United States Department of the Interior

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December 24, 2008

Ms. Christy Hunter, Engineering Geologist, P.G.
California Regional Water Quality Control Board
Lahontan Region 6
14440 Civic Drive, Suite 200
Victorville, CA 92392

Dear Ms. Hunter;

This letter summarizes the results of our cooperative water-resources study to determine the source of chromium in water-table observation wells on the Sheep Creek fan near El Mirage, California. The study was funded by the Lahontan Regional Water Quality Control Board as part of the Molycorp SEP settlement between September 2006 and November 2008. The study was completed under the direction of Dr. John Izbicki in our San Diego Projects Office.

Previous studies determined that water from five of six water-table observation wells at a dairy on the distal part of the Sheep Creek fan near El Mirage had chromium concentrations in excess of the California Environmental Protection Agency Maximum Contaminant Level (MCL) of 50 micrograms per liter, with one sample as high as 460 μg/L. The source of the high-chromium concentrations in water from these wells was not known and there was concern that these high-concentrations could be related to chromium contamination at a nearby chemical milling facility. It also is possible that high-chromium concentrations could result from naturally occurring chromium leached from the surfaces of mineral grains as water moves through the unsaturated zone beneath irrigated fields.

The purpose of this study was to determine the source of the high-chromium concentrations in the water-table wells at the dairy. The scope of this study included drilling and instrumentation of unsaturated zone monitoring sites (1) in a field historically irrigated with dairy wastewater (EM-2) and (2) in a previously unirrigated field that received its first application of dairy wastewater in spring 2008 (EM-3). Test drilling and instrument installation were done in September 2006. Water level, matric potential, temperature, and water-quality data were collected from these sites between October 2006 and November 2008. Water-quality data collection included analysis for stable chromium isotope ratios ($\delta^{53}Cr$). Data collected as part of this study were compared and contrasted with data collected as part of a regional study of chromium and chromium isotopes in rock, alluvium, and water from wells in the western Mojave Desert.

Data from this study were transmitted to Lahontan Regional Water Quality Control Board staff in September 2008. Water level, matric potential, and temperature data, collected at 4-hour intervals using data loggers, are available on the U.S. Geological Survey's Automatic Data Processing System (ADAPS); water-quality data are available on the QWDATA system. ADAPS and QWDATA are accessible on the internet through the U.S. Geological Survey's NWISWeb site (http://waterdata.usgs.gov/tx/nwis/). Results from the study were presented at the Goldschmidt meeting in Vancouver, Canada in July 2008 (Izbicki, J.A., Kulp, T.R., Bullen, T.D., Ball, J.W., and O'Leary, D., 2008, Chromium mobilization from the unsaturated zone (Abs.). Proceedings from the 2008 Goldschmidt Conference, Vancouver, Canada, July 13-18, 2008).

The data collected for this study indicate that the source of high-chromium concentrations in water-table wells at the dairy was naturally occurring chromium mobilized from the unsaturated zone as a result of irrigation with dairy wastewater. This conclusion is supported by (1) the occurrence of high concentrations of chromium in the unsaturated zone beneath the dairy, (2) increases in chromium concentrations at the water table after infiltration of irrigation return water, (3) the isotopic composition of chromium in the saturated and unsaturated zone beneath the dairy, and (4) comparison of the stable isotopes of oxygen and hydrogen in water samples from the dairy and the chemical milling facility. In addition, laboratory studies done as part of this study show that interference in the microbiologically mediated reduction of Cr (VI) to Cr (III) by high-nitrate concentrations in dairy wastewater may allow chromium, in the form of Cr (VI), to remain mobile in the unsaturated zone and reach the water table. A detailed description of the study results is included as an attachment to this letter.

If you have any questions concerning the study results, do not hesitate to contact me at (619) 225-6127 or Dr. John Izbicki at (619) 225- 6131. The U.S. Geological Survey looks forward to working with the Lahontan Regional Water Quality Control Board on future water-resource investigations.

Sincerely,

Peter Martin
Program Chief

Chromium Concentrations, Chromium Isotopes, and Nitrate in the Unsaturated Zone and at the Water-Table Interface, El Mirage, California

Introduction

Previous studies determined that water from five of six water-table observation wells at a dairy on the distal part of the Sheep Creek fan near El Mirage (fig. 1) had chromium concentrations in excess of the California Environmental Protection Agency Maximum Contaminant Level (MCL) of 50 micrograms per liter, with one sample as high as 460 μg/L (Alta EM, written commun., 2006). The source of the high-chromium concentrations in water from these wells was not known and there was concern that these high-concentrations could be related to chromium contamination at a nearby chemical milling facility (fig. 1). It also is possible that high-chromium concentrations could result from naturally occurring chromium leached from the surfaces of mineral grains as water moves through the unsaturated zone beneath irrigated fields.

