



Prepared in cooperation with the Albuquerque Bernalillo County Water Utility Authority

Potential Chemical Effects of Changes in the Source of Water Supply for the Albuquerque Bernalillo County Water Utility Authority

Scientific Investigations Report 2006–5171

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

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By Laura M. Bexfield and Scott K. Anderholm

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Conversion Factors, Abbreviations, and Datum

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft ²)	929.0	square centimeter (cm ²)
square inch (in ²)	6.452	square centimeter (cm ²)
gallon (gal)	0.003785	cubic meter (m ³)
million gallons (Mgal)	3,785	cubic meter (m ³)
cubic inch (in ³)	16.39	cubic centimeter (cm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
acre-foot (acre-ft)	1,233	cubic meter (m ³)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m ³ /s)
pound, (lb)	0.4536	kilogram (kg)
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound per cubic foot (lb/ft ³)	0.01602	gram per cubic centimeter (g/cm ³)

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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

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

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

Potential Chemical Effects of Changes in the Source of Water Supply for the Albuquerque Bernalillo County Water Utility Authority

By Laura M. Bexfield and Scott K. Anderholm

Abstract

Chemical modeling was used by the U.S. Geological Survey, in cooperation with the Albuquerque Bernalillo County Water Utility Authority (henceforth, Authority), to gain insight into the potential chemical effects that could occur in the Authority's water distribution system as a result of changing the source of water used for municipal and industrial supply from ground water to surface water, or to some mixture of the two sources. From historical data, representative samples of ground-water and surface-water chemistry were selected for modeling under a range of environmental conditions anticipated to be present in the distribution system. Mineral phases calculated to have the potential to precipitate from ground water were compared with the compositions of precipitate samples collected from the current water distribution system and with mineral phases calculated to have the potential to precipitate from surface water and ground-water/surface-water mixtures.

Several minerals that were calculated to have the potential to precipitate from ground water in the current distribution system were identified in precipitate samples from pipes, reservoirs, and water heaters. These minerals were the calcium carbonates aragonite and calcite, and the iron oxides/hydroxides goethite, hematite, and lepidocrocite. Several other minerals that were indicated by modeling to have the potential to precipitate were not found in precipitate samples. For most of these minerals, either the kinetics of formation were known to be unfavorable under conditions present in the distribution system or the minerals typically are not formed through direct precipitation from aqueous solutions.

The minerals with potential to precipitate as simulated for surface-water samples and ground-water/surface-water mixtures were quite similar to the minerals with potential to precipitate from ground-water samples. Based on the modeling results along with kinetic considerations, minerals that appear most likely to either dissolve or newly precipitate when surface water or ground-water/surface-water mixtures are delivered through the Authority's current distribution system are carbonates (particularly aragonite and calcite). Other types of minerals having the potential to dissolve or newly precipitate under conditions present throughout most of

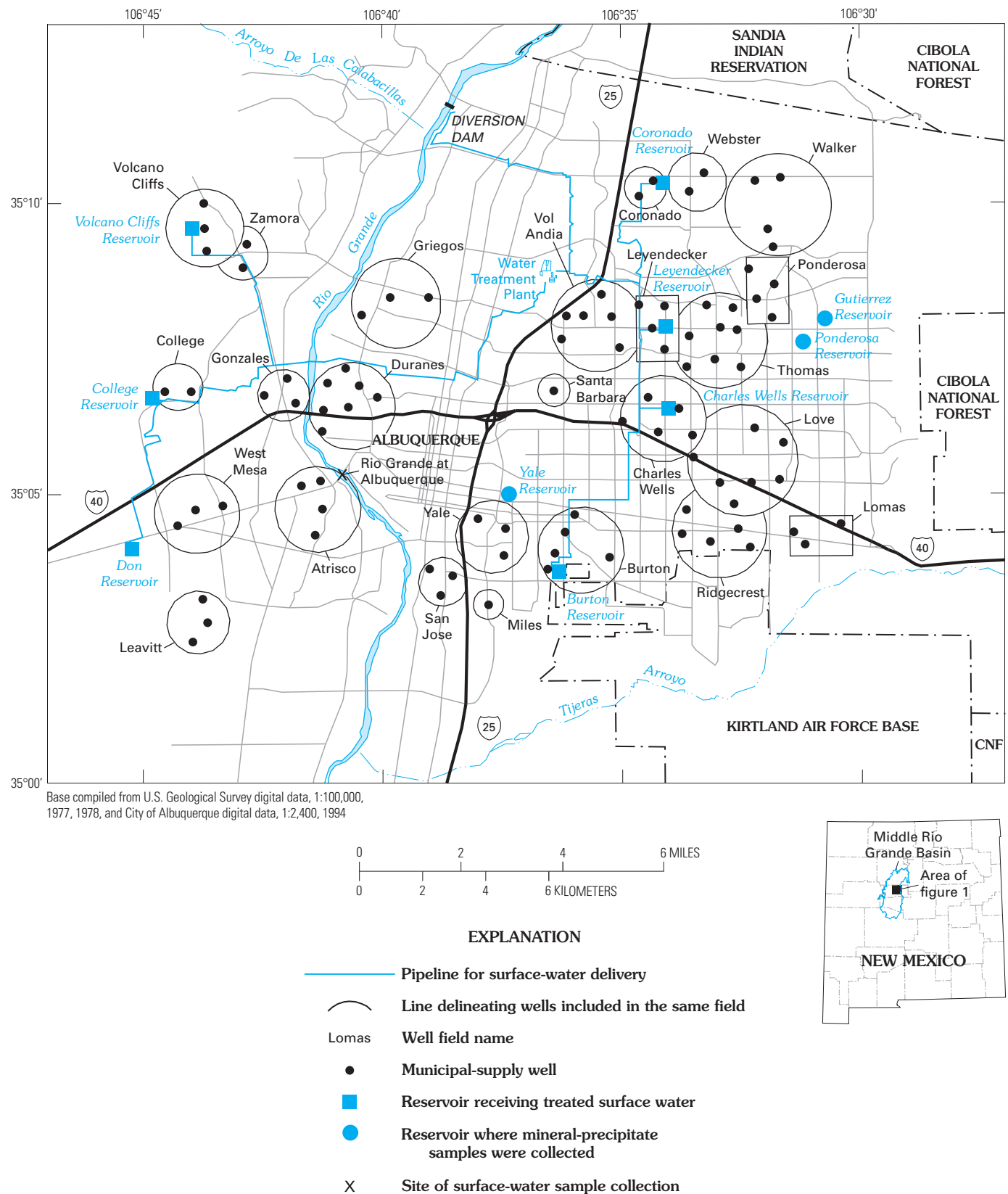
the distribution system include a form of silica, an aluminum hydroxide (gibbsite or diaspore), or the Fe-containing mineral $\text{Fe}_3(\text{OH})_8$. Dissolution of most of these minerals (except perhaps the Fe-containing minerals) is not likely to substantially affect trace-element concentrations or aesthetic characteristics of delivered water, except perhaps hardness. Precipitation of these minerals would probably be of concern only if the quantities of material involved were large enough to clog pipes or fixtures. The mineral $\text{Fe}_3(\text{OH})_8$ was not found in the current distribution system. Some Fe-containing minerals that were identified in the distribution system were associated with relatively high contents of selected elements, including As, Cr, Cu, Mn, Pb, and Zn. However, these Fe-containing minerals were not identified as minerals likely to dissolve when the source of water was changed from ground water to surface water or a ground-water/surface-water mixture.

Based on the modeled potential for calcite precipitation and additional calculations of corrosion indices ground water, surface water, and ground-water/surface-water mixtures are not likely to differ greatly in corrosion potential. In particular, surface water and ground-water/surface-water mixtures do not appear likely to dissolve large quantities of existing calcite and expose metal surfaces in the distribution system to substantially increased corrosion. Instead, modeling calculations indicate that somewhat larger masses of material would tend to precipitate from surface water or ground-water/surface-water mixtures compared to ground water alone.

Introduction

The Albuquerque Bernalillo County Water Utility Authority (henceforth, Authority), which supplies water to residents and businesses in the Albuquerque metropolitan area of central New Mexico (fig. 1), currently (2005) is in the process of implementing a major change in its approach to municipal and industrial water supply. Historically, ground water has been the sole source of water delivered to the Authority's customers. However, large declines in ground-water levels across the metropolitan area have raised concerns about sustainability of the continued use of ground water to meet all water demand by customers of the

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Authority (Anderson and Woosley, 2005). Potential regional-scale problems of concern include increased cost and decreased quality of ground water delivered to area residents, reduced surface-water availability as a result of induced infiltration of water from the Rio Grande into the aquifer system, and land-surface subsidence. The Authority (previously the City of Albuquerque) has, therefore, adopted a water-supply strategy that (in addition to conservation and water-recycling projects) calls for transition in 2008 from complete reliance on ground water to primary reliance on surface water, supplemented by ground water (Albuquerque Bernalillo County Water Utility Authority, 2006). Similar shifts in water source have been implemented previously by other communities of the southwestern United States, including Tucson, Arizona (Price and Jefferson, 1996; Swanson and others, 1998). The Authority owns rights to native Rio Grande water, in addition to water that is diverted across the Continental Divide from streams in the Colorado River Basin to the Rio Grande Basin by the San Juan-Chama Transmountain Diversion Project. Under the Authority's new water-supply strategy, San Juan-Chama water diverted from the Rio Grande will supply most municipal and industrial water demand, except during times of high demand or drought, when ground-water withdrawals will supplement surface-water supplies.

Subsequent to the transition in the primary source of water supply in 2008, the Authority plans to continue delivering water mostly through the existing infrastructure. The existing infrastructure has previously carried only ground water, in some cases for as long as about 50 years. Under the new water-supply strategy, water delivered through any particular section of the infrastructure at any particular time could consist of all surface water, all ground water, or a mixture of ground water and surface water. The chemistry of surface water being delivered will vary through time, as will the ratio of ground water to surface water in water mixtures. Because San Juan-Chama water from the Rio Grande can differ in chemical characteristics from ground water in the Albuquerque area, delivery of surface water or mixtures of ground water and surface water through the existing infrastructure could potentially result in chemical changes within the distribution system that negatively impact the quality of water delivered to customers or the efficiency of water transport. Negative impacts could include dissolution of precipitates that have previously been deposited by ground water, resulting in changes to the quality or aesthetic characteristics of water delivered to customers. Alternatively, new solid phases could precipitate in the distribution system, possibly reducing efficiency of water transport. The U.S. Geological Survey (USGS), in cooperation with the Albuquerque Bernalillo County Water Utility Authority, investigated the potential chemical effects in the distribution system of variability in the source of water used for municipal and industrial supply. This investigation could provide important knowledge in preventing or alleviating problems that could be faced by the Authority, as well as other water providers and communities along the Rio Grande that are considering similar changes in water supply.

Purpose and Scope

The purpose of this report is to illustrate the potential chemical effects of the change in the source of municipal and industrial supply for the Authority from exclusively ground water to primarily surface water, supplemented by ground water. In particular, information is presented on mineral precipitates demonstrated by laboratory analysis to be present in the Authority's distribution system, in addition to precipitates that chemical modeling with the geochemical software package PHREEQC indicates could be present. The potential (as indicated by chemical modeling) for surface water alone, or mixtures of ground water and surface water, to dissolve existing precipitates is discussed. Also, the potential for various mixtures of ground water and surface water to form new precipitates in the distribution system is examined.

Previous Investigations

Chemical data for ground water and surface water in the Albuquerque area are available from a variety of databases and published studies. For chemistry of ground water from the Authority's municipal-supply wells in particular, the Authority maintains an extensive database of field measurements, major-, minor-, and trace-element chemistry, and other selected constituents from samples collected by the Authority's staff on typically a biannual basis from each well. In Bexfield and others (1999), this database is described in detail, and summary statistics for most constituents are presented by well. Chemical data for water from the Authority's municipal-supply wells also have been presented in several investigations of overall ground-water chemistry in the Albuquerque area, including those by Anderholm (1988), Logan (1990), Bexfield and Anderholm (2002), and Plummer and others (2004). A study of arsenic in ground water of the Albuquerque area also included analysis of ground-water chemistry from the Authority's wells, in addition to analysis of solid precipitates from the Authority's reservoirs (Mark Stanton, U.S. Geological Survey, written commun., 2004).

Previous studies by the USGS have included analysis of surface-water chemistry from various sites along the Rio Grande near Albuquerque. Data on field measurements, major-, minor-, and trace-element chemistry, and other constituents are available from the USGS National Water Information Systems (NWIS) database. Detailed chemical data for sites near Albuquerque also have been published in Kelly and Taylor (1996), Wilcox (1997), and Plummer and others (2004).

Potential chemical effects of mixing surface water and ground water during proposed artificial recharge efforts in the Albuquerque area were modeled by Whitworth (1996). In particular, subsurface injection and surface infiltration of Rio Grande water were simulated with geochemical models. Results suggested that either method of artificial recharge was likely to be successful, although surface infiltration showed the higher potential to result in substantial quantities of mineral precipitation.

