sand
		Static: 9.00
		3.4
		5.60 ft below land surface
		Core 8 – 9 ft
		Pounded
		2.2 ft.
		Recovered 1 foot

Well cc05

Date: November 27, 2000

USGS Standard identification number: 385443119574202

Latitude: 385432.62

Longitude: 1195742.15

Altitude (accuracy 0.01 ft): 6,278.03

Depth below land surface, in feet		Lithologic Description
From	To	
0	2.5	Very gravelly, brown sandy loam
2.5	3.5	Brown (moist) fine sandy loam
3.5	5	Black, coarse sandy silt. Some organics (sand ~ 12 mesh)
5	7.5	Black fine sandy silt (wet)
7.5	10	Black, wet, sandy silt, sand ~ #12 mesh, (some pea gravel)
		Top water table = 6.5 ft – 7 ft
		Static: 9.00
		1.2
		7.80 ft below land surface
		Core 8 ft to 10 ft
		Completion
		#3 Aquarium Grade Sand 7.5 – 10 ft
		Silica Flour 5.5 – 7.5 ft
		Native Cuttings 2 – 5.5 ft
		Neat Cement 0 – 2 ft

Well cc06S

Date: November 28, 2000

USGS Standard identification number: 385433119574301

Latitude: 385433.08

Longitude: 1195742.57

Altitude (accuracy 0.01 ft): 6,277.37

Depth below land surface, in feet		Lithologic Description
From	To	
0	2.5	Brown, very sandy gravel
2.5	6	Coarse, sandy loam, brown
6	10	Very coarse #12 mesh sandy loam, very fluid
		Note: Hole: 8 to 10 ft with return cuttings
		Top water table ~ 7 ft
		Note: Placed csg and lost 1.5 ft of hole
		Static: 8.00
		-2.28
		5.72 ft below land surface
		Completion
		#3 Aquarium and Native 6 – 8.85 ft
		Silica Flour 5 – 6 ft
		Native Top Cuttings 2 – 5 ft
		Neat Cement Seal 0 – 2 ft

Well cc06D

Date: November 28, 2000

USGS Standard identification number: 385433119574302

Latitude: 385433.08

Longitude: 1195742.57

Altitude (accuracy 0.01 ft): 6,277.40

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Brown, sandy loam – Loam with potato size cobbles
0.5	4	Brown, sandy loam with gravel to approx 0.5 in.
4	5	Black sandy, silt loam (moist)
5	6	Pea gravel
6	10	Sandy, pea gravel, some gravels to 1 in. (Wet)
10	15	Wet very coarse sand with pea gravel
		Top water table = 7 ft
		Static 13.90 H
		3.23 C
		10.77 ft below land surface
		Completion
		Native Cuttings 2 – 15 ft
		(VCOS sand and Pea Gravel)
		Neat Cement Seal 0 – 2 ft
		Note: filled core tube with returns – too coarse to core

Well cc07

Date: November 20, 2000

USGS Standard identification number: 385433119574203

Latitude: 385433.29

Longitude: 1195742.49

Altitude (accuracy 0.01 ft): 6,273.29

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.25	Frozen. Wet, coarse sand, silt, a lot of root matter, organic matter, wet, some gravel, dark yellowish brown (10YR 4/2)
0.25	0.7	Silty, fine sand, contains abundant roots, mica ships, dusky yellowy brown (10YR 2/2) organic matter
0.7	1.1	Fine sand, silt, mica chips, roots, organic matter, dusky yellow brown (10YR 2/2)
1.1	2.4	Big root, fine sand/silt, mica chips, organic matter, dusky yellowish brown, wet (10YR 2/2)
2.4	2.9	Medium sand, wet, mica chips, only very small amt of roots, olive black (5Y 2/1)
2.9	3.4	Fine sand, silt, mica chips, wet, some roots, dark gray (N-3)
3.4	4	Fine sand, silt, clump of organic matter (still woodyish in nature) Rock 2.5 to 3 in. long, mica chips, olive black (5Y 2/1), wet
4	4.2	Fine sand, very wet, mica, dusky yellowish brown (10YR 2/2)
4.2	5	Fine/medium but mainly coarse sand, very wet, mica, olive black (5Y 2/1)
		Total depth @ 5.2 ft. Dirty, coarse sand/sloppy wet

Well cc08S

Date: November 20, 2000

USGS Standard identification number: 385432119574303

Latitude: 385432.39

Longitude: 1195743.03

Altitude (accuracy 0.01 ft): 6,278.13

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Brown gravelly loam. Gravels ~ 1 in. diameter
0.5	2	Dark brown, sandy loam (moist)
2	2.5	Gravelly loam
2.5	4	Dark dusky sandy loam (damp)
4	6	Same dark sandy loam. Some small gravel at 5 ft., 5.6 to 6 round fine, clayey type organics
6	7	Black – very coarse, sandy clayey (wet) material (dark organics)
7	9.2	Coarse, clean sand (approx. 16 mesh) with black clayey material. Sandy clay
		Core 7 to 9 ft.
		Top WT @ ~6.5 ft.
		Completion
		Screened 8 to 9 ft – six-in. sump
		#3 Aquarium sand 9.2 – 6 ft
		Silica Flour 6 – 5 ft
		Native Cuttings 5 – 1.5 ft
		Neat Cement 1.5 – 0 ft

Well cc08D

Date: November 20, 2000

USGS Standard identification number: 385432119574304

Latitude: 385433.39

Longitude: 1195743.03

Altitude (accuracy 0.01 ft): 6,278.15

Depth below land surface, in feet		Lithologic Description
From	To	
0	1.5	Brown sandy loam 1 in. gravel
1.5	4.5	Dark brown gravel (moist) Gravel to 1.5 in. Gravelly, sandy, loam
4.5	8	Sandy loam – no gravel.
8	15	Sand ~ 16 mesh to 12 mesh. Top water table at 8 ft. Sandy, silt – black – wet Water @ 8 ft Pound core 13.33 to 15 ft Completion #3 Aquarium sand 7 – 15 ft Native top cuttings 2 – 7 ft Neat Cement Seal 0 – 2 ft

Well cc09

Date: November 21, 2000

USGS Standard identification number: 385432119574305

Latitude: 385431.93

Longitude: 1195743.29

Altitude (accuracy 0.01 ft): 6,279.3

Depth below land surface, in feet		Lithologic Description
From	To	
0	1	Dark brown gravelly loam.
1	1.5	Tan silt loam
1.5	8	Organics and moist at 5.0 ft, Dark brown, gravelly, sandy loam
8	13.5	Top water table at 12.0 ft. Dark black silty clay Core 12 to 13 ft Completion #3 Mesh Aquarium sand 7.7 – 13.5 ft Silica Flour 6 – 7.7 ft Native Cuttings 2 – 6 ft Neat Cement 0 – 2 ft Static: Held 9.00 Cut 1.62 Static = 7.38 ft below land surface