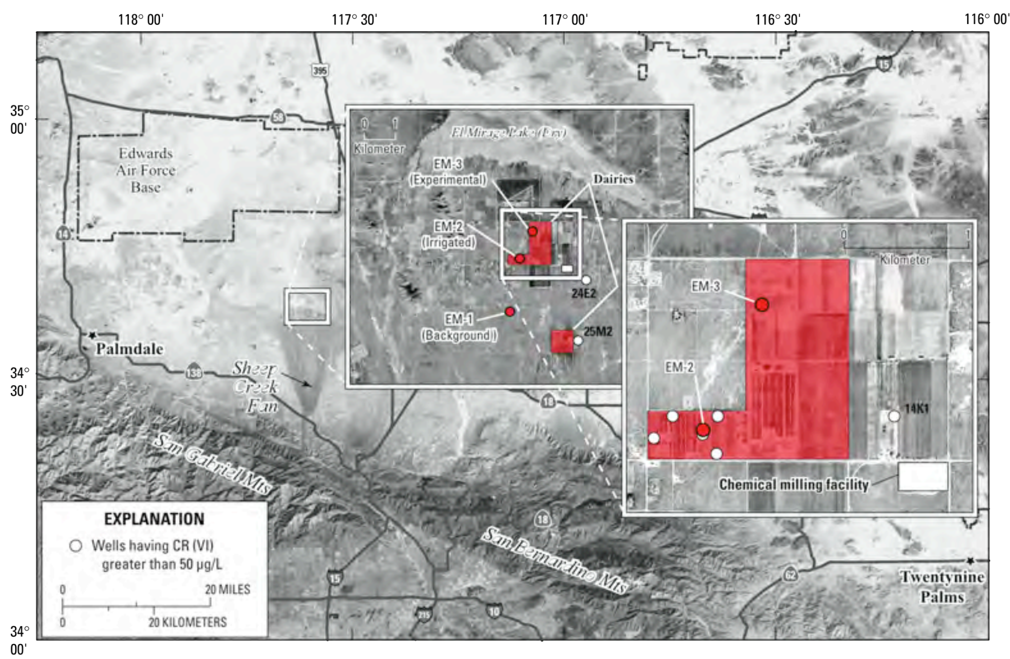

Figure 1.—Study area location

The purpose of this study was to determine the source of the high-chromium concentrations in the water-table wells at the dairy. The scope of this study included drilling and instrumentation of unsaturated zone monitoring sites (1) in a field historically irrigated with dairy wastewater (EM-2) and (2) in a previously unirrigated field that received its first application of dairy wastewater in spring 2008 (EM-3). Test drilling and instrument installation were done in September 2006. Water level, matric potential, temperature, and water-quality data were collected from these sites between October 2006 and November 2008. Water-quality data collection included analysis for stable chromium isotope ratios ($\delta^{53}Cr$). Data collected as part of this study were compared and contrasted with data collected as part of a regional study of chromium and chromium isotopes in rock, alluvium, and water from wells in the western Mojave Desert (Izbicki and others, 2008a). The EM-1 site (fig. 1) was installed as part of the regional study to represent background conditions at the water table, upgradient from the El Mirage area.

Occurrence of Chromium in the Unsaturated Zone

The occurrence of chromium in the unsaturated zone beneath the dairy site was measured in samples of solid material and pore water. Acid extractions of core and cutting material collected during drilling were used to determine the abundance of chromium sorbed to iron and manganese hydroxides on the surfaces of mineral grains. Acid extractions of core and cutting material were prepared using 4 N nitric acid using procedures described by Izbicki and others (2008a). Water samples from suction-cup lysimeters and from pressure extracts from core material were used to determine chromium concentrations in pore water in the unsaturated zone. Pressure extracts from core material were prepared by squeezing water from core material using a hydraulic press (Manheim and others, 1994). It was not possible to determine the fraction of chromium present as Cr (VI) on acid-extracts, samples from suction-cup lysimeters, or pressure extracts because of limitations in sample preservation associated with these procedures. As a consequence, chromium data for acid extracts from the unsaturated zone are reported as total chromium in milligram per kilogram of alluvium and chromium data for suction cup lysimeters and pressure extractions from core material are reported as total dissolved chromium.