Studies of methods to minimize corrosion in the Tucson, Arizona water distribution system subsequent to the transition from ground water to surface water as the primary source of municipal supply were conducted by Price and Jefferson (1996) and Swanson and others (1998). Both studies determined that maintenance of pH above certain levels was critical to reducing disturbance of existing precipitates and, consequently, to minimizing associated corrosion.

Current and Future Water-Supply Strategies for the Albuquerque Bernalillo County Water Utility Authority

Currently (2005), the Authority obtains its municipal-supply water from about 95 wells, which are grouped into 25 well fields (fig. 1). In general, ground water from each well within a field is pumped into a common reservoir. Prior to entering the reservoir, the water is treated with sodium hypochlorite for disinfection and, for wells located east of the Rio Grande, the water is fluoridated (City of Albuquerque, 2004). Water is moved by pump stations from reservoirs at lower altitudes to reservoirs at higher altitudes (including higher-altitude reservoirs that are not associated with an individual well field) along main trunk lines that run generally east-west through Albuquerque. Therefore, water in most of the Authority's reservoirs is a mixture of ground water from more than one well field. From the reservoirs, water enters distribution lines through 19 individual entry points, resulting in 19 distribution zones across the city. Within each individual distribution zone, water is of the same quality (City of Albuquerque, 2004).

Starting in 2008, the Authority plans to begin diverting San Juan-Chama water from the Rio Grande for delivery to customers. The water will be diverted from the river using an inflatable diversion dam located near the north end of Albuquerque, and will be delivered to a water treatment plant (fig. 1). Design plans for the water treatment plant (CH2M Hill, 2003a and b) indicate that the stages of water treatment will include: presettling; ferric chloride and sulfuric acid addition for coagulation; settling/clarification; ozone and hydrogen peroxide addition and biological filtration (to provide disinfection, control taste and odor, and biodegrade organic compounds); sodium hypochlorite addition for secondary disinfection, fluorosilicic acid addition for increased fluoride; and lime addition for pH control (CH2M Hill, 2003a and b). Finished water will be pumped from storage at the plant to the existing distribution system through new large-diameter pipelines that deliver water to existing reservoirs (fig. 1).

The Authority anticipates that water levels in the Rio Grande will occasionally be too low (particularly during times of drought) for diversion of surface water to be practical. At these times, ground water will be the primary or sole source of water delivered to customers. In addition, during times of high demand or relatively low surface-water

supply, surface water from the Rio Grande will be mixed with ground water to meet demand. The waters will be mixed in existing reservoirs, and then delivered through the system.

Acknowledgments

The authors thank the several individuals with the Albuquerque Bernalillo County Water Utility Authority who provided great assistance to this investigation. In particular, John Stomp with the Water Resources Division provided important information about the current and future water-supply strategies for the Authority. Barbara Gastian, Water Quality Manager, provided access to data used in this report and supplied information about the current and future water distribution system. Bill Lindberg, formerly with the Water Systems Division (later with the Wastewater Utility Division Water Quality Laboratory), also provided information about operation of the Authority's distribution system, and shared samples of precipitates from the Authority's reservoirs for laboratory analysis. Rick Duran with the Water Systems Division assisted with collection of precipitate samples from pipes. Greg Gates of CH2M Hill and Joe Chwirka, formerly of CH2M Hill, consultant to the Albuquerque Bernalillo County Water Utility Authority, provided information about expected treatment processes to be applied to future surface-water supplies. David Price, Chief Engineer for the Authority, conducted a helpful review of a draft of the report.

Several other individuals within the USGS also made substantial contributions to this investigation. Mark Stanton kindly shared chemical data for solid samples previously collected from Authority reservoirs, and provided solid samples for analysis of mineralogy. Blair Jones generously conducted analysis of mineralogy for all samples. David Parkhurst provided helpful advice about the chemical modeling of surface-water treatment processes. Stephanie Moore (formerly of the USGS) conducted selection of surface-water samples for chemical modeling. In addition, Jeff Langman of the USGS and Brad Goodell, a private citizen, provided assistance in obtaining precipitate samples.

Methods

This investigation of potential chemical effects of shifts between ground-water and surface-water sources of municipal and industrial supply for the Authority included collection of samples of mineral precipitates from the Authority's distribution system, analysis of these samples for chemical and mineralogical composition, selection of existing chemical analyses of ground water and surface water for chemical modeling, and design and implementation of modeling approaches. The methods used to accomplish each of these major tasks of the investigation are described in this section.

Collection and Analysis of Samples of Mineral Precipitates

Precipitates from ground water within the Authority's distribution system were collected and analyzed for mineralogical composition to determine whether they would be likely to dissolve in the presence of surface water or ground-water/surface-water mixtures. Precipitate samples also were analyzed to determine chemical composition and, therefore, the chemical constituents that would be likely to enter distribution water as a result of dissolution.

Samples of precipitates were collected from various parts of the Authority's distribution system to obtain information about the mineralogical and chemical compositions formed under a range of environmental conditions (in particular, temperatures and pressures). Samples from the Authority's distribution lines were obtained from two locations in the southeastern and south-central parts of Albuquerque. The availability of sample-collection sites from distribution lines was limited to areas where pipes were being repaired or replaced by the Authority. Samples were obtained from both iron and steel pipes of about 4 to 6 inches in diameter by dislodging material attached to the interior of the pipe wall. (Files of the Albuquerque Bernalillo County Water Utility Authority indicate that about 4 percent of the length of pipe in the distribution system is composed of steel/galvanized steel, about 46 percent is cast iron/ductile iron, about 29 percent is polyvinyl chloride, and about 22 percent is cement/concrete (Shawn Hardeman, University of New Mexico, written commun., 2006). Numbers do not add up to 100 percent because of rounding.) One sample of mineral precipitate was collected from the interior of a discarded residential water heater that had been used for about 10 years in the east-central part of Albuquerque. Samples from three of the Authority's storage reservoirs (Gutierrez, Ponderosa, and Yale in fig. 1) were obtained for this investigation from Mark Stanton of the USGS and Bill Lindberg of the Authority. The samples had been collected during the 1990s from the walls or floors of reservoirs that had been drained for maintenance.

With the exception of samples from Ponderosa Reservoir, all precipitate samples were divided in two, placed without further processing in plastic bags, and shipped for laboratory analysis of mineral and chemical composition. For the purposes of a previous investigation, one of the four samples from Ponderosa Reservoir had been sieved to collect and analyze only the fraction with a particle size of 2 millimeters or less, and one had been sieved to collect and analyze only the fraction with a particle size greater than 2 millimeters. All four Ponderosa Reservoir samples had previously been analyzed for chemical composition by the USGS in Denver, Colorado using inductively coupled plasma-mass spectrometry (ICPMS) (Mark Stanton, USGS, written commun., 2003). Chemical analysis of three newly collected samples was conducted through the USGS National Water-Quality Laboratory in Denver, Colorado,

also using ICPMS (Arbogast, 1996). Mineralogical analysis of all precipitate samples was conducted by Blair Jones at a USGS laboratory in Reston, Virginia using X-ray diffraction (Jenkins, 2000).

Selection of Water Samples for Chemical Modeling

As described in the "Previous Investigations" section, chemical data are available for numerous ground-water and surface-water samples collected in the Albuquerque area. For the chemical modeling conducted for this investigation, a subset of all available data was selected that would be manageable for analysis while providing adequate representation of the range in chemistry of waters that would be used as sources of municipal and industrial supply for the Authority. Selection of appropriate subsets of ground-water data and surface-water data required slightly different approaches.

Ground Water

Ground-water-chemistry data examined for selection of a representative subset for modeling were limited to data collected for the Authority's municipal-supply wells. Because of the numerous data available for each well, individual representative samples needed to be chosen for further consideration. Because the measured ground-water chemistry from an individual supply well varies through time, selection of individual representative samples required knowledge of the "typical" chemistry for each well. Bexfield and others (1999) presented statistics indicative of the "typical" chemistry of the Authority's municipal-supply wells (formerly of the City of Albuquerque) sampled from 1988 through 1997 as part of a City of Albuquerque program. Few municipal-supply wells have been added to or removed from the distribution system since 1997. The dataset evaluated by Bexfield and others (1999) was, therefore, used as the primary source of ground-water-chemistry data for this investigation.

For each well in the Bexfield and others (1999) dataset, the median values of selected parameters were compared to the measured values of those parameters in each individual sample. Parameters that were included represented oxidation/reduction conditions and major-, minor-, and trace-element chemistry. Some parameters were not included in this evaluation because they duplicated information provided by other parameters (for example, calcium as Ca in comparison to calcium as CaCO_3) or were rarely detected in samples. The ground-water samples chosen to represent individual wells were those that included a full set of the desired parameters for which the sum of the differences of the parameter values from their median values was smallest, unless any individual parameter had an exceptionally large deviation from its median or the overall electrical charge did not balance to within 10 percent.

Once representative ground-water samples were selected for each of the more than 90 municipal-supply wells operated by the Authority (table 1), the samples were evaluated for similarity and differences in general chemical composition. The purpose of this evaluation was to select a subset of samples that would adequately represent the variability in the chemistry of ground water used by the Authority for municipal and industrial supply. Bexfield and Anderholm (2002) used chemical data from the Authority's municipal-supply wells to delineate five "water-quality regions" across the Albuquerque area. Ground-water chemistry was determined to differ substantially among these regions, whereas chemistry within an individual region was relatively homogeneous. Starting with these previously observed patterns in ground-water chemistry, 10 wells were ultimately chosen for chemical modeling as a part of this study (table 1).

Surface Water

Because the USGS NWIS database contains chemical data for multiple sampling sites along the Rio Grande extending back in time for more than 30 years, this database was selected as the primary source of surface-water-chemistry data for this investigation. The two sampling sites in the database that are closest to the Authority's planned diversion point for San Juan-Chama water from the Rio Grande and that have chemical data from multiple years are the Rio Grande at San Felipe (about 20 miles north of the diversion dam) and the Rio Grande at Albuquerque (about 8 miles south of the diversion dam; fig. 1). Data from the site at San Felipe was determined not to be suitable for chemical modeling as source water for the Authority's municipal and industrial supply because inflow from the Jemez River, which has distinctly different surface-water chemistry from the Rio Grande (Plummer and others, 2004), is often sufficient to substantially alter the chemical characteristics of Rio Grande water between San Felipe and Albuquerque. Data from the site at Albuquerque was determined to be representative of the chemistry of river water that will be used by the Authority because data from Plummer and others (2004) indicate that inflows to the Rio Grande between these two points typically do not substantially alter the chemical characteristics of the river water.

Analyses for all of the major elements were available in the NWIS database for about 40 samples collected from the Rio Grande at Albuquerque between 1971 and 1995 (table 2). These samples were collected during all seasons of the year and for discharge ranging from about 20 to 7,170 cubic feet per second. A total of eight samples from various seasons and flow conditions were chosen for chemical modeling (table 2). The samples were selected to be representative of the observed range in chemical composition at the site.

Modeling Methods

Chemical modeling of the effects of changing water source on the Authority's distribution system required decisions about the modeling software to use, the chemical parameters to include, the range of environmental conditions and water treatments to model, the ground-water/surface-water mixing ratios to use, and the model output to retain and interpret. These modeling issues are discussed in this section.

Software

The public-domain software package PHREEQC 2.8 (Parkhurst and Appelo, 1999) was selected to conduct the chemical modeling for this investigation. PHREEQC is designed to perform various low-temperature aqueous geochemical calculations, including speciation and saturation-index (SI) calculations. The minteq.dat database that is distributed with the PHREEQC software was used for all calculations because this database contains thermodynamic data for some elements of interest for this study that are not included in other databases distributed with the software. Like other geochemical equilibrium models, PHREEQC has some limitations worth noting. In particular, the databases must necessarily be compiled from various literature sources, so that there is the possibility that aqueous models defined by the database files are not consistent with the original experimental data. Regardless of this issue, geochemical modeling software is very useful in identifying which minerals have the potential to dissolve in or precipitate from solution given specified conditions. For the purposes of this study, therefore, the PHREEQC software was appropriate. Input to the PHREEQC software for the calculations conducted as part of this study is provided in the Appendix.

Parameters Included in Geochemical Modeling

The geochemical models designed for this study included about 20 of the numerous chemical and physical parameters that were available for the 10 ground-water samples and 8 surface-water samples selected for the modeling effort (tables 1 and 2). These 20 parameters were selected to provide all of the information necessary in calculation of SIs for minerals known to be present in the Authority's water distribution system (as discussed in the section "Mineral Precipitates in the Current Distribution System") and any other minerals thought to have the potential to precipitate from waters of the area, given their general chemistry. Some of the available chemical parameters (particularly certain trace metals) were not included in the geochemical modeling because the database did not include the data necessary for calculation of SIs for minerals that included those particular elements. In addition, such minerals were thought to be unlikely to precipitate from area waters; even if they did precipitate, the resulting quantities would be very small.

Table 1. Representative ground-water samples used in chemical modeling.