Well cc10

Date: November 28, 2000

USGS Standard identification number: 385433119574303

Latitude: 385433.31

Longitude: 1195743.09

Altitude (accuracy 0.01 ft): 6,276.39

Depth below land surface, in feet		Lithologic Description
From	To	
0	1	Brown, sandy loam with minor potato sized cobbles
1	3	Brown, sandy, gravelly loam
3	4	Dark brown silty, sandy loam
4	5.5	Very black, silty sand (moist)
5.5	10	#12 mesh sand. Very wet at 7 ft.
		Top water table at 7 ft Core 8 to 10 ft
		Static water level 7.90
		4.05
		3.95 ft below land surface
		Completion
		Native Cos sand 6 – 10 ft
		Silica Flour 5 – 6 ft
		Native top cuttings 1.5 – 5 ft
		Neat Cement 0 – 1.5 ft

Well cc11

Date: November 20, 2000

USGS Standard identification number: 385434119574401

Latitude: 385433.65

Longitude: 1195743.52

Altitude (accuracy 0.01 ft): 6,272.83

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.58	Grass, organic a lot of organic matter, roots, silt, fine sand, mica chips, mica present (small amount), moist, friable, moderate brown (5YR 3/4)
0.58	1	Fine sand, small amount of mica, silt, roots, moist and friable, some medium sand, organic matter, moderate brown (5YR 3/4)
1	?	Roots, organic matter, fine sand, silt, some medium sand, mica flakes (more than above) moist and friable greenish brown (5YR 3/2)
?	1.71	Moist and friable; bottom bucket = sand (medium), top bucket fine sand, silt roots and organic matter. Top = grayish brown (5YR 3/2) mica. Bottom brownish sand/mica
1.71	2.5’	Top of bucket is sand (medium), mica flakes present; bottom bucket mica fine sand silt, organic matter; moist fine sand, silt = dusky yellow brown (10YR 2/2)
2.5	2.83	Root (pretty woody), part of the bucket fine moist sand/silt, fine-medium sand, organic matter, dusky yellowy brown (10YR 2/2), mica, sand = white and dusky yellowy brown fill
2.83	3.6	Major woody root, roots, organic matter, moist, mica, fine/medium sand silt. Dusky brown (5YR 2/2)
3.6	5.5	Sloppy wet, coarse sand-med. Sand, silt, roots, fine sand, dusky yellowy brown (10YR 2/2). Gravelly coarse sand, silt

Well cc12

Date: November 20, 2000

USGS Standard identification number: 385434119574402

Latitude: 385433.95

Longitude: 1195743.86

Altitude (accuracy 0.01 ft): 6,272.64

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.125	Top 1.5 – 2 in. frozen. Fine sand/silt, moist
0.125	0.29	Large amt of root material, moist, fine sand/silt, moderate brown (5YR 3/4)
0.29	0.67	Roots, silty/fine sand, mica chips, organic matter, dusky brown (5YR 2/2)
0.67	1.08	Mica chips, root matter (less than above), moist fine sand/silt, bottom of bucket; fine sand silt, rock (2 in.), moist, organic matter top of bucket. Grayish/brn (5YR 3/2), moderately brn (5YR 3/4)
1.08	1.4	Fine sand/silt slightly clayey, moist, some gravel sized rocks, oxidized (orange) spots. Fine sand/silt, slightly clayey. Some gravel size one at ~1 in., moist, oxidized (orange spots) Moderate brown (5YR 4/4) orange spots = light brown (5YR 5/6); moderate brown (5YR 4/4), orange spots = light brown (5YR 5/6)
1.4	1.75	Fine to medium sand, some gravel, moderate yellowish brown; moist, mica chips, silt. Silty, gravel, one rock at 1 in., moist silt, mica chips. (10YR 5/4), dusky yellowy brown (10YR 2/2)
1.75	2.15	Some clay, mica chips, fine sand silt, some organic matter, moist, root, moist, some organic matter, mica chips, fine sand/silt. Dusky yellow brown (10YR 2/2)
2.15	2.41	Some clay, fine medium sand/silt. Some gravel, moist, some roots, organic matter, mica chips, fine medium sand, silt, some roots, organic matter. Gravel rock, mica chips. Dusky yellow brown (10YR 2/2)
2.41	3.8	Medium/fine sand, silt, chunk of wood ~ 1.5 to 2 in., long, mica chips, organic matter. Spots of moderate brown (5YR 4/4), greenish black (5G 2/1), moist mica chips
3.8	4.05	Getting wetter, greenish black (5G 2/1) and dusky yellowy brown (10YR 2/2) and primary color increased moisture content, silt, fine sand, some roots, some gravel (wood chip ~ 2.5 in. long), organic matter
4.05	4.75	Hole collapsing – hit water below 4.05 ft top of bucket, fine sand/silt, bottom bucket, coarse sand and gravel, wet dusky yellowy brown (10YR 2/2)
		Depth to water at 2 ft

Well cc13S

Date: November 30, 2000

USGS Standard identification number: 385433119574401

Latitude: 385433.03

Longitude: 1195744.01

Altitude (accuracy 0.01 ft): 6,275.14

Depth below land surface, in feet		Lithologic Description
From	To	
0	2.5	Reddish tan, fine, silty sandy (#16) loam-minor gravel
2.5	3.5	Black silty (balls) fine moist sandy loam
3.5	5	Black, silty sand (#12) small pea gravel particles
5	7	Black, very fine silty sand
7	8.5	Black coarse, silty sand (wet)
8.5	10	Very coarse (#3 Aquarium) black sandy silt, wet
		Static: 9.00 ft
		5.24 ft
		3.76 ft below land surface
		Top W.T. ~ 7 ft
		Completion
		Native cuttings 6 – 10 ft
		Silica Flour 5 – 6 ft
		Native cuttings 2 – 5 ft
		Neat Cement Seal 0 – 2 ft
		Coarse 8 – 10 ft

Well cc13D

Date: November 29, 2000

USGS Standard identification number: 385433119574402

Latitude: 385433.03

Longitude: 1195744.01

Altitude (accuracy 0.01 ft): 6,275.69

Depth below land surface, in feet		Lithologic Description
From	To	
0	1.5	Dark brown gravelly, sandy loam
1.5	3	Cinnamon colored, silty, fine sand
3	6	Dark brown, fine sandy #16 mesh loam
6	12	Black, coarse, silty sand, mustard colored
12	15	Coarse DG
		Static water level: 10.00
		5
		5 ft
		-0.2
		4.80 ft below land surface
		Top water table 7.5 ft
		Core 13 ft to 15 ft
		Completion
		Native Cuttings 2 – 15 ft
		Neat Cement Seal 0 – 2 ft