Chromium was present at concentrations as high as 53 milligrams per kilogram of alluvium in acid extracts from alluvial material composing the unsaturated zone beneath the dairy at the EM-2 and EM-3 sites (fig. 2). This value is about half of the average concentration of chromium in the earth’s crust (Nriagu, 1988; Reimann and Caritat, 1998). Chromium sorbed to iron and manganese hydroxides on the surfaces of mineral grains is likely to be more mobile than chromium in the mineral grains that compose the bulk of the alluvium—especially at alkaline pH’s in the unsaturated zone underlying arid areas such as the Sheep Creek fan.

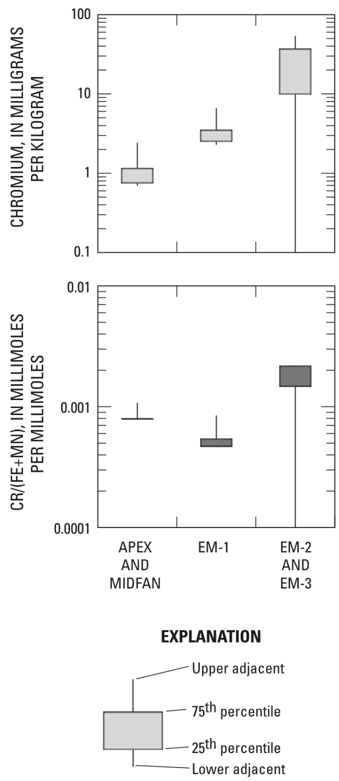

Figure 2.—Acid-extraction data for selected sites from the Sheep Creek fan, Calif.

Comparison of acid-extract data from the EM-2 and EM-3 sites with data from sites elsewhere on the Sheep Creek fan (Izbicki and others, 2008a) showed that chromium is almost an order of magnitude more abundant at the EM-2 and EM-3 sites than at the background EM-1 site also on the distal part of the Sheep Creek fan, or at other sites farther upslope on the fan (fig. 2). High-chromium concentrations in alluvium of the Sheep Creek fan are the result of the erosion of naturally occurring chromium in mafic rock in the San Gabriel Mountains (Izbicki and others, 2008a). Concentrations are higher on the distal part of the fan where EM-1, EM-2, and EM-3 are located because of the finer-grained deposits in this area, and the subsequent increase in surface area and surface absorption sites compared to the apex and mid-fan areas (Izbicki, and others, 2008a). However, even after normalizing the data for iron and manganese concentrations in the extracts (fig. 2), and thereby accounting for the increase surface absorption sites, concentrations at the EM-2 and EM-3 sites are as much as four times greater than concentrations in core and cutting material from EM-1 and other areas on the fan. These results suggest that the alluvium beneath the dairy is naturally higher in chromium than other locations sampled.

Chromium concentrations in pore-water samples from suction-cup lysimeters in the unsaturated zone at the EM-2 and EM-3 sites ranged from less than 1 to 270 μg/L. Chromium concentrations, in excess of 100 μg/L, were measured in samples from the lysimeters at 2.1 and 8.3 m below land surface at EM-2 and EM-3, respectively. Water from these suction-cup lysimeters had specific conductance values as high as 39,200 μS/cm and chloride concentrations as high as 18,000 mg/L. Chromium concentrations, between 27 and 58 μg/L, were measured in samples from the suction-cup lysimeter near the water table at EM-2, 15.8 m below land surface. The remaining suction-cup lysimeters yielded water having chromium concentrations occasionally as high as 7.4 μg/L, but generally less than 1 μg/L.

Chromium was present at concentrations less than 1 μg/L in pore-water pressure extractions from core material collected during drilling at EM-2 and EM-3. These data are consistent with data collected from most suction-cup lysimeters sampled at EM-2 and EM-3. It was not possible to pressure extract pore water from the saline intervals having high chromium concentrations because cores were not collected at these depths during drilling.

The presence of high concentrations of acid-extractable chromium in cores and cuttings collected beneath the dairy sites combined with the presence of chromium concentrations in excess of 100 μg/L in some suction-cup lysimeters beneath the dairy sites suggests that the migration of irrigation return water through the unsaturated zone could mobilize chromium from the unsaturated zone to the underlying water table.