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; deg. C, degrees Celsius; mV, millivolts; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter. Values in bold are estimated concentrations substituted for less-than values. Values in italics are estimated concentrations substituted for missing values]

Albuquerque Bernalillo County Water Utility Authority well field and well number (fig. 1)	Specific conduct- ance ($\mu\text{S}/\text{cm}$)	pH, field (standard units)	Water temper- ature (deg. C)	Eh, field (mV)	Calcium (mg/L as Ca)	Magne- sium (mg/L as Mg)	Sodium (mg/L as Na)	Potas- sium (mg/L as K)	Alkalin- ity (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chlor- ide (mg/L as Cl)	Fluor- ide (mg/L as F)	Silica (mg/L as SiO_2)	Nitrate (mg/L as N)	Alumi- num ($\mu\text{g}/\text{L}$ as Al)	Arsenic ($\mu\text{g}/\text{L}$ as As)	Copper ($\mu\text{g}/\text{L}$ as Cu)	Iron (mg/L as Fe)	Manga- nese (mg/L as Mn)	Zinc ($\mu\text{g}/\text{L}$ as Zn)
Charles 2	327	7.64	19.0	176	41.1	3.9	23.3	1.6	135	35.7	11.3	0.58	31.4	0.44	3.0	2.0	0.5	0.007	0.001	6.6
Duranes 6	514	7.48	19.0	131	51.6	12.1	42.5	9.5	205	96.0	14.1	0.46	69.6	0.05	3.0	4.0	0.5	0.021	0.003	1.0
Leavitt 2	508	8.85	23.8	185	4.4	0.5	102.4	1.2	179	65.0	18.2	1.44	29.1	1.28	<i>3.0</i>	33.0	<i>0.5</i>	0.003	0.001	<i>1.0</i>
Love 5	338	7.73	22.7	161	37.9	3.0	26.9	2.8	133	19.4	24.3	0.60	28.1	0.32	3.0	2.0	0.5	0.010	0.001	1.0
Miles 1	440	7.76	25.7	138	33.6	7.4	40.1	7.4	130	43.6	37.8	0.74	67.2	0.22	3.0	21.0	0.5	0.011	0.001	6.7
Ridgecrest 1	406	7.35	22.5	204	49.4	7.6	28.7	2.1	182	55.4	11.5	0.58	28.2	0.87	<i>3.0</i>	2.0	<i>0.5</i>	0.003	0.001	<i>1.0</i>
Thomas 6	522	7.45	23.3	67	61.0	4.7	40.8	3.0	157	31.3	62.4	0.51	35.2	0.18	3.0	6.0	0.5	0.018	0.009	12.0
Vol Andia 3	394	7.91	18.0	180	47.1	5.7	18.3	2.7	123	50.4	19.6	0.48	36.7	0.72	<i>3.0</i>	8.0	<i>0.5</i>	0.003	0.001	<i>1.0</i>
Walker 2	632	7.75	28.7	109	39.5	5.6	77.3	4.8	174	37.2	87.4	1.19	41.5	0.05	<i>3.0</i>	36.0	<i>0.5</i>	0.013	0.018	<i>1.0</i>
Zamora 1	417	7.88	24.3	206	20.2	3.4	58.0	6.4	158	54.6	9.3	0.72	70.1	0.86	<i>3.0</i>	14.0	<i>0.5</i>	0.003	0.001	<i>1.0</i>

Table 2. Representative surface-water samples from the Rio Grande at Albuquerque used in chemical modeling.

[cfs, cubic feet per second; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; deg. C, degrees Celsius; mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; —, no data. Values in bold are estimated concentrations substituted for less-than values. Values in italics are estimated concentrations substituted for missing values]

Date of sample col- lection	Discharge (cfs)	Specific conduct- ance ($\mu\text{S}/\text{cm}$)	pH, field (standard units)	Water temper- ature (deg. C)	Dis- solved oxygen (mg/L)	Calcium (mg/L as Ca)	Magne- sium (mg/L as Mg)	Sodium (mg/L as Na)	Potas-si- um (mg/L as K)	Alkalinity (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chlor- ide (mg/L as Cl)	Fluor- ide (mg/L as F)	Silica (mg/L as SiO_2)	Nitrate (mg/L as N)	Alum- inum ($\mu\text{g}/\text{L}$ as Al)	Arse- nic ($\mu\text{g}/\text{L}$ as As)	Copper ($\mu\text{g}/\text{L}$ as Cu)	Iron (mg/L as Fe)	Manga- nese (mg/L as Mn)	Zinc ($\mu\text{g}/\text{L}$ as Zn)
08/16/1971	214	690	7.70	25.5	—	70.0	9.0	60.0	5.9	163	150.0	37.0	0.70	28.0	—	<i>5.0</i>	<i>3.0</i>	<i>2.0</i>	<i>0.012</i>	<i>0.004</i>	<i>5.0</i>
05/03/1982	3,350	290	8.30	15.0	—	37.0	6.7	16.0	2.9	110	68.0	5.6	0.40	17.0	—	<i>5.0</i>	2.0	<i>2.0</i>	0.009	<i>0.004</i>	5.0
07/15/1986	2,750	260	7.80	10.5	7.6	28.0	4.9	17.0	3.1	99	45.0	4.5	0.20	17.0	—	<i>5.0</i>	<i>3.0</i>	<i>2.0</i>	0.020	<i>0.004</i>	<i>5.0</i>
11/07/1986	2,030	350	8.05	9.0	—	42.0	7.0	27.0	3.4	135	59.0	12.0	0.40	21.0	—	<i>5.0</i>	3.0	2.0	0.014	<i>0.004</i>	3.0
02/03/1987	2,810	325	7.90	5.0	11.5	39.0	6.9	23.0	2.8	134	61.0	14.0	0.40	21.0	—	<i>5.0</i>	<i>3.0</i>	<i>2.0</i>	<i>0.012</i>	<i>0.004</i>	<i>5.0</i>
05/11/1988	1,800	390	8.70	20.5	7.9	41.0	8.5	32.0	2.6	143	76.0	13.0	0.50	18.0	—	<i>5.0</i>	<i>3.0</i>	<i>2.0</i>	0.010	<i>0.004</i>	<i>5.0</i>
11/07/1988	414	470	8.46	16.0	8.3	53.0	9.7	33.0	3.8	183	73.0	13.0	0.40	22.0	—	<i>5.0</i>	4.0	4.0	0.010	<i>0.004</i>	5.0
08/22/1995	881	372	7.81	24.0	7.0	37.0	8.3	24.0	3.2	141	57.0	7.6	0.40	19.0	—	20.0	3.0	2.0	<i>0.012</i>	0.006	1.0

Not every sample selected for geochemical modeling included a quantified value for each of the parameters listed in tables 1 and 2. For several ground-water samples and one surface-water sample, at least one of the metals was not detected by the laboratory and was reported as being less than a specified value. When this occurred, the non-detection was substituted with a quantified value selected from historical data obtained from a laboratory with lower detection limits, such as from Plummer and others (2004), for the same or nearby sampling sites. Most ground- and surface-water samples also were missing data entirely for at least one trace element. Substitution values again were assigned based on historical data for the same or similar sites; substitution values were generally the historical median. These substitution values should be sufficiently accurate for the primary purpose of the geochemical modeling in this study, which is to establish the general tendency for selected minerals to dissolve in or precipitate from solution.

Some individual samples also were missing a reliable indicator of the degree to which the water was oxygenated. For the surface-water samples, any samples without a dissolved-oxygen concentration were assumed to be near or at saturation, which appears to be reasonable based on historical dissolved-oxygen concentrations for the Rio Grande at Albuquerque. For the ground-water samples, the available Eh values were all positive, which is a qualitative indication that the samples were all at least slightly aerobic. However, the samples for Duranes 6 and Walker 2 had nitrate concentrations less than the detection level of 0.05 milligrams per liter (mg/L) as nitrate, and previous geochemical studies in the area (Plummer and others, 2004) have indicated that such small nitrate concentrations typically are associated with small dissolved-oxygen concentrations (less than 0.5 mg/L). Therefore, historical dissolved-oxygen data from Plummer and others (2004) for either the same wells or nearby wells were used to assign the general degree of oxygenation that would be assumed for the starting ground-water compositions during geochemical modeling.

Range of Physical and Chemical Conditions Modeled

Water delivered to the Authority's customers will be subjected to a variety of physical and chemical conditions during transport through the new distribution system. Surface water in particular will undergo treatment that will include the addition of compounds to induce settling, alter pH, and otherwise adjust water chemistry as described in the section "Current and Future Water-Supply Strategies for the Albuquerque Bernalillo County Water Utility Authority." Even subsequent to treatment, surface and ground water will be exposed to variations in water temperature, atmospheric-gas pressure, and oxidation/reduction conditions. PHREEQC simulations were designed to account for the various conditions that could affect water chemistry (fig. 2).

PHREEQC was used to model the surface-water treatment processes described by CH2M Hill (2003a and b) and their effects on the eight surface-water samples of table 2 as closely as possible (fig. 2). The processes were modeled to use average anticipated chemical doses applied in the order that follows, which reflects the order outlined in CH2M Hill (2003a and b). The addition of a fixed quantity of 30 mg/L of ferric chloride to the original surface-water composition was simulated, along with addition of sufficient sulfuric acid to reduce the pH of the water to 6 (for enhanced coagulation). Because no organic matter had been included in the surface-water compositions used in initial modeling, the water composition was modified to include a quantity of organic matter (0.6 mg/L) equivalent to quantities typically detected in samples from the Rio Grande. Next, the simulation included the addition of 1.5 mg/L of ozone (an oxidizer of organic compounds), 0.2 mg/L of hydrogen peroxide, and sufficient oxygen to increase the dissolved-oxygen concentration of the water to near the 24 mg/L expected in the treatment plant design plans as a result of the ozonation process. Reduction of the dissolved-oxygen concentration back to about 10 mg/L also was simulated, along with removal of about 75 percent of the carbon dioxide content of the water through stripping, to match specifications in CH2M Hill (2003a). Finally, addition of 4 mg/L of sodium hypochlorite, 1 mg/L of fluorosilicic acid, and sufficient hydrated lime to bring the pH of the water to 8.0 were simulated. The resulting solution compositions were saved for analysis, as were additional compositions having simulated water temperatures of 2 and 50 degrees Celsius (°C) to simulate transport through parts of the water distribution system that could be exposed to cold outdoor temperatures or to heating such as occurs in a residential water heater (fig. 2).

For ground water, the chlorination and fluoridation processes applied prior to distribution were not simulated in PHREEQC because the effects of these treatments alone were judged to have negligible effect on ground-water chemistry in terms of parameters that were important to the geochemical modeling of this study. However, in addition to the native ground-water compositions, PHREEQC was used to model other compositions reflecting the environmental conditions ground water was likely to be exposed to during distribution. In particular, compositions having simulated water temperatures of 2 and 50°C were saved for analysis (fig. 2). Also, compositions equilibrated with a log partial pressure of carbon dioxide (log pCO₂) equal to -3.5 and a log partial pressure of oxygen (log pO₂) equal to -0.67 were simulated to reflect complete equilibration with atmospheric conditions. Also, compositions with a log pCO₂ of -3.0 and a log pO₂ of -5.0 (values generally between the partial pressures found in starting waters and partial pressures in the atmosphere) were simulated to reflect partial equilibration with atmospheric conditions, as might occur in a storage tank and downstream distribution areas.