Well cc14

Date: November 21, 2000

USGS Standard identification number:385433119574403

Latitude: 385433.26

Longitude: 1195744.09

Altitude (accuracy 0.01 ft): 6,272.60

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.29	Frozen to 2 ins. Organic matter, roots, grass, fine sand, silt, mica chips, moist moderate brown (5YR 3/4)
0.29	0.92	Roots, organic matter, fine sand, silt, mica chips, moist moderate brown (5YR 3/4)
0.92	1.33	Increasing moistness, fine sand, silt, roots (though not as much as above two buckets), mica, dusky yellowish brown (10YR 2/2)
1.33	1.71	(Same as above) fewer roots, same moisture, but not as much organic matter. Dusky yellowish brown (10YR 2/2)
1.71	2.25	Fine sand, silt, increasing mica content, same moisture as above. Same amount of root matter as above bucket, some organic matter, dusky yellowish brown (10YR 2/2)
2.25	2.75	Slight increase in moisture content, mica, fine sand, silt, some root matter, grayish black (N2), some organic matter
2.75	3.1	Same as above in moisture and texture, approx. same amt root matter, grayish black (N2), some organic matter
3.1	3.6	Fine sand, silt, some organic matter. Not a brown sand like yesterday. Part of bucket primarily fine sand, mica Fine sand/silt = grayish black (N2). Sand = medium dark grey (N-4) fine/medium sand
3.6	5.7	Wet, medium sand, mica. Medium dark grey (N4)

Well cc15

Date: November 30, 2000

USGS Standard identification number: 385432119574401

Latitude: 385432.33

Longitude: 1195744.03

Altitude (accuracy 0.01 ft): 6,278.33

Depth below land surface, in feet		Lithologic Description
From	To	
0	1.5	Reddish brown sandy loam, small gravels to 0.5 in. (rounded)
1.5	8	#16 mesh. Dark (Blackish) fine sandy #16 mesh
8	8.5	Black bog layer – sandy
8.5	10	Coarse (black) #12 to #3 mesh, sandy silt
		Water table at 7.5 to 8 ft
		Core: 8 ft to 10 ft
		Static: 9 ft
		2
		7.00 ft below land surface
		Completion
		#3 Aquarium Sand 7 – 10 ft
		Silica Flour 6 – 7 ft
		Native Cuttings 2 – 6 ft
		Neat Cement Seal 0 – 2 ft

Well cc16

Date: December 05, 2000

USGS Standard identification number: 385433119574404

Latitude: 385432.56

Longitude: 1195744.440

Altitude (accuracy 0.01 ft): 6,273.47

Depth below land surface, in feet		Lithologic Description
From	To	
0	1.5	Backfill – reddish brown sandy silt; 2 ft length of coiled electrical wire and used i-hoses
1.5	5	Dark gray organic-rich sandy silt with lots of mica, some streaks. Dark reddish brown—organic smell
5	7.2	Medium gray gravelly silty sand with lots of mica. Clump of dark reddish brown organic peat at bottom (decomposing wood)

Well cc17S

Date: November 21, 2000

USGS Standard identification number:385433119574501

Latitude: 385432.69

Longitude: 1195744.86

Altitude (accuracy 0.01 ft): 6,272.71

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.58	Hard but not frozen. High organic matter, roots, moist, charcoal? (N-1), mica present, maybe silt, some coarse sand or small gravel present. Dusky brown (5YR 2/2) with moderate brown (5YR 3/4)
0.58	?	Organic matter present (a lot), roots, charcoal present, mica present, silt, dusky brown (5YR 3/4) some gravel, moist
?	?	Organic matter, roots, mica present, silt, a few gravels, dusky brown (5YR 2/2). Charcoal? present, moist
?	1.67	Fine sand/silt, roots, a little organic matter, mica, moist, dusky brown (5YR 2/2) a few coarse sandy grains, moist
1.67	?	Fine sand/silt, roots, a little organic matter, mica, moist, dusky brown (5YR 2/2) a few coarse sandy grains, moist
?	2.75	Fine sand/silt, mica present, some organic matter, dusky brown (5YR 2/2)
2.75	3.25	Fine sand/silt, mica present, some organic matter, some roots present, dusky brown (5YR 2/2), moist
3.25	3.7	Fine sand/silt, mica present, some organic matter, moist, dusky brown (5YR 2/2)
4	4.4	Fine sand/silt, top bucket moist, bottom bucket wet, mica present, dusky brown (5YR 2/2)
4.4	6.3	Organic rich, very reduced, has smell (like swamp), heavy in mica

Well cc17D

Date: November 27, 2000

USGS Standard identification number:385433119574502

Latitude: 385432.69

Longitude: 1195744.86

Altitude (accuracy 0.01 ft): 6,272.82

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Organic loam with red/brown streaks, worms, moist
0.5	1.9	Mica present, loam, roots present, moist, brown streaks (moderate brn 5YR 4/4), dark yellowish brown (10YR 2/2)
1.9	2.8	Increased moisture content, sandy loam, roots, increased mica content, dark yellowish brown (10YR 2/2)
2.8	3.6	Roots, organic matter present, coarse sand evident, still pretty loamy about same mica content as above (1.9 ft – 2.67 ft) = dark grey (N3) with black (N1)
3.6	4.7	Dark grey (N3) with some dark yellow and brown (10YR 2/2) streaks, roots, loamy with some medium/ coarse sand about same moisture content as 2.8 to 3.6 ft, wet
4.7	5.8	Wet, micaceous, dark grey (N3), organic matter, swampy smell, roots, coarse sandy loam, wet
5.8	7.2	Wet zone falling into hole, wet, grayish black (N2), micaceous, organic matter present but no roots, coarse sandy loam
7.2	7.8	Coarse sandy loam, micaceous wet grayish black (N2), no roots, faint swampy smell
7.8	8.5	6 inches of silty, coarse sand, near 8.5 feet sandy silt, very wet dark grey (N3) to med. Dark grey sandy layer (N4)
8.5	9.9	8.5 ft = clayey silt, micaceous, wet dark grey (N3) with moderate brn (5YR 3/4). 9.9 ft = medium sand, micaceous, dark yellowish brown (10YR 4/2) to moderate yellowish brown (10YR 5/4)
9.9	10.8	Coarse sand/fine gravel, wet, dark yellowish orange (10YR 6/6) – no swampy smell at 10.8 ft coarse gravel Final Depth 10.5 ft