Increases in Chromium Concentrations after Infiltration of Irrigation Return Water

Chromium concentrations in the water table well at the historically irrigated EM-2 monitoring site ranged from 54 to 77 μg/L during the study; Cr (VI) concentrations ranged from 47 to 48 mg/L. Although these concentrations were lower than concentrations in samples from some of the other water table wells beneath the dairy, they are higher than chromium concentrations in native water from wells in the perched aquifer near El Mirage, and higher than the California Environmental Protection Agency MCL for chromium.

Chromium concentrations in the water-table well at the EM-3 monitoring site were initially less than the reporting level of 0.3 μg/L; however, concentrations increased after the onset of irrigation with dairy wastewater in spring 2008. By November 2008, chromium concentrations reached a maximum of 21 μg/L and Cr (VI) concentrations rose to a maximum of 8.7 μg/L (fig. 3). The increase in chromium and Cr (VI) concentrations was accompanied by a water-level rise of 0.4 m (fig. 3). Although, the increase in chromium and Cr (VI) was small relative to concentrations in water-table wells elsewhere at the dairy, and small relative to the chromium concentrations in the unsaturated zone, the data demonstrate that irrigation return water can mobilize chromium from the unsaturated zone. The chromium concentrations measured at the water table at EM-3 are believed to be lower than concentrations measured at the EM-2 site because the irrigation return flows have not yet migrated through the unsaturated zone at the EM-2 site.

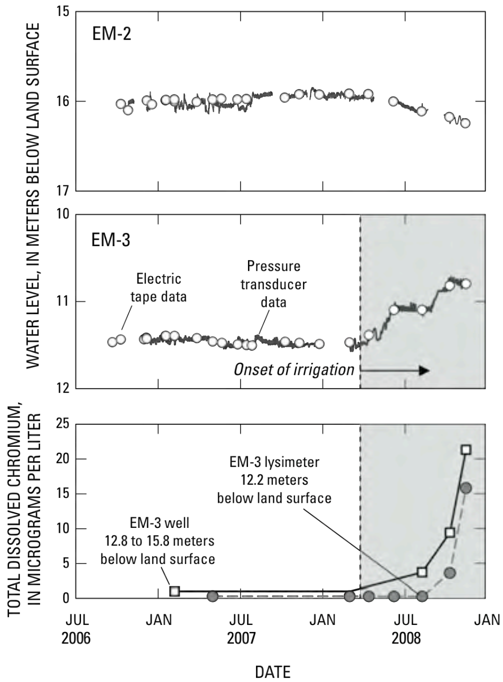

Figure 3.—Water-level hydrographs and chromium data for water-table wells at EM-2 and EM-3 monitoring sites, near El Mirage, Calif.

The movement of the irrigation-return flows through the unsaturated zone at EM-2 and EM-3 was estimated by inspecting the water-content data measured from core material collected at the sites. Water-content data from core material collected during the drilling of EM-2 show that the unsaturated zone at the EM-2 site was wet compared to native unsaturated deposits underlying the Mojave Desert, with volumetric water contents as high as 0.36 cm^3/cm^3. The range in total potential data (calculated as the sum of the measured matric potential data from data loggers and the height above the water table, also known as gravity potential) show gravity drainage through the unsaturated zone at the EM-2 site to a depth of about 11 m (fig. 4). Saturated conditions were present intermittently above this depth at 1.8 and 7.9 m below land surface. Gravity drainage was not measured through a low-permeability clay encountered near 11 m below land surface, and irrigation return water presumably moved around this clay to the water table near 16.9 m. Seasonal variations in matric potential (and temperature) measured in the unsaturated zone at this site are related to irrigation and precipitation patterns.

Water-content data from core material collected during the drilling of EM-3 show that the upper part of the unsaturated zone at the EM-3 site was initially dry, with volumetric water contents as low as 0.03 cm^3/cm^3. These low values are typical of native unsaturated deposits underlying the Sheep Creek fan and elsewhere in the Mojave Desert (Izbicki and others, 2000), and indicate that irrigation return had not migrated through these deposits. The water-content measured in core material collected at EM-3 below 9 m was wetter than measured in core material collected above 9 m, with volumetric water contents similar to those measured at EM-2. It is unclear if wetter deposits below 9 m are the result of residual water remaining in the unsaturated zone after water-level declines due to pumping, or from the lateral migration of irrigation return from nearby fields. The range in total potential data do not show gravity drainage through the unsaturated zone at EM-3, even in the deeper, wetter part of the unsaturated zone (fig. 4). Matric and total potential data became progressively less negative and total potential increased after irrigation in spring 2008. However, the site was still too dry for gravity drainage even after the onset of irrigation. These data suggest that irrigation return at the EM-3 site has not yet migrated downward through the unsaturated zone, and that the source of the chromium measured in samples from the water table at EM-3 is lateral migration from other parts of the field. Chromium concentrations at the water table at the EM-3 site may increase further as irrigation continues and the unsaturated zone at this site becomes progressively wetter with time.