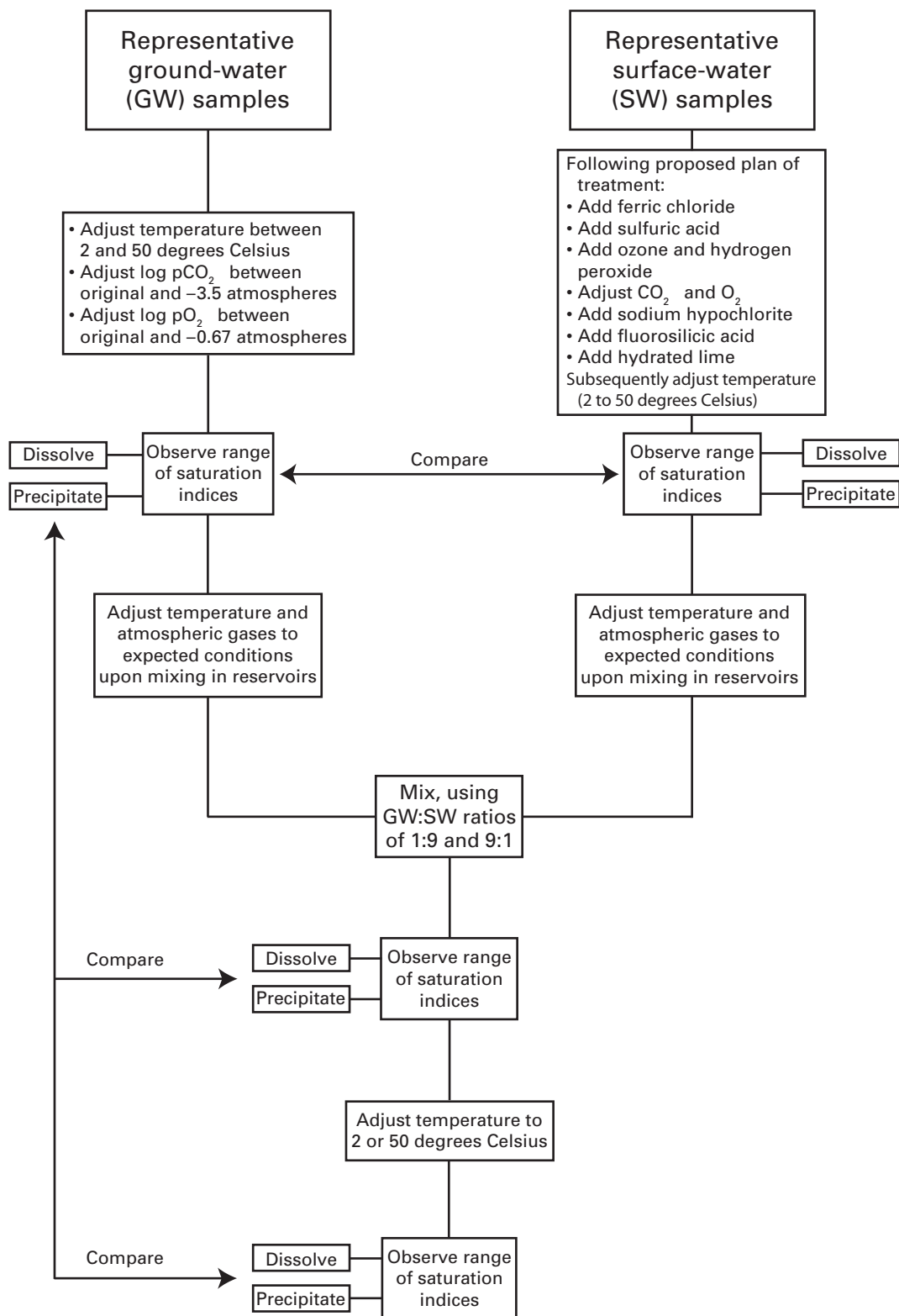


Figure 2. Flow chart of chemical modeling tasks.

Range of Mixing Ratios Modeled

In addition to separate ground-water and surface-water solutions, solutions resulting from the mixture of the two water sources were modeled in PHREEQC. Each treated surface-water composition was mixed individually with each of the ground-water compositions that had been simulated to represent partial equilibration with atmospheric conditions. The solutions were mixed in ratios of 9 to 1 and 1 to 9 (fig. 2) to cover a wide range of potential mixing scenarios and resulting chemical compositions. The compositions of all resulting ground-water/surface-water mixtures were saved for evaluation, including mixtures that were cooled to 2°C and heated to 50°C.

Evaluation of Modeling Results

For each individual ground-water or surface-water composition simulated prior to the modeling of ground-water/surface-water mixtures, the SIs calculated by PHREEQC were saved for all minerals. The SI for a mineral is defined as the log of the result of dividing the ion-activity product for the mineral-water reaction by the thermodynamic equilibrium constant of the mineral. If the resulting SI is positive, the solution is supersaturated with respect to that mineral and the mineral would have the potential to precipitate. If the resulting SI is negative, the solution is undersaturated with respect to that mineral and the mineral would tend to dissolve, assuming that the mineral was present and in contact with the solution. An SI that is about 0 ± 0.1 indicates little or no potential for a mineral to either dissolve or precipitate. Because PHREEQC generated SIs for a very large number of minerals, the SIs for only selected minerals were retained for further analysis. Table 3 lists these minerals, which each had an SI greater than 0.1 for at least one of the simulated ground-water or surface-water compositions.

The SIs for the minerals shown in table 3 were compared among pairs of simulated compositions of ground-water, surface-water, and (or) ground-water/surface-water mixtures that could potentially be present in the same part of the distribution system during different times. For example, SIs were compared between the treated surface-water compositions and the ground-water compositions that had been simulated to represent partial equilibration with atmospheric conditions (as might be present throughout much of the distribution system). This comparison was conducted to determine whether any minerals with SIs greater than 0.1 for the ground-water compositions had SIs less than -0.1 for the surface-water compositions, or vice versa. A mineral with an SI greater than 0.1 for the ground-water composition would have the potential to have precipitated out of solution and to be present in the current distribution system. If the same mineral had an SI less than -0.1 for any of the treated surface-water compositions, that mineral would tend to be dissolved when the source of water flowing through the distribution system changed from ground water to surface water. Depending on

the mineral composition and the quantity dissolved, the surface water subsequently delivered to customers could potentially have degraded quality or aesthetic characteristics. There would be a similar concern for minerals having an SI greater than 0.1 for surface water and an SI less than -0.1 for ground water during times when a long period of surface-water delivery was followed by a period of ground-water delivery. The same would be true for switches between the delivery of either ground water or surface water and any ground-water/surface-water mixture.

Analysis of the SI results from the geochemical modeling conducted during this study focused on the minerals with reaction kinetics favorable to the formation of substantial quantities of precipitate under temperatures and pressures expected to be present in the distribution system. Some of the minerals listed in table 3 commonly have been found to precipitate from natural waters and, therefore, would have a reasonable likelihood of forming within the Authority's distribution system when their SIs exceeded 0.1. These minerals include:

- a form of calcium carbonate (aragonite or calcite); and
- a form of iron oxide or hydroxide (ferrihydrite, goethite, hematite, lepidocrocite, maghemite).

In general, these minerals are made up of elements that are present within the ground-water and (or) surface-water compositions being studied (tables 1 and 2) at a concentration that could allow for substantial quantities of precipitate to form.

Several other types of minerals in table 3 are considered unlikely to precipitate in substantial quantities from water within the Authority's distribution system because of known kinetic limitations, because there is little geologic evidence that the minerals commonly form at low temperature and pressure, and (or) because at least one element making up the minerals has very small dissolved concentrations in the waters being studied. These include igneous and metamorphic minerals of the amphibole group (tremolite), the feldspar group (albite/analcite, microcline, and sanidine), the mica group (muscovite), the pyroxene group (diopside), the serpentine group (chrysotile), and the zeolite group (analcime and laumontite/leonhardite), most of which form at high temperatures and (or) pressures (Kraus and others, 1951; Klein and Hurlbut, 1985; Judson and Kauffman, 1990). Clay minerals (halloysite, kaolinite, montmorillonite, nontronite, pyrophyllite, sepiolite, and talc), which are secondary minerals that typically form through weathering of primary aluminosilicate minerals (Klein and Hurlbut, 1985; Langmuir, 1997), also are considered unlikely to precipitate from water within the Authority's distribution system. Although some clay minerals capable of forming in low-temperature environments could potentially form within the Authority's distribution system where the appropriate primary minerals were present, the rates of reaction would be very slow (Langmuir, 1997).

Table 3. Minerals having at least one calculated saturation index greater than 0.1.

[Minerals in bold were the focus of this study because they were considered most likely to form under conditions present in the Albuquerque Bernalillo County Water Utility Authority distribution system.]

Mineral name	Chemical formula
albite	$\text{NaAlSi}_3\text{O}_8$
analbite	$\text{NaAlSi}_3\text{O}_8$
analcime	$\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$
aragonite	CaCO_3
birnessite	MnO_2
bixbyite	Mn_2O_3
Ca-nontronite	$\text{Fe}_2\text{Al}_{0.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2\text{Ca}_{0.165}$
calcite	CaCO_3
chalcedony	SiO_2
chrysotile	$\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$
cristobalite	SiO_2
cupric ferrite	CuFe_2O_4
cuprous ferrite	CuFeO_2
diaspore	AlOOH
diopside	$\text{CaMgSi}_2\text{O}_6$
dolomite	$\text{CaMg}(\text{CO}_3)_2$
$\text{Fe}(\text{OH})_2 \cdot 7\text{ClO}_3$	$\text{Fe}(\text{OH})_{2.7}\text{Cl}_{0.3}$
$\text{Fe}_3(\text{OH})_8$	$\text{Fe}_3(\text{OH})_8$
ferrhydrite	$\text{Fe}(\text{OH})_3$
goethite	FeOOH
halloysite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
hausmannite	Mn_3O_4
hematite	Fe_2O_3
huntite	$\text{CaMg}_3(\text{CO}_3)_4$
jarosite-K	$\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$
K-nontronite	$\text{Fe}_2\text{Al}_{0.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2\text{K}_{0.33}$
kaolinite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$
laumontite	$\text{CaAl}_2\text{Si}_4\text{O}_{12} \cdot 4\text{H}_2\text{O}$
leonhardite	$\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 7\text{H}_2\text{O}$
lepidocrocite	FeOOH
maghemite	Fe_2O_3
magnesite	MgCO_3
magnetite	Fe_3O_4
manganite	MnOOH
Mg-ferrite	MgFe_2O_4
Mg-nontronite	$\text{Fe}_2\text{Al}_{0.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2\text{Mg}_{0.165}$
microcline	KAlSi_3O_8
montmorillonite	$\text{Mg}_{0.485}\text{Fe}_{0.22}\text{Al}_{1.71}\text{Si}_{3.81}\text{O}_{10}(\text{OH})_2$
muscovite	$\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$
Na-nontronite	$\text{Fe}_2\text{Al}_{0.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2\text{Na}_{0.33}$
nsutite	MnO_2
pyrolusite	MnO_2
pyrophyllite	$\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$
quartz	SiO_2
sanidine	KAlSi_3O_8
sepiolite	$\text{Mg}_2\text{Si}_3\text{O}_7 \cdot 0.5\text{OH} \cdot 3\text{H}_2\text{O}$
talc	$\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$
tremolite	$\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2$
willemite	Zn_2SiO_4
ZnSiO_3	ZnSiO_3

The kinetics of some minerals listed in table 3 are not well known, which complicates efforts to determine whether the minerals would be likely to form in the Authority's distribution system when their SI exceeded 0.1. One example is diasporite, which is typically a product of diagenesis or hydrothermal alteration (Deer and others, 1962). Even if diasporite could form under conditions in the distribution system, concentrations of Al also are probably too small to allow formation of substantial quantities. As indicated in table 3, three silica minerals (chalcedony, cristobalite, and quartz) had a calculated SI greater than 0.1 for at least one of the modeled ground-water or surface-water solutions. Chalcedony is a cryptocrystalline variety of quartz that can precipitate from aqueous solution at low temperatures. Xu and others (1998) indicate that chalcedony is the most likely silica mineral to precipitate when a solution is undersaturated with respect to amorphous silica but oversaturated with respect to quartz. However, chalcedony generally is found as a pseudomorph, lining or filling cavities in rocks (Klein and Hurlbut, 1985), and may or may not form under conditions present within the Authority's distribution system. Cristobalite is not likely to form within the Authority's distribution system because it crystallizes at high temperatures (Klein and Hurlbut, 1985). Whitworth (1996) indicates that pure quartz does not typically precipitate at short time scales (residence times of water in the Authority's distribution system probably are on the order of hours to days), and that α -quartz usually forms as amorphous silica (Whitworth, 1996). However, none of the modeled solutions had an SI greater than 0.1 for amorphous silica, indicating that it may not be likely to form.

Table 3 shows that three magnesium or calcium-magnesium carbonates (dolomites, huntite, and magnesite) have at least one SI greater than 0.1. However, dolomite does not easily precipitate from most natural waters at low temperatures (Deer and others, 1962; Langmuir, 1997). Large deposits of dolomite are thought to be secondary in origin, resulting from replacement of some calcium in limestone with magnesium (Klein and Hurlbut, 1985). Huntite forms in low-temperature environments, but is thought to typically occur as an alteration product of existing carbonates (Deer and others, 1962; Dollase and Reeder, 1986). Magnesite tends to precipitate at elevated temperatures and (or) pressures, and most commonly occurs as an alteration product of magnesium-rich igneous and metamorphic rocks (Deer and others, 1962). Therefore, calcite and aragonite are the carbonate minerals most likely to precipitate from water within the Authority's distribution system.

The reaction kinetics are not well known for formation of some Fe, Mn, Cu, and Zn minerals listed in table 3. For most of the water compositions being studied (tables 1 and 2), concentrations of Mn, Cu, and Zn are very small. Therefore, even if conditions within the Authority's distribution system were kinetically favorable for the formation of minerals containing these elements, only small quantities of these minerals would be expected to form. Minerals containing Fe would be more likely to form in substantial quantities, particularly given the planned addition of ferric chloride

during surface-water treatment. Of the Fe minerals in table 3, ferrihydrite, goethite, hematite, lepidocrocite, and maghemite appear most likely to precipitate from natural waters at low temperatures (Deer and others, 1962; Pough, 1998).