Well cc18

Date: November 21, 2000

USGS Standard identification number: 385433119574503

Latitude: 385433.07

Longitude: 1195745.37

Altitude (accuracy 0.01 ft): 6,271.93

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.58	Frozen to 7 ins. depth. Roots, organic matter, moist a bit frozen, fine sand/silt, medium sand present, mica, dusky yellowish brown (10YR 2/2)
0.58	?	Roots, organic matter present, fine sand, silt, some medium sand, a few small gravels, mica, moist, dusky yellowish brown (10YR 2/2)
?	1.58	Moist, fine sand/silt, some medium sand present, a few small gravels, roots/some organic matter, mica, dusky yellowish brown (10YR 2/2)
1.58	2	Some very black splotches (N1), fine sand/silt. Some medium sand present, mica, moist, dusky yellowish brown (10YR 2/2)
2	2.625	Moist, silt, fine sand, mica with small black blotches (N1) or organic matter present, some med sand and small amount of small gravel. Dusky yellowy brown (10YR 2/2)
2.625	3.15	Medium sand/some fine sand present mica, wet, some gravel. Dusky yellowish brown (10YR 2/2)
3.15	4.625 Hit clay	Medium/coarse sand, mist (5YR 2/1), clayey silt. Clay in areas of organic matter and mica, sand and gravel. Organic matter = between *moderate brown (5YR 4/4) moderate brown (5YR 3/4)

Well cc19S

Date: November 22, 2000

USGS Standard identification number: 385433119574504

Latitude: 385432.74

Longitude: 1195745.49

Altitude (accuracy 0.01 ft): 6,272.19

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.54	Frozen to 6.5 in. Roots, organic matter, silt/some fine sand, 1 big quartz chunk, moist, mica quartz pieces, dusky brown (5YR 2/2)
0.54	0.83	Wood chunks, small gravel present, roots, organic matter, moist, fine sand silt, mica, dusky yellowish brown (10YR 2/2)
0.83	1.29	Coarse sand instead of small gravel
1.29	1.67	Moist, fine sand silt, mica present, roots, some coarse sand present, dusky yellowish brown (10YR 2/2)
1.67	2.17	Wet, fine sand, silt, some medium and coarse sand present, some small gravel, roots, mica
2.17	2.79	Fine sand/medium sand, some coarse sand present, roots, mica, wet, dark yellowish brown (10YR 4/2)
2.79	3.2	Dark yellowish brown, fine medium sand (10YR 4/2) mica present, wet
3.2	3.9	(10YR 4/2) Dark yellowish brown/fine, medium sand, greenish black (5GY 2/1), fine quartz, silt, mica Some cave in expected due to same reading (1 bucket)
3.9	4.2	Mixture of wet fine medium sand and greenish black sand. Final depth 5.4 ft

Well cc19D

Date: November 27, 2000

USGS Standard identification number: 385433119574505

Latitude: 385432.74

Longitude: 1195744.49

Altitude (accuracy 0.01 ft): 6,272.11

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Moist, organic rich, roots a few gravels, loam, mica present, dusky yellowish brown (10YR 2/2)
0.5	1.5	Loam, organic rich, roots, moist, mica present, dusky yellowish brown (10YR 2/2)
1.5	3	Roots increasing moisture content, micaceous loam, some medium sand, a few small gravels, dusky yellowy brown (10YR 2/2)
3	3.5	Coarse sand, wet, still pretty loamy, micaceous, dark yellowish brown (10YR 4/2)
3.5	4	Fine/medium sand, no readily apparent root material, wet, mica present, primarily dark yellowish brown (10YR 4/2)
4	5.5	Sandy silt, dark grey (N-3), mica present, wet
5.5	6	Same material as above (sandy silt and dark grey), however at 6 ft became micaceous, wet
6	7.7	Essentially same material as above. At about 6.0 ft started to hit clayey silt, micaceous, wet at 7.7 ft really getting clayey or at least “formable”
7.7	~9	Presence of “heavy” silty soil = grayish black (N2) mixed in with sandy silt of dary grey (N3) color, mica present in both fractions. Sandy material, olive black (5YR 2/2) – medium/coarse sand at about 9.5 ft medium dark gray (a lot of mica) very micaceous
~9	10	Sandy material a bit browner than grey material above dusky yellowish brown (10YR 2/2). Final depth 10 ft

Well cc20

Date: December 5, 2000

USGS Standard identification number: 385432119574501

Latitude: 385432.24

Longitude: 1195745.190

Altitude (accuracy 0.01 ft): 6,272.77

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Organic rich clayey silt—numerous roots, dark brownish gray
0.5	2.9	Dark brownish gray sandy silt—organic rich
2.9	5	Dark brownish gray mixed , sandy silt mixed with reddish gray silt, lots of mica—sediment wet but little water in hole
5	7.2	Gray gravelly sandy silt; sediments wet and sloppy – about 2 ft of water in hole
		Total depth 7.2 ft.
		Sandy gravel 4.5 – 7.2 ft
		Silica flour 4.5 – 7.2 ft
		Sandy silt 1.5 – 2.5 ft
		Neat cement 0.2 – 1.5 ft
		Top soil 0.0 – 0.2 ft

Well cc21

Date: December 5, 2000

USGS Standard identification number: 385432119574601

Latitude: 385432.48

Longitude: 1195745.690

Altitude (accuracy 0.01 ft): 6,272.19

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Dark brownish gray clayey silt – organic rich and numerous roots upper 0.25 ft frozen
0.5	1.65	Dark brownish gray sandy silt – organic rich
1.65	3.15	Light grayish brown. Coarse sandy gravel. Gravels are granitic. Water at 2.5 ft
3.15	5	Grayish brown, coarse sandy gravel; very wet – hole collapses
		Total Depth 5.0 ft.
		Backfill:
		Coarse sandy gravel 3.0 – 5.0 ft
		Silica flour 1.5 – 3.0 ft
		Neat cement 0.2 – 1.5 ft
		Top soil 0.0 – 0.2 ft

Well cc22

Date: November 28, 2000

USGS Standard identification number: 385433119574701

Latitude: 385432.71

Longitude: 1195746.670

Altitude (accuracy 0.01 ft): 6,271.94

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.6	Sandy organic loam, moist, moderate brown (5YR 3/4), some mica present, roots
0.6	?	Upper part organic loam (bottom part sandy organic loam), small amt of sand in the loam, root matter throughout moist, mica present, dusky brown (5YR 2/2)
?	2.7	Top part slightly sandy loam. Dusky brown (5YR 2/2); bottom bucket = wet medium/coarse sand, no visible roots in sandy portion. Sandy fraction pale yellowish brown (10YR 2/2)
2.7	3.4	Gravelly coarse sand, wet, no roots, mica present, pale yellowish brown (10YR 2/2)
3.4	3.6	Same as above bucket. Disturbed core from this depth increment
3.6	5.6	Same as above. Final well depth 5.6 ft