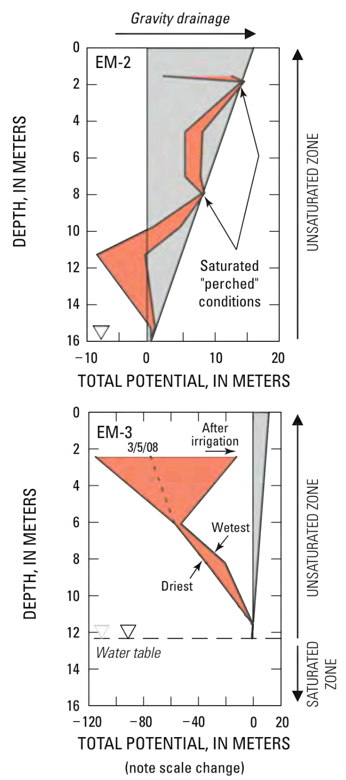

Figure 4.—Total potential data for EM-2 and EM-3 unsaturated zone monitoring sites, near El Mirage, Calif., October, 2006 to November, 2006

Isotopic Composition of Chromium

There are four naturally occurring isotopes of chromium having masses of 50, 52, 53, and 54 (White and Cameron, 1948). In some settings, variations in the ratios of the two most abundant isotopes, ^{52}Cr and ^{53}Cr, can be used to identify chromium from anthropogenic sources or to identify chemical processes involving chromium. This approach was used in previous studies (Izbicki and others, 2008a) to evaluate the extent of chromium contamination, and Cr (VI) reduction to Cr (III) in the contaminant plume at the chemical milling facility near the dairy site. In that study, anthropogenic chromium released at the facility had a $\delta^{53}Cr$ composition near 0 per mil; whereas, natural chromium in the perched aquifer near El Mirage had a $\delta^{53}Cr$ composition near 3 per mil. The isotopic composition of chromium within the plume became increasingly heavier (positive $\delta^{53}Cr$ values) as a result of isotopic fractionation of chromium as Cr (VI) within the plume was reduced to Cr (III) and removed from solution. Fractionation of the chromium in the contaminant plume changed the $\delta^{53}Cr$ from near 0 per mil at the source of the plume to about 3 per mil in samples collected about 300 m downgradient of the suspected release point (Izbicki and others 2008a).

The chromium concentrations in water samples collected as part of this study from five of the six water-table observation wells beneath (or adjacent to) irrigated fields at the dairy ranged from 38 to 140 μg/L, with 61 to 100 percent of the chromium as Cr (VI). The sixth well (MW-2) was not located beneath an irrigated field and had a lower chromium concentration of 17 μg/L and a Cr (VI) concentration of 14 μg/L. The $\delta^{53}Cr$ isotopic composition of samples from the five water-table observation wells beneath irrigated fields at the dairy ranged from 0.53 to 1.0 per mil, and were within the range of $\delta^{53}Cr$ values of anthropogenic chromium (Izbicki and others, 2008a) (fig. 5). The $\delta^{53}Cr$ composition of water from the sixth well, having the lower chromium concentration was 3.4 per mil, and within the range of $\delta^{53}Cr$ values for native water in the perched aquifer near El Mirage (fig. 5).

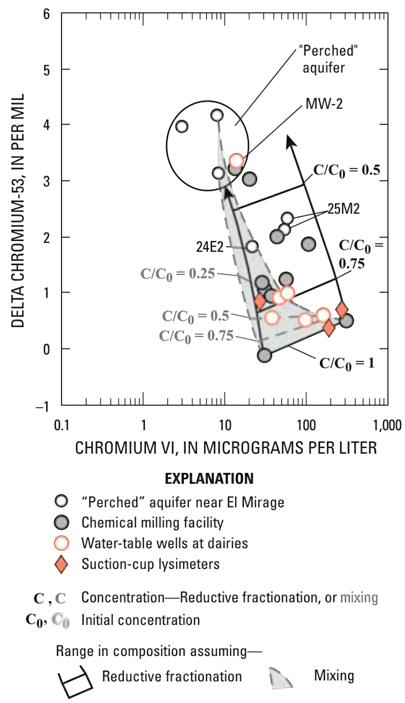

Figure 5.—delta Chromium-53 ($\delta^{53}Cr$) composition of water from selected wells and suction-cup lysimeters, near El Mirage, Calif., October, 2006 to November, 2008 (Modified from Izbicki and others, 2008a)