Calculation of Corrosion Indices

To further evaluate the potential of the various ground-water and surface-water compositions to dissolve (rather than precipitate) solid phases with subsequent adverse effects on water quality or possible damage to distribution lines, corrosion indices were calculated and compared among water compositions. Most of these indices focus on stability of calcite. Calcite formation helps to protect pipes from corrosion, even though the formation of large quantities of calcite can reduce the area of pipe available to conduct water. Dissolution of existing calcite could expose metal pipes to greater corrosion, in addition to possibly affecting the quality or aesthetic characteristics—taste, odor, and appearance—of water delivered to customers (depending on elemental composition of any material associated with the calcite precipitate). Potential effects of water compositions on lead and copper corrosion in particular were not examined.

For this study, the Langelier, Ryznar, and Larson-Skold corrosion indices were calculated. The Langelier and Ryznar equations used for this study included corrections for temperature and dissolved-solids concentration. The Langelier Saturation Index (LSI) is defined as the difference between the actual pH of the water and the hypothetical pH the water would have if it was in equilibrium with calcite. The index is calculated as:

$$\begin{aligned} \text{LSI} &= \text{pH}_f - \text{pH}_s; \\ \text{pH}_s &= [9.3 + (\log_{10}(\text{DS}) - 1 / 10) + (-13.12 \\ &\quad \times \log_{10}(T + 273) + 34.55)] - \\ &\quad [(\log_{10}(\text{Ca}^{2+}) - 0.4) + \log_{10}(\text{alk})], \end{aligned}$$

where pH_f is the field pH, pH_s is the hypothetical pH for equilibrium with calcite, DS is the dissolved-solids concentration in mg/L, T is the water temperature in °C, Ca^{2+} is calcium in mg/L as calcium bicarbonate, and alk is alkalinity in mg/L as calcium carbonate (Kingston Technical Software, 2004). A positive LSI value indicates that calcium

carbonate scale is likely to form in pipes, whereas a negative value indicates that calcium carbonate is likely to dissolve, exposing pipes to potential corrosion in the presence of oxygen. The Ryznar Stability Index (RSI) is a modification of the LSI based on field studies. The $\text{RSI} = 2(\text{pH}_s) - \text{pH}_f$; in general, a value less than 6 indicates that calcium carbonate scale is likely to form and a value greater than 8 indicates that the water is fairly corrosive (Kingston Technical Software, 2004). The Larson-Skold Index (LKI) also is based on field studies and measures whether the chloride and sulfate content of water might interfere with scale formation. The $\text{LKI} = (\text{Cl}^- + \text{SO}_4^{2-}) / (\text{HCO}_3^- + \text{CO}_3^{2-})$, where the constituents shown are chloride, sulfate, bicarbonate, and carbonate, respectively, all with units of equivalents per million. An LKI below about 0.8 indicates that chloride and sulfate probably will not interfere with scale formation, whereas values above 0.8 indicate the potential for chloride and sulfate to reduce scale formation and enhance corrosion (Kingston Technical Software, 2004).

Mineral Precipitates in the Current Distribution System

As described in the section, “Collection and Analysis of Samples of Mineral Precipitates,” samples of mineral precipitates were collected from various parts of the Authority’s distribution system and analyzed for mineralogical and chemical compositions. The laboratory results can be compared to results expected based on the SIs calculated using PHREEQC and can be used to determine the chemical constituents that would be likely to enter distribution water if mineral dissolution was to occur.

Laboratory Results

A total of 10 samples of mineral precipitate from three reservoirs, two pipes, and one residential water heater were analyzed for mineralogical compositions. Chemical data were obtained for a total of 13 samples, mostly from reservoirs. Similar minerals were found in most samples, whereas the overall chemical compositions were somewhat variable (tables 4 and 5).

Table 4. Mineral composition of mineral-precipitate samples.

Sample description	Minerals identified
Whole sample collected from a residential water heater near the intersection of Monroe and Candelaria NE	calcite, aragonite, goethite, total clay
Whole sample collected from a 4-inch diameter pipe near the intersection of Hazeldine and Barelás SW	magnesite, goethite, and quartz trace
Whole sample collected from Yale Reservoir (fig. 1)	hematite, goethite, and total clay trace
Whole sample collected from Gutierrez Reservoir (fig. 1)	calcite, traces of quartz and feldspars, and total clay trace
Whole sample collected from a 4-inch diameter coupling near the intersection of Cagua and Bell SE	rhodochrosite, goethite, total clay trace, and weak possibility of gypsum and zeolite-hornblende
Whole sample collected from a reducer near the intersection of Hazeldine and Barelás SW	lepidocrocite-goethite and gibbsite
Sample of particles greater than 2 millimeters in size, obtained from the collector line at Ponderosa Reservoir (fig. 1)	amorphous iron oxyhydroxide (?) and calcite as determined by reaction of sample to dilute hydrochloric acid
Sample of particles less than 2 millimeters in size, obtained from the collector line inflow at Ponderosa Reservoir (fig. 1)	quartz, plagioclase, calcite, potassium feldspar trace, amorphous iron, and clay traces
Whole sample collected from Ponderosa Reservoir overflow (fig. 1)	quartz, potassium feldspar, plagioclase, calcite, amorphous iron, and clay traces
Whole sample collected from the floor of Ponderosa Reservoir at the overflow (fig. 1)	quartz, potassium feldspar, plagioclase, calcite, amorphous iron, and clay traces

Table 5. Chemical composition of mineral-precipitate samples.

[Data for Ponderosa Reservoir samples provided by Mark Stanton, USGS, written commun., 2003; ppm, parts per million]

Sample description	Calcium (percent)	Magnesium (percent)	Sodium (percent)	Potassium (percent)	Phosphorus (percent)	Aluminum (percent)	Iron (percent)	Titanium (percent)	Arsenic (ppm)	Antimony (ppm)	Barium (ppm)	Beryllium (ppm)	Bismuth (ppm)	Cadmium (ppm)
Whole sample collected from Yale Reservoir (fig. 1)	0.34	0.005	0.005	0.008	0.072	0.024	46	<0.005	150	0.4	56	<0.1	<1	<0.1
Whole sample collected from Gutierrez Reservoir (fig. 1)	41	0.91	0.032	0.007	0.007	0.016	0.27	<0.005	7.3	<0.1	770	<0.1	<1	1.2
Whole sample collected from a 4-inch diameter coupling near the intersection of Cagua and Bell SE	0.32	0.073	0.026	0.06	0.013	0.16	44	0.008	96	5.7	51	<0.1	<1	0.3
Sample of particles greater than 2 millimeters in size, obtained from the collector line at Ponderosa Reservoir (fig. 1)	2.9	0.26	1.4	1.70	0.04	3.9	22	0.12	170	1.0	900	1.8	<1	3.7
Sample of particles less than 2 millimeters in size, obtained from the collector line inflow at Ponderosa Reservoir (fig. 1)	1.6	0.13	1.2	1.30	0.032	3.2	34	0.11	190	2.8	610	1.4	<1	0.8
Whole sample collected from Ponderosa Reservoir (fig. 1), between the collector line overflow and silt ring	3.0	0.42	1.1	1.90	0.066	4.1	13	0.25	250	5.4	1,300	1.3	<1	8.4
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	2.4	0.35	0.042	0.19	0.059	0.92	12	0.029	120	0.3	5,100	1.6	<1	9.2
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	4.6	0.44	0.039	0.21	0.10	1.1	9.4	0.069	680	1.5	2,200	1.4	<1	11
Whole sample collected from the Ponderosa Reservoir overflow (fig. 1)	1.6	0.28	0.044	0.16	0.05	0.87	6.4	0.069	230	0.8	510	0.6	<1	5
Whole sample collected from the overflow-floor of Ponderosa Reservoir (fig. 1)	10	0.50	0.052	0.18	0.058	1.2	8.6	0.054	540	2.1	2,200	1.0	<1	16
Whole sample collected from the floor of Ponderosa Reservoir at the overflow (fig. 1)	2.9	0.40	0.048	0.26	0.064	1.2	7.5	0.092	210	0.9	590	0.9	<1	7.2
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	20	0.62	0.026	0.09	0.027	0.51	5.8	0.038	53	0.3	460	0.3	<1	40
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	38	0.72	0.021	0.033	0.015	0.23	0.8	0.018	28	0.1	600	0.2	<1	5.7

Table 5. Chemical composition of mineral-precipitate samples.—Continued

Sample description	Cerium (ppm)	Chromium (ppm)	Cobalt (ppm)	Copper (ppm)	Europium (ppm)	Gallium (ppm)	Gold (ppm)	Holmium (ppm)	Lanthanum (ppm)	Lead (ppm)	Lithium (ppm)	Manganese (ppm)	Molybdenum (ppm)	Neodymium (ppm)
Whole sample collected from Yale Reservoir (fig. 1)	1.4	44	<2	7.4	<1	<1	<1	<1	<1	<1	<1	60	22	<1
Whole sample collected from Gutierrez Reservoir (fig. 1)	<1	1.1	14	11	<1	<1	<1	<1	<1	10	2	180	<0.5	<1
Whole sample collected from a 4-inch diameter coupling near the intersection of Cagua and Bell SE	1.4	94	410	310	<1	21	<1	<1	<1	7.3	1.4	1,100	20	<1
Sample of particles greater than 2 millimeters in size, obtained from the collector line at Ponderosa Reservoir (fig. 1)	30	16	11	370	<1	10	<1	<1	17	70	10	1,200	9.8	13
Sample of particles less than 2 millimeters in size, obtained from the collector line inflow at Ponderosa Reservoir (fig. 1)	34	56	24	350	<1	11	<1	<1	17	52	10	2,900	7.9	14
Whole sample collected from Ponderosa Reservoir (fig. 1), between the collector line overflow and silt ring	49	62	32	2,600	<1	12	<1	<1	26	350	17	13,000	9.8	21
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	34	110	32	5,400	<1	5	<1	1.7	24	370	8	50,000	1.5	20
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	42	160	36	4,200	<1	5	<1	1.1	24	600	12	47,000	9.4	20
Whole sample collected from the Ponderosa Reservoir overflow (fig. 1)	36	58	15	2,000	<1	4	<1	<1	20	230	9	5,300	9.5	16
Whole sample collected from the overflow floor of Ponderosa Reservoir (fig. 1)	25	110	42	3,600	<1	5	<1	<1	14	310	13	49,000	9.9	12
Whole sample collected from the floor of Ponderosa Reservoir at the overflow (fig. 1)	45	54	25	2,000	<1	6	<1	<1	24	270	12	8,600	5	21
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	14	6	30	490	<1	2	<1	<1	7.6	210	8	1,000	1.4	6.5
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	6.8	4	6	140	<1	1	<1	<1	3.7	42	6	900	1.4	2.9

Table 5. Chemical composition of mineral-precipitate samples.—Continued

Sample description	Nickel (ppm)	Niobium (ppm)	Scandium (ppm)	Silver (ppm)	Strontium (ppm)	Tantalum (ppm)	Thallium (ppm)	Thorium (ppm)	Tin (ppm)	Uranium (ppm)	Vanadium (ppm)	Ytterbium (ppm)	Yttrium (ppm)	Zinc (ppm)
Whole sample collected from Yale Reservoir (fig. 1)	<1	<4	<2	<0.1	14	<1	<1	<1	<1	19	130	<1	<1	8.2
Whole sample collected from Gutierrez Reservoir (fig. 1)	1.3	<4	<2	<0.1	1,600	<1	<1	<1	1.9	3.6	<2	<1	<1	3,200
Whole sample collected from a 4-inch diameter coupling near the intersection of Cagua and Bell SE	150	<4	<2	<0.1	23	<1	<1	<1	7.6	20	79	<1	<1	100
Sample of particles greater than 2 millimeters in size, obtained from the collector line at Ponderosa Reservoir (fig. 1)	22	5	2	<0.1	320	<1	1	4.5	14	11	77	1.4	14	6,900
Sample of particles less than 2 millimeters in size, obtained from the collector line inflow at Ponderosa Reservoir (fig. 1)	55	8	<2	0.2	160	<1	<1	3.3	25	6.6	41	1.6	14	840
Whole sample collected from Ponderosa Reservoir (fig. 1), between the collector line overflow and silt ring	50	8	5	0.3	310	<1	1.4	5.6	330	6	70	2.5	23	5,400
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	63	<4	3	0.1	420	<1	2.9	2.6	53	16	21	5.1	49	10,000
Whole sample collected from the center of Ponderosa Reservoir (fig. 1)	43	<4	3	0.3	320	<1	1.2	4.4	320	8.5	85	3.2	32	8,500
Whole sample collected from the Ponderosa Reservoir overflow (fig. 1)	25	<4	3	0.1	100	<1	<1	3.6	140	5.5	48	1.4	14	6,200
Whole sample collected from the overflow floor of Ponderosa Reservoir (fig. 1)	59	4	3	0.3	550	<1	1.6	2.1	420	6	87	2.1	28	7,500
Whole sample collected from the floor of Ponderosa Reservoir at the overflow (fig. 1)	30	<4	4	0.2	170	<1	1.1	5	160	6.8	56	1.8	19	12,000
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	59	<4	<2	<0.1	800	<1	<1	1.6	51	8.6	23	<1	6	75,000
Whole sample collected from the floor of Ponderosa Reservoir (fig. 1)	13	<4	<2	<0.1	1,600	<1	<1	<1	16	4.9	11	<1	3	14,000

Mineral Composition

Analysis with X-ray diffraction determined that some minerals were common to several of the 10 samples submitted for analysis (table 4). In particular, calcite was identified in Gutierrez Reservoir, the residential water heater, and all four samples from the Ponderosa Reservoir. Goethite was identified in Yale Reservoir, the residential water heater, and the three pipe samples (in one of the pipe samples, it was recorded as lepidocrocite-goethite). Iron found in the Ponderosa Reservoir was in the form of amorphous iron and possible amorphous iron oxyhydroxides. Other minerals that were detected in one sample each were aragonite, hematite, rhodochrosite (MnCO_3), and gibbsite; one sample also had a weak possibility of gypsum (CaSO_4) and zeolite-hornblende.