Well cc23

Date: November 28, 2000

USGS Standard identification number: 385433119574702

Latitude: 385432.81

Longitude: 1195747.180

Altitude (accuracy 0.01 ft): 6,271.08

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.55	Frozen to 0.55 ft. Loam, some mica present, roots, organic matter, moist, some charcoal present. Dusky brown (5YR 2/2) with moderate brown (5YR 3/4)
0.55	1.7	Dusky yellowish brown (10YR 2/2) with moderate brn (5YR 4/4) marbled throughout moist, loamy mica present, organic matter, roots, some coarse sand present
1.7	2.8	About the same moisture content as (0.55 to 1.7 ft bucket). Gravel med sand patches of dark yellowish brn (1-YR 4/2). Gravel present, brownish black (5YR 2/1) – roots organic matter, mica present
2.8	3.3	Chunk of loam with mica present predominantly grayish black (N2) – some fine sand, moderate yellowish brown (10YR 5/4); sandy gravel dirth moderate yellowish brown (10YR 5/4) moist – wet. Disturbed core taken from this depth increment
3.3	3.5	Increased moisture = wet part fine sand/silt (grayish black N2) with some olive grey (5YR 4/1), mica present, the rest of the bucket coarse sand gravel
3.5	4.4	Coarse sand/gravel, wet (dirty)
4.4	4.8	Top part of bucket – coarse sand/gravel. Bottom bucket – clayey silt (olive black 5Y2) some mica, but not much
4.8	5	Coarse sand/gravel wet (I think this was from higher up same as 3.5 to 4.4 ft bucket)
5	5.5	Clayey silt (olive black 5Y 2/1) and part of bucket medium coarse sand, mica present (medium dark grey N4)
		Sand backfill to 3 ft from surface. Silica flour top 7 ft from surface. Final well depth at 5.5 ft

Well cc24

Date: November 28, 2000

USGS Standard identification number: 385432119574701

Latitude: 385432.25

Longitude: 1195747.04

Altitude (accuracy 0.01 ft): 6,271.97

Depth below land surface, in feet		Lithologic Description
From	To	
0	0.5	Moist, organic matter, roots, coarse sand present. Some charcoal present. Moderate brown (5YR 3/4) with light brown (5YR 5/6)
0.5	1.25	Moist fine/medium sand (with organic matter), roots, moderate brown (5YR 3/4), bottom portion little gravels present. Bottom portion dusky yellowish brown (10YR 2/2), loam, organic, mica present
1.25	2.4	Gravelly coarse sand loam, organic matter, roots, moist, dusky yellowish brown (10YR 2/2). Mica present
2.4	2.9	Wet, coarse sand loam, mica present, organic matter, dusky yellowish brown (10YR 2/2)
2.9	3.5	Wet gravelly coarse sand, micaceous, some root matter, sand, dirty but close to dark yellowish brown (10YR 4/2)
3.5	4.2	Same material as above. Gravelly sand, wet, dark yellowish brown sand (10YR 4/2), no root matter, some mica present. Depth disturbed core taken
4.2	4.6	Same material as above. Near 4.6 ft depth fine sand/silt, mica present, grayish black (N2)
4.6	5.6	Coarse sand (dark yellowish brown (10YR 4/2) which probably fell from above) and the fine sand silt grayish black (N2)
		Total well depth at 5.6 ft

Appendix B

Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05.

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05.

[Symbol: --, not determined]

Well number	Water-level measurement in feet above mean sea level							
	2001							
	11/22	12/7	1/9	5/9	6/12	7/17	8/30	9/5
cc01	--	6,275.74	6,275.90	6,276.14	6,275.90	--	6,276.85	--
cc02	--	6,276.17	6,276.18	6,276.32	6,276.09	--	6,276.82	--
cc03S	6,272.64	6,272.60	6,272.51	6,272.99	6,272.45	--	6,272.33	6,272.04
cc03D	6,272.72	6,272.58	6,272.49	6,273.12	6,272.53	--	--	6,272.13
cc04	6,273.52	6,273.56	6,273.49	6,273.85	6,273.43	6,273.15	6,273.32	--
cc05	6,270.23	6,272.43	6,272.36	6,272.76	6,272.32	6,272.03	6,272.08	--
cc06S	6,271.65	6,271.59	6,271.53	6,271.86	6,271.50	6,271.25	6,271.19	--
cc06D	6,271.63	6,271.55	6,271.87	6,271.53	6,271.27	6,271.26	--	--
cc07	6,271.44	6,271.84	6,271.70	6,271.95	6,271.69	6,271.46	6,271.44	--
cc08S	6,271.90	6,271.84	6,271.74	6,272.07	6,271.67	--	--	6,271.37
cc08D	--	6,272.05	6,271.95	6,272.35	6,271.89	6,271.59	--	6,271.57
cc09	6,271.92	6,271.87	6,271.79	6,272.22	6,271.70	--	6,271.36	--
cc10	--	6,271.18	6,271.08	6,271.37	6,271.09	6,270.87	6,270.82	--
cc11	--	6,270.62	6,270.53	6,270.72	--	--	6,270.32	--
cc12	--	6,270.50	6,270.35	6,270.51	--	6,270.20	6,270.11	--
cc13S	6,271.38	6,271.37	6,271.25	6,271.57	6,271.23	6,270.98	--	6,270.92
cc13D	6,270.89	6,270.76	6,270.66	6,270.88	6,270.61	6,270.37	--	6,270.27
cc14	--	6,270.19	6,270.11	6,270.25	6,270.11	6,270.00	--	--
cc15	6,271.33	6,271.31	6,271.21	6,271.56	6,271.08	--	6,270.68	--
cc16	--	6,268.98	6,270.82	6,271.04	6,270.51	6,270.21	6,270.12	--
cc17S	--	6,270.75	6,270.45	6,270.61	6,269.95	6,269.73	6,269.50	--
cc17D	--	6,270.60	6,270.44	6,270.84	6,270.41	6,270.18	6,270.01	--
cc18	--	6,269.36	6,269.26	6,269.43	6,269.31	6,269.13	6,269.03	--
cc19S	--	6,269.45	6,269.28	6,269.28	6,269.40	6,269.04	6,268.56	--
cc19D	--	--	6,269.38	6,269.50	6,269.15	6,268.63	6,268.81	--
cc20	--	6,269.95	6,269.73	6,270.02	6,269.29	6,269.04	6,268.84	--
cc21	--	6,269.56	6,269.37	6,269.58	6,269.28	--	6,268.90	--
cc22	--	6,269.01	6,268.84	6,269.04	6,268.72	6,268.57	6,268.39	--
cc23	--	--	6,268.62	6,268.78	6,268.52	6,268.44	6,268.24	--
cc24	--	6,268.77	6,268.61	6,268.82	6,268.36	6,268.16	6,268.00	--

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05—Continued.