If the $\delta^{53}Cr$ data from the wells were the only data available, one might conclude that the chromium in five of the water-table wells at the dairy originated from the chemical milling facility because of the near 0 per mil $\delta^{53}Cr$ values. Water from the sixth well also could have originated from the facility if sufficient Cr (VI) had been reduced to Cr (III) as water moved through the aquifer. However, the $\delta^{53}Cr$ values in samples from suction-cup lysimeters in the unsaturated zone at the EM-2 and EM-3 sites also were near 0 per mil, ranging from 0.38 to 0.85 per mil (fig. 5). Surface discharge of chemical milling waste has not occurred at these sites; therefore, the near 0 per mil $\delta^{53}Cr$ values analyzed in samples from the unsaturated zone cannot be the result of contamination from the chemical milling waste. Recent work at a chromium contamination site near Topoc, Calif. along the Colorado River has shown that chromium in native water having high salinity has $\delta^{53}Cr$ compositions near 0 per mil (CH2M-Hill, 2008). Naturally occurring water with near 0 per mil $\delta^{53}Cr$ values could occur if the bacterially mediated reduction of Cr (VI) to Cr (III) that results in the isotopic fractionation of Cr (VI) remaining in solution did not occur, or was interfered with, in saline ground water.

As previously discussed, the $\delta^{53}Cr$ data analyzed in samples from wells at the chemical milling facility shows that the $\delta^{53}Cr$ values increase downgradient from the suspected discharge point at the chemical milling facility as a result of isotopic fractionation as Cr (VI) is reduced to Cr (III) (fig. 3) (Izbicki and others, 2008a). The shift in isotopic composition is relatively rapid, and within 300 m of the facility sufficient Cr (VI) has been reduced to Cr (III) to render the chromium concentrations and δ^{53}Cr values nearly indistinguishable from that of native ground water. EM-2 and EM-3 are almost 2 km northwest of the chemical milling facility (fig. 1). Water-level data show ground water is moving to the northeast from the chemical milling facility (Balderman Consulting, Inc., 2001 and 2004; Stamos and others, 2003; Smith, 2003). Even if the hydrology of the area were so poorly characterized that the movement of ground water was in a northwest direction toward EM-2 and EM-3, it is unlikely, given the reactivity of Cr (VI) in the perched aquifer, that water could flow almost 2 kilometers without measurable fractionation of the δ^{53}Cr isotopic composition. Therefore, the source of δ^{53}Cr compositions near 0 per mil in samples from the water-table wells at EM-2 and EM-3 is likely the downward migration of naturally occurring chromium with near 0 per mil δ^{53}Cr values present in the unsaturated zone beneath the irrigated fields.

Evaporative History of Ground Water in the Study Area

Oxygen-18 and deuterium (δ^{18}O and δD, respectively) are naturally occurring stable isotopes of oxygen and hydrogen, respectively. Most of the world's precipitation originates from the evaporation of seawater. As a result, the δ^{18}O and δD composition of precipitation and most ground water is linearly correlated and distributed along a line known as the global meteoric water line (Craig, 1961). The δ^{18}O and δD composition of a water sample relative to the meteoric water line and relative to the composition of water from other areas provides a record of the source and evaporative history of the water. Partial evaporation and subsequent fractionation of water shifts the δ^{18}O and δD composition of the water to the right of the meteoric water line along a line known as the evaporative trend line.

The stable isotopes of oxygen and hydrogen were used to evaluate the source and evaporative history of water from the saturated and unsaturated zone beneath the dairy. These data were compared with δ^{18}O and δD data from the chemical milling facility and from other wells sampled on the Sheep Creek fan by Izbicki and others (2008a). The data show much of the water from the contaminant plume at the chemical milling facility to be highly evaporated, possibly as a result of partial evaporation in disposal ponds at the site (fig. 6). The most heavily evaporated water was from well 6N/7W-14K1 to the north of the facility—consistent with the direction of ground water movement from previous studies (Balderman Consulting Inc., 2001 and 2004; Stamos and others, 2001; Smith, 2003). Although water from the water-table wells and from suction-cup lysimeters in the unsaturated zone beneath the dairy were fractionated as a result of irrigation, the highly evaporated water characteristic of the contaminant plume at the chemical milling facility was not present at the dairy site (fig. 6). These data suggest water from water table wells at the dairy originated as irrigation return.