Quartz, plagioclase feldspar, potassium feldspar, and a trace quantity of clay were reported for several samples. These minerals were typically found together in the reservoir samples. Because of their locations within the reservoirs combined with kinetic considerations (see “Evaluation of Modeling Results” section), it appears likely that most of these minerals are associated with sand and clay particles that were suspended in water during pumping and subsequently settled out once the water reached the reservoirs.

Use of X-ray diffraction for identification of minerals has some limitations. The technique can identify minerals in crystalline form, but is not able to identify amorphous minerals. In particular, the presence of amorphous SiO_2 or amorphous Mn oxides and oxyhydroxides will not be detected by X-ray diffraction. Also, minerals present at small weight fractions (less than about 5 percent) may not be apparent (Jenkins, 2000).

Chemical Composition

Chemical compositions for all 13 samples analyzed by ICPMS are listed in table 5. Four samples (3 from Ponderosa Reservoir and 1 from Gutierrez Reservoir) are more than 10 percent calcium, likely indicating a large portion of calcite. Six samples (4 from Ponderosa Reservoir, 1 from Yale Reservoir, and 1 from a pipe) are more than 10 percent iron. All samples except the one from Yale Reservoir contain Mn, Cu, and (or) Zn exceeding 1,000 parts per million (ppm). No minerals containing Cu or Zn were identified during X-ray analysis, perhaps because such minerals were present only in small weight fractions, or because these two metals are sorbed onto other materials, including clays and Fe oxides or oxyhydroxides. Three other heavy metals—Cr, Pb, and Sn—and As exceed 100 parts per million in some samples. Samples that are highest in percent Ca are lowest in As content, which probably indicates that As does not tend to co-precipitate with calcite, and is more likely to co-precipitate with or be sorbed by Fe-containing minerals. The contents of Ba and Sr, two alkali earth metals, also exceeded 100 parts per million in several mineral samples. For individual precipitate samples, Si and (or) O (which were not included in analysis) probably make up most of the mass that is not accounted for by the elements listed in table 5.

Water that had a tendency to dissolve the solid phases found in the Authority’s current distribution system could be adversely affected in terms of quality or aesthetic characteristics if substantial dissolution occurred. Dissolution of calcite could increase water hardness. Dissolution of solid phases having high contents of Fe or other metals (whether because of sorption or incorporation into the mineral structure) could affect the color and taste of water, in addition to the quality of the water relative to U.S. Environmental Protection Agency (USEPA) drinking-water standards. Of the elements listed in the previous paragraph as being found in substantial quantities in the mineral precipitates sampled, As, Ba, Cr, Cu, and Pb have enforceable, health-based USEPA drinking-water standards (USEPA, 2006). For the metals Fe, Mn, and Zn, the USEPA has established non-enforceable guidelines related to water taste, odor, and color. Any increases that occurred in trace-element concentrations as a result of mineral dissolution would likely vary throughout the Authority’s distribution system, depending on factors that included the composition of the minerals present in a particular part of the system, the degree to which the water was already saturated with respect to those minerals, the volume of water in contact with the minerals, and the contact time between the minerals and the water. The concentration of a particular metal in the water prior to contact with minerals in the distribution system also would be a determining factor in whether mineral dissolution could cause the water to approach or exceed a drinking-water standard for that metal. In addition to mineral dissolution, desorption of trace elements from solid phases could potentially increase trace-element concentrations in delivered water. Again, the starting trace-element concentrations of the water, the volume of water in contact with the minerals, and the contact time between the minerals and the water would be determining factors in the magnitude of any concentration increases that might occur as a result of desorption. Modeling of adsorption and desorption processes within the Authority’s distribution system was not conducted for this study.

Modeling Results

Geochemical modeling using 10 ground-water compositions representative of water currently delivered through the Authority’s distribution system indicated that the SIs of multiple minerals were greater than 0.1. Of the minerals listed in table 3, the only one without an SI greater than 0.1 for any ground-water composition was $\text{Fe}_3(\text{OH})_8$. As described in the section “Analysis of Modeling Results,” some of the minerals in table 3 could reasonably be expected to precipitate in the distribution system, whereas others probably would not because of kinetic considerations. For the ground-water compositions, table 6 shows the SIs of minerals from table 3 having reaction kinetics considered favorable to their precipitation under conditions present in the Authority’s distribution system, in addition to selected minerals having kinetics that are not well known. The SIs for some minerals varied depending on the modeled temperature and atmospheric-gas pressures. Higher temperatures resulted in smaller SIs for

Table 6. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water compositions.

[deg. C, degrees Celsius; pCO₂, partial pressure of carbon dioxide; pO₂, partial pressure of oxygen; atm, atmospheres]

Sample source (from table 1)	Simulated temperature (deg. C)	Simulated log pCO ₂ (atm)	Simulated log pO ₂ (atm)	pH	aragonite	birnessite	calcite	chalcedony	cupric ferrite	cuprous ferrite	diaspore	Fe(OH) _{2.7} Cl _{0.3}	ferrihydrite
Charles 2	unaltered	unaltered	unaltered	7.64	-0.27	-12.54	-0.13	0.11	11.00	11.34	1.49	5.73	1.15
Duranes 6	unaltered	unaltered	unaltered	7.48	-0.21	-12.75	-0.07	0.45	11.34	11.59	1.56	6.05	1.39
Leavitt 2	unaltered	unaltered	unaltered	8.85	0.07	-8.04	0.21	-0.02	10.34	9.72	0.34	4.77	0.50
Love 5	unaltered	unaltered	unaltered	7.73	-0.16	-12.41	-0.02	0.01	11.88	11.57	1.40	6.05	1.39
Miles 1	unaltered	unaltered	unaltered	7.76	-0.17	-12.51	-0.04	0.36	12.29	11.65	1.29	6.16	1.46
Ridgecrest 1	unaltered	unaltered	unaltered	7.35	-0.33	-13.95	-0.19	0.02	9.55	10.67	1.65	5.04	0.37
Thomas 6	unaltered	unaltered	unaltered	7.45	-0.19	-12.65	-0.05	0.11	11.65	11.64	1.59	6.19	1.33
Vol Andia 3	unaltered	unaltered	unaltered	7.91	-0.02	-11.40	0.12	0.18	10.57	10.94	1.35	5.51	0.94
Walker 2	unaltered	unaltered	unaltered	7.75	0.03	-11.50	0.17	0.11	12.66	11.71	1.18	6.34	1.53
Zamora 1	unaltered	unaltered	unaltered	7.88	-0.21	-11.94	-0.07	0.39	11.14	11.01	1.23	5.42	0.94
Charles 2	23.0	-3.50	-0.67	8.59	0.69	6.47	0.83	0.04	11.41	2.35	0.63	5.37	1.07
Duranes 6	23.0	-3.50	-0.67	8.74	1.03	6.82	1.17	0.38	12.12	2.70	0.48	5.71	1.43
Leavitt 2	23.0	-3.50	-0.67	8.72	-0.06	6.37	0.08	0.00	10.48	1.88	0.51	4.93	0.61
Love 5	23.0	-3.50	-0.67	8.58	0.66	6.48	0.80	-0.01	11.73	2.51	0.64	5.63	1.23
Miles 1	23.0	-3.50	-0.67	8.57	0.56	6.48	0.69	0.37	11.83	2.56	0.65	5.74	1.28
Ridgecrest 1	23.0	-3.50	-0.67	8.70	0.97	6.38	1.11	-0.01	10.50	1.89	0.52	4.88	0.62
Thomas 6	23.0	-3.50	-0.67	8.64	0.94	7.39	1.08	0.09	12.15	2.72	0.58	5.95	1.44
Vol Andia 3	23.0	-3.50	-0.67	8.55	0.66	6.49	0.80	0.11	10.73	2.01	0.67	5.12	0.74
Walker 2	23.0	-3.50	-0.67	8.68	0.83	7.65	0.97	0.16	11.79	2.54	0.53	5.80	1.27
Zamora 1	23.0	-3.50	-0.67	8.66	0.50	6.42	0.64	0.39	10.57	1.93	0.57	4.91	0.66
Charles 2	unaltered	-3.00	-5.00	8.08	0.16	5.13	0.30	0.10	11.47	3.24	1.22	5.77	1.32
Duranes 6	unaltered	-3.00	-5.00	8.25	0.54	5.89	0.68	0.45	12.31	3.66	1.09	6.17	1.75
Leavitt 2	unaltered	-3.00	-5.00	8.24	-0.48	4.31	-0.35	0.01	11.10	3.29	0.92	5.37	0.91
Love 5	unaltered	-3.00	-5.00	8.11	0.21	4.32	0.34	0.01	12.13	3.75	1.09	6.01	1.47
Miles 1	unaltered	-3.00	-5.00	8.11	0.17	3.62	0.31	0.35	12.49	4.08	0.97	6.11	1.51
Ridgecrest 1	unaltered	-3.00	-5.00	8.23	0.53	4.58	0.67	0.01	10.98	3.17	0.99	5.32	0.91
Thomas 6	unaltered	-3.00	-5.00	8.17	0.51	5.23	0.65	0.10	12.66	4.05	1.01	6.35	1.71
Vol Andia 3	unaltered	-3.00	-5.00	8.03	0.10	5.26	0.24	0.18	10.64	2.78	1.27	5.50	0.96
Walker 2	unaltered	-3.00	-5.00	8.25	0.51	4.46	0.65	0.11	12.82	4.39	0.70	6.20	1.54
Zamora 1	unaltered	-3.00	-5.00	8.19	0.09	4.10	0.23	0.39	11.19	3.36	0.95	5.32	0.93

Table 6. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water compositions.—Continued

Sample source (from table 1)	Simulated temperature (deg. C)	Simulated log pCO ₂ (atm)	Simulated log pO ₂ (atm)	pH	aragonite	birnessite	calcite	chalcedony	cupric ferrite	cuprous ferrite	diaspore	Fe(OH) _{2.7} Cl _{0.3}	ferrihydrite
Charles 2	2.0	-3.00	-5.00	7.90	-0.29	9.07	-0.12	0.32	9.69	1.45	0.65	5.83	1.33
Duranes 6	2.0	-3.00	-5.00	8.08	0.11	9.84	0.27	0.67	10.63	1.92	0.65	6.27	1.80
Leavitt 2	2.0	-3.00	-5.00	8.03	-1.03	9.30	-0.86	0.29	8.96	1.08	0.65	5.49	0.96
Love 5	2.0	-3.00	-5.00	7.90	-0.32	9.07	-0.15	0.27	10.00	1.60	0.65	6.09	1.49
Miles 1	2.0	-3.00	-5.00	7.89	-0.42	9.02	-0.25	0.65	10.08	1.64	0.65	6.19	1.52
Ridgecrest 1	2.0	-3.00	-5.00	8.03	0.02	9.30	0.19	0.27	8.96	1.08	0.65	5.42	0.96
Thomas 6	2.0	-3.00	-5.00	7.96	-0.02	10.12	0.15	0.37	10.51	1.86	0.65	6.44	1.74
Vol Andia 3	2.0	-3.00	-5.00	7.86	-0.32	8.98	-0.15	0.39	8.95	1.07	0.65	5.54	0.96
Walker 2	2.0	-3.00	-5.00	8.01	-0.12	10.50	0.05	0.44	10.23	1.72	0.65	6.33	1.60
Zamora 1	2.0	-3.00	-5.00	7.97	-0.47	9.20	-0.30	0.67	8.96	1.09	0.65	5.42	0.96
Charles 2	50.0	-3.00	-5.00	8.23	0.69	-1.25	0.85	-0.25	14.15	5.98	-0.19	5.69	1.28
Duranes 6	50.0	-3.00	-5.00	8.38	1.02	-0.53	1.18	0.08	14.96	6.38	-0.35	6.07	1.68
Leavitt 2	50.0	-3.00	-5.00	8.36	-0.05	-1.02	0.11	-0.29	13.29	5.55	-0.33	5.27	0.85
Love 5	50.0	-3.00	-5.00	8.22	0.66	-1.25	0.82	-0.30	14.47	6.14	-0.18	5.94	1.44
Miles 1	50.0	-3.00	-5.00	8.21	0.55	-1.30	0.72	0.08	14.56	6.19	-0.17	6.05	1.48
Ridgecrest 1	50.0	-3.00	-5.00	8.34	0.96	-1.06	1.12	-0.31	13.31	5.56	-0.30	5.23	0.86
Thomas 6	50.0	-3.00	-5.00	8.27	0.93	-0.23	1.09	-0.20	14.93	6.37	-0.24	6.28	1.67
Vol Andia 3	50.0	-3.00	-5.00	8.18	0.66	-1.35	0.82	-0.18	13.45	5.63	-0.15	5.42	0.93
Walker 2	50.0	-3.00	-5.00	8.32	0.83	0.16	0.99	-0.14	14.60	6.21	-0.29	6.14	1.50
Zamora 1	50.0	-3.00	-5.00	8.30	0.50	-1.13	0.66	0.09	13.36	5.59	-0.26	5.24	0.88