[Symbol: --, not determined]

Well number	Water-level measurement in feet above mean sea level								
	2002								
	10/3	10/24	4/1	4/10	5/16	6/11	6/19	7/11	8/19
cc01	--	6,275.72	6,276.36	6,276.15	6,276.13	6,276.17	6,276.11	6,275.82	6,275.58
cc02	--	6,275.91	--	6,276.55	6,276.41	6,276.39	6,276.33	6,276.03	6,275.90
cc03S	--	6,271.87	--	6,274.25	6,273.63	6,273.16	6,272.83	6,272.38	6,271.88
cc03D	--	6,272.09	--	6,274.53	6,273.82	6,273.24	6,272.90	6,272.44	6,272.11
cc04	--	6,273.09	6,275.20	6,274.58	6,274.19	6,273.93	6,273.73	6,273.34	6,273.36
cc05	--	6,271.86	6,273.82	6,273.56	6,273.13	6,272.87	6,272.65	6,272.25	6,271.95
cc06S	6,271.26	6,271.21	6,273.00	6,272.67	6,272.22	6,272.05	6,271.88	6,271.49	6,271.37
cc06D	6,271.28	6,271.21	6,272.90	6,272.65	6,272.22	6,272.04	--	6,271.52	6,271.43
cc07	--	6,271.42	6,272.59	6,272.53	6,272.21	6,272.12	6,272.00	6,271.70	6,271.47
cc08S	6,271.40	6,271.30	--	6,272.96	6,272.52	6,272.29	6,272.07	6,271.64	6,271.32
cc08D	6,271.62	6,271.58	--	6,273.20	6,272.75	6,272.51	6,272.32	6,271.89	6,271.54
cc09	--	6,271.36	6,273.36	6,273.06	6,272.60	6,272.35	6,272.14	6,271.68	6,271.27
cc10	--	--	--	6,272.01	6,271.65	6,271.59	--	6,271.12	--
cc11	--	6,270.37	6,270.91	6,270.92	6,270.82	6,270.95	--	6,270.60	6,270.40
cc12	--	--	--	6,270.58	6,270.59	6,270.74	--	6,270.41	6,270.31
cc13S	6,270.99	6,270.96	6,272.49	6,272.31	6,271.95	6,271.75	6,271.66	6,271.27	6,271.04
cc13D	6,270.33	6,270.38	6,271.34	6,271.30	6,271.11	6,271.07	6,271.02	6,270.65	6,270.35
cc14	--	6,269.99	6,270.27	6,270.36	6,270.37	6,270.52	6,270.49	6,270.23	6,270.08
cc15	--	6,270.82	6,272.61	6,272.30	6,271.87	6,271.71	6,271.52	6,271.04	--
cc16	--	6,270.42	6,272.56	6,271.77	6,271.37	6,271.23	6,271.04	6,270.45	6,270.14
cc17S	--	6,270.09	6,271.78	6,271.52	6,270.91	6,270.69	6,270.50	6,269.86	6,269.50
cc17D	--	6,270.20	6,271.63	6,271.44	6,271.13	6,271.07	6,270.89	6,270.42	6,270.12
cc18	--	6,269.12	6,269.39	6,269.53	6,269.57	6,269.83	6,269.75	6,269.46	6,269.23
cc19S	--	6,269.05	6,270.18	6,270.01	6,269.63	6,269.68	6,269.56	6,269.07	6,268.81
cc19D	--	6,269.12	6,269.29	6,269.45	6,269.68	6,269.81	6,269.70	6,269.30	6,269.08
cc20	--	6,269.40	6,271.81	6,271.33	6,270.43	6,270.14	6,269.92	6,269.40	6,269.06
cc21	--	6,268.82	6,270.26	6,270.00	6,269.78	6,269.90	6,269.78	6,269.40	6,269.00
cc22	--	6,268.62	6,269.95	6,269.59	6,269.24	6,269.30	6,269.15	6,268.82	6,268.21
cc23	--	6,268.43	6,269.24	6,269.14	6,268.93	6,269.06	6,268.98	6,268.59	6,268.26
cc24	--	6,268.32	6,270.19	6,269.64	6,268.99	6,268.96	6,268.78	6,268.35	6,267.99

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05—Continued.

[Symbol: --, not determined]