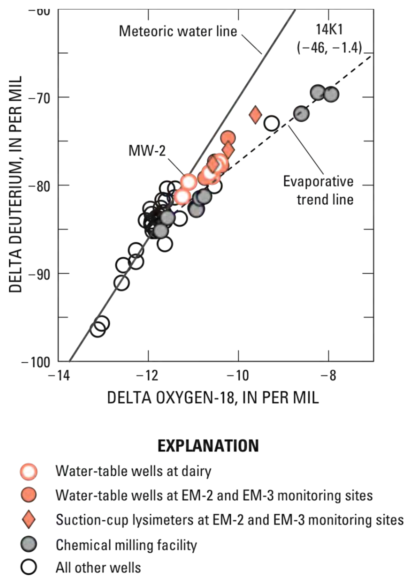

Figure 6.—delta Deuterium and delta Oxygen-18 composition of water from selected wells and suction-cup lysimeters near El Mirage, Calif., October, 2006 to November, 2008 (Modified from Izbicki and others, 2008a)

Processes Controlling Mobilization of Chromium in the Unsaturated Zone

At first it would seem unlikely that chromium would be mobile in the unsaturated zone beneath fields irrigated with dairy wastewater, because organic material in the dairy wastewater would be expected to reduce mobile Cr (VI) to the relatively immobile form Cr (III). However, nitrate is more readily reduced than chromium (Ahmann and others, 1997; Thauer and others. 1977). As a consequence, high-nitrate concentrations in dairy wastewater may interfere with the bacterially mediated reduction of Cr (VI) to Cr (III), thereby allowing chromium in the form of Cr (VI) to move through the unsaturated zone to the water table.

Nitrate concentrations in pressure extractable porewater in the unsaturated zone ranged from 0.73 to 210, and < 0.6 to 44 mg/L as nitrogen at EM-2 and EM-3 respectively (fig. 7). Water extractable nitrate concentrations ranged from 0.12 to 61 and 0.06 to 22 mg/kg of alluvium as nitrogen (fig. 7). The presence of nitrite in the unsaturated zone just above the water table at EM-2, and beneath the water table at EM-2 and EM-3 suggests that some bacterially mediated nitrate reduction to nitrite occurs. De-nitrifying bacteria just above and below the water table at EM-2 and EM-3 suggests that the further reduction nitrite to nitric oxide, then nitrous oxide, and finally to nitrogen gas also occurs.

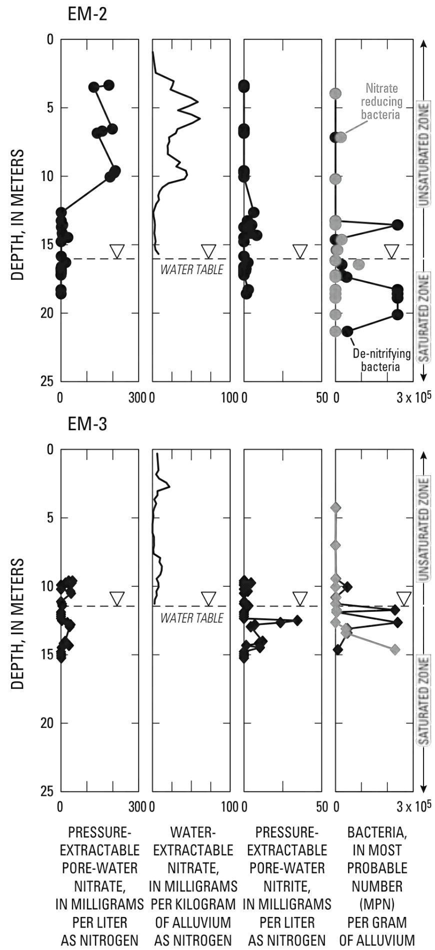

Figure 7.—Pressure extractable nitrate and nitrite, water extractable nitrate, and nitrate reducing and de-nitrifying bacteria concentrations from the unsaturated and saturated zones at EM-2 and EM-3 monitoring sites near El Mirage, Calif., September, 2006