Table 6. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water compositions.—Continued

Sample source (from table 1)	Simulated temperature (deg. C)	Simulated log pCO ₂ (atm)	Simulated log pO ₂ (atm)	goethite	hematite	huntite	lepidocrocite	maghemite	manganite	Mg-ferrite	nsutite	pyrolusite
Charles 2	unaltered	unaltered	unaltered	5.32	15.62	-7.13	4.67	5.69	-5.85	5.65	-11.95	-10.75
Duranos 6	unaltered	unaltered	unaltered	5.57	16.11	-5.70	4.91	6.19	-5.90	6.27	-12.16	-10.96
Leavitt 2	unaltered	unaltered	unaltered	4.84	14.69	-5.33	4.02	4.39	-2.56	6.63	-7.45	-5.90
Love 5	unaltered	unaltered	unaltered	5.70	16.40	-6.77	4.91	6.18	-5.81	6.84	-11.83	-10.35
Miles 1	unaltered	unaltered	unaltered	5.87	16.76	-5.36	4.98	6.31	-5.94	7.89	-11.92	-10.23
Ridgecrest 1	unaltered	unaltered	unaltered	4.67	14.34	-6.56	3.89	4.14	-6.97	4.37	-13.37	-11.90
Thomas 6	unaltered	unaltered	unaltered	5.67	16.33	-6.87	4.85	6.07	-5.77	6.43	-12.06	-10.54
Vol Andia 3	unaltered	unaltered	unaltered	5.07	15.12	-5.83	4.46	5.27	-4.98	5.75	-10.81	-9.69
Walker 2	unaltered	unaltered	unaltered	6.05	17.12	-4.98	5.05	6.45	-4.92	8.36	-10.91	-9.01
Zamora 1	unaltered	unaltered	unaltered	5.30	15.61	-5.92	4.46	5.27	-5.49	6.52	-11.35	-9.76
Charles 2	23.0	-3.50	-0.67	5.39	15.79	-3.09	4.59	5.55	4.02	8.07	7.06	8.56
Duranos 6	23.0	-3.50	-0.67	5.75	16.50	-0.53	4.95	6.25	4.38	9.51	7.41	8.91
Leavitt 2	23.0	-3.50	-0.67	4.93	14.85	-5.87	4.13	4.61	3.92	6.45	6.96	8.46
Love 5	23.0	-3.50	-0.67	5.55	16.10	-3.47	4.75	5.86	4.03	8.27	7.06	8.56
Miles 1	23.0	-3.50	-0.67	5.60	16.20	-2.53	4.80	5.96	4.03	8.72	7.07	8.57
Ridgecrest 1	23.0	-3.50	-0.67	4.94	14.87	-1.35	4.14	4.63	3.94	7.64	6.97	8.47
Thomas 6	23.0	-3.50	-0.67	5.76	16.53	-2.36	4.96	6.29	4.94	8.97	7.97	9.47
Vol Andia 3	23.0	-3.50	-0.67	5.05	15.11	-2.90	4.26	4.87	4.04	7.46	7.08	8.58
Walker 2	23.0	-3.50	-0.67	5.59	16.17	-1.99	4.79	5.93	5.20	8.77	8.24	9.74
Zamora 1	23.0	-3.50	-0.67	4.97	14.95	-3.11	4.18	4.71	3.97	7.28	7.01	8.51
Charles 2	unaltered	-3.00	-5.00	5.50	15.97	-5.39	4.84	6.04	3.43	6.88	5.72	6.92
Duranos 6	unaltered	-3.00	-5.00	5.92	16.82	-2.70	5.27	6.89	4.19	8.50	6.48	7.68
Leavitt 2	unaltered	-3.00	-5.00	5.25	15.51	-7.56	4.43	5.21	3.01	6.25	4.89	6.45
Love 5	unaltered	-3.00	-5.00	5.78	16.56	-5.30	4.99	6.34	2.93	7.75	4.91	6.38
Miles 1	unaltered	-3.00	-5.00	5.93	16.87	-3.99	5.03	6.42	2.48	8.70	4.21	5.90
Ridgecrest 1	unaltered	-3.00	-5.00	5.21	15.42	-3.12	4.43	5.22	3.17	7.21	5.17	6.63
Thomas 6	unaltered	-3.00	-5.00	6.04	17.08	-4.06	5.23	6.81	3.89	8.61	5.82	7.34
Vol Andia 3	unaltered	-3.00	-5.00	5.10	15.17	-5.35	4.48	5.32	3.47	6.04	5.85	6.98
Walker 2	unaltered	-3.00	-5.00	6.06	17.14	-3.06	5.06	6.47	3.56	9.37	5.04	6.95
Zamora 1	unaltered	-3.00	-5.00	5.29	15.59	-4.72	4.45	5.25	2.84	7.12	4.68	6.28

Table 6. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water compositions.—Continued

Sample source (from table 1)	Simulated temperature (deg. C)	Simulated log pCO ₂ (atm)	Simulated log pO ₂ (atm)	goethite	hematite	huntite	lepidocrocite	maghemite	manganite	Mg-ferrite	nsutite	pyrolusite
Charles 2	2.0	-3.00	-5.00	4.83	14.56	-8.06	4.85	6.06	5.82	3.47	9.66	9.51
Duranes 6	2.0	-3.00	-5.00	5.30	15.49	-5.32	5.32	6.99	6.59	5.19	10.43	10.29
Leavitt 2	2.0	-3.00	-5.00	4.46	13.82	-10.84	4.48	5.32	6.04	2.06	9.88	9.74
Love 5	2.0	-3.00	-5.00	4.99	14.87	-8.46	5.01	6.37	5.82	3.66	9.66	9.51
Miles 1	2.0	-3.00	-5.00	5.03	14.95	-7.50	5.04	6.44	5.77	4.09	9.61	9.47
Ridgecrest 1	2.0	-3.00	-5.00	4.46	13.82	-6.21	4.48	5.32	6.05	3.25	9.88	9.74
Thomas 6	2.0	-3.00	-5.00	5.24	15.38	-7.26	5.26	6.88	6.87	4.47	10.71	10.56
Vol Andia 3	2.0	-3.00	-5.00	4.46	13.81	-7.89	4.48	5.31	5.73	2.79	9.56	9.42
Walker 2	2.0	-3.00	-5.00	5.10	15.09	-6.89	5.12	6.59	7.25	4.34	11.09	10.94
Zamora 1	2.0	-3.00	-5.00	4.47	13.83	-8.06	4.48	5.33	5.95	2.80	9.78	9.64
Charles 2	50.0	-3.00	-5.00	6.49	18.10	-2.31	4.80	5.96	-0.56	11.86	-0.67	2.63
Duranes 6	50.0	-3.00	-5.00	6.89	18.90	0.22	5.20	6.76	0.16	13.39	0.05	3.35
Leavitt 2	50.0	-3.00	-5.00	6.06	17.24	-5.06	4.37	5.10	-0.32	10.32	-0.43	2.87
Love 5	50.0	-3.00	-5.00	6.65	18.42	-2.69	4.96	6.27	-0.55	12.06	-0.66	2.64
Miles 1	50.0	-3.00	-5.00	6.70	18.51	-1.76	5.00	6.36	-0.61	12.49	-0.72	2.58
Ridgecrest 1	50.0	-3.00	-5.00	6.07	17.26	-0.59	4.38	5.12	-0.36	11.50	-0.47	2.83
Thomas 6	50.0	-3.00	-5.00	6.88	18.88	-1.62	5.19	6.73	0.47	12.78	0.36	3.65
Vol Andia 3	50.0	-3.00	-5.00	6.14	17.39	-2.14	4.45	5.25	-0.65	11.22	-0.76	2.54
Walker 2	50.0	-3.00	-5.00	6.72	18.55	-1.23	5.02	6.40	0.86	12.62	0.75	4.04
Zamora 1	50.0	-3.00	-5.00	6.10	17.31	-2.33	4.40	5.16	-0.43	11.12	-0.54	2.75

most Mn oxides/hydroxides and some silicates and larger SIs for most carbonates. The mineral huntite tended to have positive SIs only when the simulated water temperature was 50°C. Ground-water compositions simulated with less oxygenation generally resulted in smaller, and in some cases negative, SIs for Mn oxides/hydroxides.

Of the minerals shown in table 6, several were positively identified in x-ray diffraction analysis of mineral precipitates from the Authority's distribution system. These were aragonite, calcite, goethite, hematite, and lepidocrocite. Also identified through examination of the precipitates were amorphous forms of Fe or Fe oxyhydroxides, which can form more readily than some Fe minerals with distinct crystalline structure. The lack of detection of some minerals listed in table 6 is not surprising—particularly, minerals with SIs greater than 0.1 for only a limited number of ground-water compositions at high temperatures and amorphous forms of Mn that typically are not detected by x-ray diffraction. The lack of detection of other minerals containing Mn or Cu could be explained by quantities of these minerals being very small or by their formation not being kinetically favored. Comparison between the modeled SIs and the minerals identified in the distribution system is helpful in demonstrating that many of these minerals are not of substantial concern for changes in the source of water delivered through the distribution system, despite having SIs greater than 0.1 in the model simulations. Formation of most of the minerals that have SIs greater than 0.1 but were not identified by x-ray diffraction probably is not kinetically favorable under conditions present within the distribution system.

Rhodochrosite (MnCO_3) and gibbsite were positively identified among samples from the Authority's distribution system, despite having SIs less than -0.1 for all modeled ground-water compositions. Rhodochrosite generally forms in high temperature metasomatic deposits and hydrothermal veins (Deer and others, 1962); therefore, its presence may be the result of transportation into the Authority's distribution system from an outside source. Gibbsite typically occurs as an alteration product of aluminosilicate minerals or as a low-temperature hydrothermal mineral, although it has been prepared artificially by autoprecipitation from aqueous solutions at temperatures as low as 30°C (Deer and others, 1962). Therefore, it cannot be determined whether the gibbsite was transported into the system from an outside source, formed in situ by alteration of other minerals, or precipitated as a more kinetically favorable form of Al hydroxide than diaspore (which had positive SIs for all ground-water compositions except those with at 50°C).

The PHREEQC models did not include simulation of the co-precipitation of elements such as As and Zn with—or their sorption onto—precipitating minerals. Therefore, the chemical compositions determined during laboratory analysis of mineral precipitates from the Authority's distribution system may include larger quantities of these elements than were simulated during modeling.

PHREEQC can be used to estimate the likely quantity of solid phases that could precipitate from or be dissolved by a simulated solution. For each mineral listed in table 6, the

maximum quantity that could potentially precipitate or dissolve per kilogram (kg) of water was estimated for all the ground-water compositions that had been simulated to represent partial equilibration with atmospheric conditions (without a temperature change). This was done by designing individual simulations for each mineral that allowed that mineral to come to equilibrium with its solution. The simulations indicated that most minerals could potentially form about 1×10^{-3} to 2×10^{-2} mg of precipitate per kg of water. These quantities apply to all of the minerals containing heavy metals in their structures. Calcite, aragonite, and chalcedony could potentially form as much as about 1 to 60 mg of precipitate per kg of water. Calcite showed the potential to form the largest quantities of precipitate, ranging from about 10 to 60 mg with a median of about 20 mg per kg of water; only one ground-water composition showed the potential to dissolve calcite. Given 20 mg of precipitate per kg of water at about 23°C, calcite could form up to about 6 cubic feet of precipitate per filling of a 6-million-gallon-capacity reservoir, covering a floor 150 feet in diameter to a depth of about 0.0045 inches. At about 50 mg of precipitate per kg of water heated to 50°C, calcite could form up to about 0.22 cubic inches of precipitate per filling of a 50-gallon-capacity water heater, covering a floor 1.5 feet in diameter to a depth of about 0.0008 inches. The estimated quantities of precipitate for these ground-water compositions can be compared with the estimated quantities for surface-water compositions to determine whether those quantities might change substantially when the source of water delivered through the distribution system changes.