Well number	Water-level measurement in feet above mean sea level											
	2003											
	10/4	11/5	12/4	3/13	3/27	4/11	5/29	6/23	7/29	8/4	8/27	9/25
cc01	6,275.77	6,275.77	--	--	6,276.17	--	--	6,276.29	6,275.96	6,276.03	6,275.91	6,275.74
cc02	6,275.96	6,276.49	--	--		--	--	6,276.57	6,276.22	6,276.23	6,276.09	6,275.92
cc03S	6,272.09	6,272.19	6,272.82	--	6,274.59	6,274.16	6,273.77	6,273.07	6,273.63	6,274.00	6,273.81	6,272.41
cc03D	6,272.11	6,272.27	--	--	6,274.57	6,274.11	6,273.77	6,273.21	6,273.77	6,274.13	6,273.94	--
cc04	6,273.19	6,273.27	6,274.74	6,274.52	6,274.94	6,275.68	6,274.48	6,273.95	6,274.25	6,274.48	6,274.39	6,273.38
cc05	6,272.04	6,272.12	6,272.63	6,273.47	6,274.02	6,273.73	6,273.49	6,272.90	6,273.23	6,273.48	6,273.33	6,272.31
cc06S	6,271.30	6,271.35	6,271.87	6,272.61	6,273.38	6,272.97	6,272.72	6,272.09	6,272.45	6,272.70	6,272.47	6,271.53
cc06D	6,271.30	6,271.36	6,271.86	6,272.58	6,273.30	6,272.92	6,272.72	6,272.11	--	6,272.67	6,272.45	6,271.55
cc07	6,271.49	6,271.51	6,271.90	--	6,272.79	6,272.57	--	--	6,272.38	6,272.51	6,272.32	6,271.67
cc08S	6,271.44	6,271.53	6,272.03	6,272.93	6,273.48	6,273.13	6,272.94	6,272.34	6,272.65	6,272.87	6,272.67	6,271.92
cc08D	6,271.67	6,271.76	6,272.23	6,273.19	6,273.68	6,273.35	6,273.12	6,272.59	6,272.82	6,273.05	6,272.85	6,272.34
cc09	6,271.47	6,271.57	6,272.05	--	6,273.53	6,273.20	--	6,272.43	6,272.60	6,272.83	6,272.64	6,271.74
cc10	6,270.95	6,270.95	6,271.38	6,271.74	--	6,272.14	6,272.17	6,271.78	6,271.80	6,271.98	6,271.76	6,271.08
cc11	6,270.51	6,270.45	6,270.62	6,270.86	6,271.03	6,270.91	6,271.39	6,270.94	6,270.84	6,271.00	6,270.71	6,270.45
cc12	6,270.33	6,270.27	6,270.38	6,270.50	6,270.60	6,270.55	6,271.13	6,271.00	6,270.55	6,270.59	6,270.39	6,270.22
cc13S	6,271.04	6,271.12	6,271.51	6,272.26	6,272.76	6,272.48	6,272.44	6,271.93	6,272.05	6,272.26	6,272.01	6,271.25
cc13D	6,270.46	6,270.51	6,270.71	6,271.32	6,271.54	6,271.38	6,271.69	6,271.34	6,271.09	6,271.22	6,271.01	6,270.57
cc14	6,270.07	--	--	6,270.33	6,270.44	6,270.38	6,271.10	6,270.90	6,270.46	6,270.50	6,270.26	6,270.10
cc15	6,270.91	6,271.01	6,271.40	6,272.18	6,272.32	6,272.41	6,272.32	--	6,271.83	6,271.99	6,271.79	6,270.88
cc16	6,270.50	6,270.60	6,270.93	6,272.03	6,272.15	6,271.86	6,271.82	6,271.90	6,271.22	6,271.37	6,271.14	6,270.50
cc17S	6,270.10	6,270.33	6,270.67	6,271.93	6,271.96	6,271.53	6,271.41	6,270.81	6,270.73	6,270.97	6,270.68	6,269.97
cc17D	6,270.33	6,270.41	6,270.70	6,271.65	6,271.82	6,271.57	6,271.76	6,271.23	6,271.04	6,271.16	6,270.92	6,270.46
cc18	6,269.23	6,269.12	6,269.24	6,269.82	6,269.73	6,269.89	6,270.74	--	6,270.14	6,269.76	6,269.45	6,269.32
cc19S	6,269.11	6,269.20	6,269.40	6,270.91	6,270.71	6,270.39	6,270.63	6,270.24	6,269.55	6,269.70	6,269.35	6,268.96
cc19D	6,269.20	6,269.21	6,269.68	6,270.44	6,270.40	6,270.33	6,270.70	6,270.16	6,269.61	6,269.41	6,268.77	6,268.88
cc20	6,269.49	6,269.64	6,269.98	6,272.22	6,272.05	6,271.53	6,271.24	6,271.16	6,270.17	6,270.57	6,270.18	6,269.47
cc21	6,269.24	6,269.23	6,269.44	6,270.71	6,270.74	6,270.33	6,270.70	6,270.06	6,269.81	6,269.87	6,269.59	6,269.35
cc22	6,268.73	6,268.72	6,268.87	6,270.32	6,270.31	6,269.72	6,270.00	6,269.68	6,269.17	6,269.24	6,268.98	6,268.78
cc23	6,268.51	6,268.48	6,268.56	6,268.89	6,269.36	6,269.08	6,269.69	6,269.23	6,268.83	6,268.89	6,268.63	6,268.51
cc24	6,268.39	6,268.45	6,268.62	--	6,269.50	6,269.57	6,269.63	6,269.30	6,268.79	6,268.83	6,268.63	6,268.40

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05—Continued.

[Symbol: --, not determined]

Well number	Water-level measurement above mean sea level								
	2004								
	10/16	10/30	11/6	11/25	4/9	4/16	4/30	5/21	5/27
cc01	6,275.79	--	6,275.85	--	6,276.19	6,276.12	--	--	6,276.05
cc02	6,276.00	--	6,276.09	6,276.11	6,276.49	6,276.41	6,276.30	6,276.26	6,276.27
cc03S	6,272.27	6,272.31	6,272.43	--	6,273.98	6,273.62	--	--	6,272.85
cc03D	6,272.34	6,272.38	6,272.45	--	6,274.08	6,273.70	6,273.22	6,273.07	6,272.92
cc04	6,273.32	6,273.33	6,273.47	6,273.58	6,274.59	6,274.30	6,273.98	6,273.85	6,273.75
cc05	6,272.19	6,272.22	6,272.33	6,272.47	6,273.58	6,273.32	6,272.88	6,272.79	6,272.65
cc06S	6,271.39	6,271.42	6,271.50	6,271.65	6,272.78	6,272.42	6,272.00	6,271.96	6,271.78
cc06D	6,271.42	6,271.44	6,271.53	6,271.67	6,272.75	6,272.41	6,272.01	6,271.95	6,271.81
cc07	6,271.58	6,271.59	6,271.68	6,271.77	6,272.79	6,272.33	6,272.06	6,272.02	6,271.93
cc08S	6,271.60	6,271.62	--	6,271.88	6,273.00	6,272.70	6,272.30	6,272.20	6,272.05
cc08D	6,271.83	6,271.86	--	6,272.12	6,273.22	6,272.91	6,272.52	6,272.43	6,272.29
cc09	6,271.64	6,271.68	--	--	6,273.07	6,272.77	6,272.38	6,272.26	6,272.13
cc10	6,270.99	6,271.00	--	--	--	6,272.19	--	6,271.42	6,271.31
cc11	6,270.45	6,270.46	--	6,270.53	6,270.89	6,270.78	6,270.66	6,270.67	6,270.65
cc12	6,270.25	6,270.25	--	6,270.31	6,270.56	6,270.48	6,270.42	6,270.43	6,270.43
cc13S	6,271.17	6,271.19	--	6,271.40	6,272.36	6,272.08	6,271.74	6,271.69	6,271.55
cc13D	6,270.58	6,270.61	--	6,270.75	6,271.37	6,271.20	6,271.03	6,270.98	6,270.94
cc14	6,270.12	6,270.09	--	6,270.16	6,270.44	6,270.35	6,270.30	6,270.32	6,270.32
cc15	6,271.06	6,271.12	--	6,271.37	6,271.73	6,272.06	6,271.75	6,271.31	6,271.51
cc16	6,270.59	--	6,270.87	6,270.94	6,271.78	6,271.56	6,271.25	6,271.13	6,271.02
cc17S	6,270.19	--	6,270.59	6,270.61	6,271.46	6,271.21	6,270.88	6,270.71	6,270.59
cc17D	6,270.48	--	6,270.67	6,270.73	6,271.49	6,271.32	6,271.08	6,270.98	6,270.90
cc18	6,269.35	--	6,269.52	6,269.41	6,269.61	6,269.52	6,269.49	6,269.52	6,269.51
cc19S	6,269.18	--	6,269.54	6,269.53	6,270.21	6,269.93	--	6,269.51	6,269.43
cc19D	6,269.25	--	6,269.36	6,269.02	6,270.05	6,269.96	6,269.58	6,269.62	6,269.57
cc20	6,269.61	--	6,270.11	6,270.07	6,271.33	6,271.05	6,270.48	6,270.13	6,270.00
cc21	6,269.39	--	6,269.57	--	6,270.11	6,269.93	6,269.78	6,269.72	6,269.70
cc22	6,268.84	--	6,269.03	6,268.99	6,269.62	6,269.41	6,269.23	6,269.15	6,269.12
cc23	6,268.54	--	6,268.69	6,268.64	6,269.11	6,268.95	6,268.84	6,268.81	6,268.78
cc24	6,268.50	--	6,268.70	6,268.72	6,269.61	6,269.28	6,269.03	6,268.90	6,268.84