Interference in bacterially mediated chromium reduction by nitrate was demonstrated in a series of laboratory microcosm experiments done as part of this study by the U.S. Geological Survey Menlo Park, Calif. To establish that reduction of Cr (VI) to Cr (III) would occur in these experiments, low-nitrate lake sediments were slurried with distilled water and glucose (as an energy source) and amended with Cr (VI) then incubated for 40 days. During this incubation period almost all the Cr (VI) was reduced to Cr (III) and much of the Cr (III) was removed from solution (fig. 8A). In contrast, when core material from the EM-2 site, having high-nitrate porewater, was slurried and incubated, reduction of Cr (VI) to Cr (III) was incomplete after 40 days (fig. 8B). Even less reduction of Cr (VI) to Cr (III) occurred during the incubation period when additional nitrate was added to the slurry (fig. 8B). When the sediment slurries from the EM-2 site were heat sterilized, reduction of Cr (VI) to Cr (III) did not occur (fig. 8C)—consistent with a microbiologically mediated process.

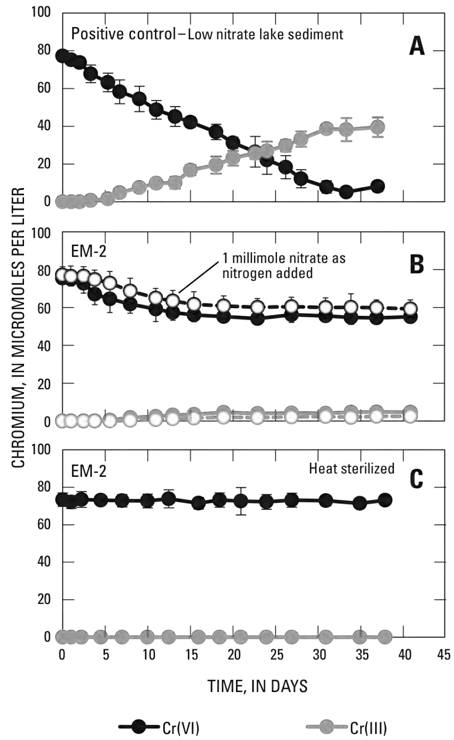

Figure 8.—Cr (VI) reduction to Cr (III) in laboratory microcosm experiments

High concentrations of nitrate and the low abundance of nitrate reducing and denitrifying bacteria in the upper part of the unsaturated zone (fig. 7) suggests limited biologically mediated reduction of nitrate in the unsaturated zone. Given the lack of nitrate reduction, Cr (VI) mobilized from aquifer deposits would likely be mobile and move with infiltrating water with little reduction to Cr (III) at these depths. Redox changes at the water table that facilitates reduction of nitrate, and then chromium, may limit the subsequent transport of Cr (VI) laterally or with depth below the water table.

Conclusions

The data collected for this study suggest that the high-chromium concentrations in water table wells at the dairy were from naturally occurring chromium mobilized from the unsaturated zone as a result of irrigation with dairy wastewater (Izbicki and others 2008b). This conclusion is consistent with previous work that showed that (1) the dairy was cross-gradient from the chemical milling facility and that the plume at the facility was not moving toward the dairy (Balderman Consulting Inc., 2001 and 2004; Stamos and others, 2001; Smith, 2003), and (2) anthropogenic contaminants associated with the chemical milling facility were not detected at the dairy (Advanced Technology Laboratories, Signal Hill, Calif., written commun., Sept. 2004).

Processes that facilitate the mobility of chromium from the unsaturated zone beneath the dairy near El Mirage may be somewhat unique and may result from the high concentrations of chromium on exchange sites on the surfaces of mineral grains (fig. 2). However, Cr (VI) concentrations in excess of the California MCL have been measured in water from well 6N/7W-25M2 (fig. 1) on the Sheep Creek fan (Ball and Izbicki, 2004; Izbicki and others 2008a). This well, located in a similar geologic setting, also is near a dairy and has high-nitrate concentrations that may facilitate the transport of chromium through the unsaturated zone. Cr (VI) concentrations as high as 200 μg/L also have been reported at the water table in alluvium eroded from mafic rock near Davis, Calif. (Chung and others, 2001; Bob Devany, Weiss Associates, written commun., July, 2007). The origin of the chromium at the Davis site is unclear. However large amounts of animal manure were disposed of at this location and Chung and others (2001) suggested a natural geologic origin for chromium at this site. Collectively these data suggest that processes that have mobilized chromium from the unsaturated zone near El Mirage also may occur in other areas.

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