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05—Continued.

[Symbol: --, not determined]

Well number	Water-level measurement above mean sea level							
	2004—Continued							
	6/4	6/25	7/9	7/22	8/9	8/18	8/19	9/10
cc01	6,276.09	6,275.93	6,275.83	6,275.75	6,275.73	--	--	6,275.54
cc02	6,276.26	6,276.00	6,276.00	6,275.94	6,275.93	--	--	6,275.89
cc03S	6,272.90	6,272.51	6,272.37	6,272.21	6,272.10	6,272.02	6,272.02	--
cc03D	6,272.99	6,272.61	6,272.45	6,272.31	6,270.09	6,270.06	6,270.07	6,270.09
cc04	6,273.82	6,273.51	6,273.38	6,273.29	6,273.14	6,273.15	6,273.18	6,273.13
cc05	6,272.76	6,272.41	6,272.27	6,272.16	6,272.09	6,272.01	6,272.03	6,271.97
cc06S	6,271.96	6,271.61	6,271.48	6,271.39	6,271.27	6,271.24	6,271.26	6,271.19
cc06D	6,271.96	6,271.61	6,271.49	6,271.41	6,271.30	6,271.27	6,271.29	6,271.22
cc07	6,272.03	6,271.77	6,271.66	6,271.59	6,271.49	6,271.45	6,271.43	6,271.40
cc08S	6,272.17	6,271.78	6,271.63	6,271.54	6,271.41	6,271.39	6,271.39	6,271.34
cc08D	6,272.39	6,272.02	6,271.88	6,271.78	6,271.48	6,271.45	6,271.47	6,271.41
cc09	6,272.21	6,271.84	6,271.69	6,271.58	6,271.46	6,271.42	6,271.45	6,271.38
cc10	6,271.45	6,271.16	6,271.06	6,270.98	6,270.88	--	--	6,270.82
cc11	6,270.73	6,270.59	6,270.50	6,270.44	6,270.37	6,270.34	6,270.35	6,270.31
cc12	6,270.52	6,270.40	6,270.29	6,270.25	6,270.17	--	--	6,270.11
cc13S	6,271.69	6,271.35	6,271.21	6,271.13	6,271.02	6,270.99	6,271.02	6,270.95
cc13D	6,271.00	6,270.75	6,270.62	6,270.56	6,270.47	6,270.42	6,270.47	6,270.39
cc14	6,270.40	6,270.27	6,270.16	6,270.12	6,270.06	6,270.02	6,270.04	6,269.98
cc15	6,271.55	6,271.20	6,271.05	6,270.95	6,270.85	6,270.82	6,270.87	6,270.80
cc16	6,271.03	6,270.58	6,270.41	6,270.33	6,270.29	6,270.21	6,270.43	6,270.28
cc17S	6,270.81	6,269.98	6,269.77	6,269.74	6,269.71	6,269.58	6,269.76	6,269.75
cc17D	6,270.66	6,270.60	6,270.45	6,270.35	6,270.26	6,270.14	6,270.30	6,270.22
cc18	6,269.61	6,269.49	6,269.37	6,269.33	6,269.24	--	--	6,269.18
cc19S	6,269.43	6,269.09	6,268.91	6,268.80	6,268.73	--	--	6,268.79
cc19D	6,269.60	6,269.33	6,269.18	6,269.10	6,269.02	--	--	6,269.02
cc20	6,269.95	6,269.46	6,269.23	6,269.19	6,269.22	6,269.19	6,269.32	6,269.29
cc21	6,269.74	6,269.50	6,269.35	6,269.29	6,269.23	6,269.17	6,269.25	6,269.19
cc22	6,269.13	6,268.89	6,268.74	6,268.66	6,268.64	6,268.60	6,268.69	6,268.63
cc23	6,268.82	6,268.60	6,268.48	6,268.39	6,268.37	--	--	6,268.38
cc24	6,268.81	6,268.50	6,268.33	6,268.22	6,268.18	--	--	6,268.20

Appendix B. Measured water levels for monitoring wells in the vicinity of Cattlemans detention basin, South Lake Tahoe, California, water year 2001–05—Continued.

[Symbol: --, not determined]

Well number	Water-level measurement above mean sea level	
	2005	
	10/1	10/15
cc01	6,275.79	6,275.77
cc02	6,275.97	6,275.94
cc03S	6,272.03	6,272.13
cc03D	6,270.08	6,270.11
cc04	6,273.20	6,273.23
cc05	6,272.05	6,272.07
cc06S	6,271.25	6,271.27
cc06D	6,271.27	6,271.30
cc07	6,271.44	6,271.46
cc08S	6,271.42	6,271.46
cc08D	6,271.49	6,271.54
cc09	6,271.47	6,271.51
cc10	6,270.84	6,270.87
cc11	6,270.31	6,270.35
cc12	6,270.12	6,270.17
cc13S	6,271.01	6,271.04
cc13D	6,270.45	6,270.47
cc14	6,269.99	6,269.98
cc15	6,270.92	6,270.96
cc16	6,270.51	6,270.56
cc17S	6,270.10	6,270.27
cc17D	6,270.34	6,270.31
cc18	6,269.18	6,269.19
cc19S	6,269.09	6,269.16
cc19D	6,269.18	6,269.21
cc20	6,269.53	6,269.60
cc21	6,269.26	6,269.28
cc22	6,268.73	6,268.76
cc23	6,268.46	6,268.49
cc24	6,268.37	6,268.43

Appendix C

Water Quality Data

Appendix C is provided as an Excel spreadsheet.