Corrosion Indices

Corrosion indices were calculated for the ground-water compositions resulting when samples from table 1 were simulated to have a log $p\text{CO}_2$ of -3.0 and a log $p\text{O}_2$ of -5.0 (representing partial equilibration with atmospheric conditions). The LSIs (table 7) for the ground-water compositions vary from -0.6 to 0.5, with only the value for water pumped from Leavitt 2 being less than 0. These values are consistent with PHREEQC simulations of the same ground-water compositions (table 6), which show calcite being above saturation for all compositions except the one derived from Leavitt 2 water. Based on the calculated LSIs and the simulated calcite SIs, ground water delivered through the Authority's current distribution system would tend to precipitate a protective coating of calcite and, therefore, is typically non-corrosive. LKIs for the ground-water compositions range from 0.4 to 1.1, which is consistent with the LSIs, indicating that the ground-water samples are typically non-corrosive. RSIs range from 7.2 to 9.4; two ground-water compositions have values greater than 8.0, indicating moderate corrosion potential. These corrosion indices can be compared with the ones calculated for surface water to determine whether there might be a substantial change in corrosivity when the source of water delivered through the Authority's distribution system changes. Higher corrosivity would generally be associated with a higher tendency for mineral dissolution and oxidation of metals to adversely affect the quality and aesthetic characteristics of delivered water.

Table 7. Corrosion indices calculated for selected ground-water compositions, surface-water compositions, and ground-water/surface-water mixtures.

[For ground water, calculations are for compositions modeled to represent partial equilibration with atmospheric conditions. For surface water, calculations are for compositions modeled to have undergone treatment at the water treatment plant. For ground-water/surface-water mixtures, calculations are for mixtures of these compositions in the ratios shown. Calcite SI, calcite saturation index calculated with PHREEQC; LSI, Langelier Saturation Index; LKI, Larson-Skold Index; RSI, Ryznar Stability Index]

Sample source (from tables 1 and 2)	Calcite SI	LSI	LKI	RSI
Charles 2	0.30	0.1	0.4	7.9
Duranes 6	0.68	0.5	0.6	7.3
Leavitt 2	-0.35	-0.6	0.6	9.4
Love 5	0.34	0.1	0.5	7.8
Miles 1	0.31	0.1	0.9	7.9
Ridgecrest 1	0.67	0.5	0.4	7.3
Thomas 6	0.65	0.5	0.9	7.2
Vol Andia 3	0.24	0.0	0.7	8.0
Walker 2	0.65	0.5	1.1	7.3
Zamora 1	0.23	0.0	0.5	8.2
Rio Grande at Albuquerque 8/16/1971	0.30	0.2	3.5	7.6
Rio Grande at Albuquerque 5/3/1982	-0.20	-0.3	2.5	8.7
Rio Grande at Albuquerque 7/15/1986	-0.36	-0.5	2.1	9.1
Rio Grande at Albuquerque 11/7/1986	-0.13	-0.3	2.2	8.6
Rio Grande at Albuquerque 2/3/1987	-0.21	-0.4	2.2	8.8
Rio Grande at Albuquerque 5/11/1988	-0.01	-0.1	2.6	8.3
Rio Grande at Albuquerque 11/7/1988	0.14	-0.0	2.2	8.0
Rio Grande at Albuquerque 8/22/1995	0.05	-0.1	2.1	8.1
Mixture of Charles 2 with Rio Grande at Albuquerque 8/16/1971, ratio 1:9	0.30	0.2	3.1	7.6
Mixture of Charles 2 with Rio Grande at Albuquerque 5/3/1982, ratio 1:9	-0.13	-0.3	2.1	8.6
Mixture of Charles 2 with Rio Grande at Albuquerque 7/15/1986, ratio 1:9	-0.28	-0.5	1.8	8.9
Mixture of Charles 2 with Rio Grande at Albuquerque 11/7/1986, ratio 1:9	-0.08	-0.3	1.9	8.6
Mixture of Charles 2 with Rio Grande at Albuquerque 2/3/1987, ratio 1:9	-0.15	-0.4	1.9	8.7
Mixture of Charles 2 with Rio Grande at Albuquerque 5/11/1988, ratio 1:9	0.03	-0.1	2.3	8.2
Mixture of Charles 2 with Rio Grande at Albuquerque 11/7/1988, ratio 1:9	0.16	-0.0	2.0	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 8/22/1995, ratio 1:9	0.08	-0.1	1.9	8.1
Mixture of Charles 2 with Rio Grande at Albuquerque 8/16/1971, ratio 9:1	0.30	0.1	0.7	7.9
Mixture of Charles 2 with Rio Grande at Albuquerque 5/3/1982, ratio 9:1	0.25	0.0	0.6	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 7/15/1986, ratio 9:1	0.24	0.0	0.5	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 11/7/1986, ratio 9:1	0.26	0.0	0.6	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 2/3/1987, ratio 9:1	0.25	0.0	0.6	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 5/11/1988, ratio 9:1	0.27	0.1	0.6	8.0
Mixture of Charles 2 with Rio Grande at Albuquerque 11/7/1988, ratio 9:1	0.28	0.1	0.6	7.9
Mixture of Charles 2 with Rio Grande at Albuquerque 8/22/1995, ratio 9:1	0.27	0.1	0.6	7.9
Mixture of Duranes 6 with Rio Grande at Albuquerque 8/16/1971, ratio 1:9	0.35	0.2	2.9	7.5
Mixture of Duranes 6 with Rio Grande at Albuquerque 5/3/1982, ratio 1:9	-0.07	-0.2	2.0	8.5
Mixture of Duranes 6 with Rio Grande at Albuquerque 7/15/1986, ratio 1:9	-0.21	-0.4	1.7	8.8
Mixture of Duranes 6 with Rio Grande at Albuquerque 11/7/1986, ratio 1:9	-0.03	-0.2	1.8	8.5
Mixture of Duranes 6 with Rio Grande at Albuquerque 2/3/1987, ratio 1:9	-0.10	-0.3	1.8	8.7
Mixture of Duranes 6 with Rio Grande at Albuquerque 5/11/1988, ratio 1:9	0.08	-0.1	2.2	8.1
Mixture of Duranes 6 with Rio Grande at Albuquerque 11/7/1988, ratio 1:9	0.20	0.0	1.9	7.9
Mixture of Duranes 6 with Rio Grande at Albuquerque 8/22/1995, ratio 1:9	0.13	-0.0	1.8	8.0

Table 7. Corrosion indices calculated for selected ground-water compositions, surface-water compositions, and ground-water/surface-water mixtures.—Continued

Sample source (from tables 1 and 2)	Calcite SI	LSI	LKI	RSI
Mixture of Duranes 6 with Rio Grande at Albuquerque 8/16/1971, ratio 9:1	0.64	0.4	0.8	7.3
Mixture of Duranes 6 with Rio Grande at Albuquerque 5/3/1982, ratio 9:1	0.61	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 7/15/1986, ratio 9:1	0.60	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 11/7/1986, ratio 9:1	0.61	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 2/3/1987, ratio 9:1	0.61	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 5/11/1988, ratio 9:1	0.62	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 11/7/1988, ratio 9:1	0.62	0.4	0.7	7.4
Mixture of Duranes 6 with Rio Grande at Albuquerque 8/22/1995, ratio 9:1	0.62	0.4	0.7	7.4
Mixture of Leavitt 2 with Rio Grande at Albuquerque 8/16/1971, ratio 1:9	0.31	0.2	2.9	7.5
Mixture of Leavitt 2 with Rio Grande at Albuquerque 5/3/1982, ratio 1:9	-0.13	-0.2	2.0	8.5
Mixture of Leavitt 2 with Rio Grande at Albuquerque 7/15/1986, ratio 1:9	-0.28	-0.4	1.7	8.8
Mixture of Leavitt 2 with Rio Grande at Albuquerque 11/7/1986, ratio 1:9	-0.08	-0.2	1.8	8.5
Mixture of Leavitt 2 with Rio Grande at Albuquerque 2/3/1987, ratio 1:9	-0.15	-0.3	1.8	8.7
Mixture of Leavitt 2 with Rio Grande at Albuquerque 5/11/1988, ratio 1:9	0.03	-0.1	2.2	8.1
Mixture of Leavitt 2 with Rio Grande at Albuquerque 11/7/1988, ratio 1:9	0.16	0.0	1.9	7.9
Mixture of Leavitt 2 with Rio Grande at Albuquerque 8/22/1995, ratio 1:9	0.08	-0.0	1.8	8.0
Mixture of Leavitt 2 with Rio Grande at Albuquerque 8/16/1971, ratio 9:1	0.01	-0.2	0.8	8.6
Mixture of Leavitt 2 with Rio Grande at Albuquerque 5/3/1982, ratio 9:1	-0.14	-0.3	0.7	8.9
Mixture of Leavitt 2 with Rio Grande at Albuquerque 7/15/1986, ratio 9:1	-0.19	-0.4	0.7	9.0
Mixture of Leavitt 2 with Rio Grande at Albuquerque 11/7/1986, ratio 9:1	-0.12	-0.3	0.7	8.8
Mixture of Leavitt 2 with Rio Grande at Albuquerque 2/3/1987, ratio 9:1	-0.14	-0.3	0.7	8.9
Mixture of Leavitt 2 with Rio Grande at Albuquerque 5/11/1988, ratio 9:1	-0.11	-0.3	0.7	8.8
Mixture of Leavitt 2 with Rio Grande at Albuquerque 11/7/1988, ratio 9:1	-0.06	-0.3	0.7	8.7
Mixture of Leavitt 2 with Rio Grande at Albuquerque 8/22/1995, ratio 9:1	-0.12	-0.3	0.7	8.8

Chemical Modeling of Surface Water and Ground-Water/Surface-Water Mixtures

As described in the section “Analysis of Modeling Results,” chemical modeling was conducted for both surface-water compositions and ground-water/surface-water mixtures to determine the SIs of selected solid phases relative to the SIs of the same minerals for the ground-water compositions. Surface-water compositions used for mixing and for direct comparisons with ground-water compositions were the compositions that resulted from the simulation of surface-water treatment as described in the section “Range of Physical and Chemical Conditions Modeled.”

Surface Water

Similar to the modeling results for ground water, the modeling results for surface water indicated that nearly all of the minerals of table 3 had an SI greater than 0.1 for at least one of the simulated surface-water compositions. The exceptions were analbite, analcime, diopside, huntite, magnesite, sepiolite,

and willemite. The mineral $\text{Fe}_3(\text{OH})_8$ had an SI greater than 0.1 for several surface-water compositions, but no ground-water compositions. For the surface-water compositions, the SIs of selected minerals from table 3 with favorable or uncertain reaction kinetics for formation are shown in table 8.

For some of the solid phases listed in table 8, several ground-water compositions have SIs greater than 0.1 and only about half or fewer of the simulated surface-water compositions have SIs greater than 0.1. These minerals are aragonite, calcite, and chalcedony. Because the SIs of these minerals are positive for several ground-water compositions but negative for several surface-water compositions, there is a reasonable likelihood that a switch to delivery of surface water will result in dissolution of these minerals where they have already been deposited in the distribution system by ground water. However, of these minerals, only aragonite and calcite have actually been identified in samples of mineral precipitate from the Authority’s distribution system. Laboratory analysis indicated that the metal content of mineral samples with a high portion of calcite tended to be relatively low, with the notable exception of relatively high Zn content. Therefore, the dissolution of these minerals would probably result primarily in an increase in water hardness and perhaps in the Zn concentration of delivered water. Despite having no positive SIs for the

Table 8. Saturation indices for selected minerals, as calculated by PHREEQC for selected surface-water compositions.

[All results are for surface-water samples simulated to have undergone treatment at the proposed treatment plant. deg. C, degrees Celsius]

Sample source (from table 2)	Simulated temperature (deg. C)	pH	aragonite	birnessite	calcite	chalcedony	cupric ferrite	cuprous ferrite	diaspore	Fe(OH) _{2.7} Cl _{0.3}	Fe ₃ (OH) ₈
Rio Grande at Albuquerque 8/16/1971	unaltered	8.00	0.16	6.15	0.30	-0.01	19.05	6.53	1.29	9.17	0.33
Rio Grande at Albuquerque 5/3/1982	unaltered	8.00	-0.34	8.71	-0.20	-0.10	18.06	5.52	1.51	9.09	-0.27
Rio Grande at Albuquerque 7/15/1986	unaltered	8.00	-0.51	9.86	-0.36	-0.04	17.60	5.06	1.38	9.08	-0.55
Rio Grande at Albuquerque 11/7/1986	unaltered	8.00	-0.29	10.22	-0.13	0.07	17.43	4.89	1.30	9.11	-0.66
Rio Grande at Albuquerque 2/3/1987	unaltered	8.00	-0.37	11.26	-0.21	0.12	17.00	4.46	1.07	9.12	-0.92
Rio Grande at Albuquerque 5/11/1988	unaltered	8.00	-0.15	7.36	-0.01	-0.14	18.59	6.06	1.47	9.11	0.05
Rio Grande at Albuquerque 11/7/1988	unaltered	8.00	0.00	8.44	0.14	0.00	18.43	5.90	1.51	9.11	-0.22
Rio Grande at Albuquerque 8/22/1995	unaltered	8.00	-0.09	6.72	0.05	-0.16	18.93	6.40	1.96	9.09	0.26
Rio Grande at Albuquerque 8/16/1971	2.0	8.02	-0.18	12.08	-0.01	0.28	16.66	4.11	0.87	9.17	-1.15
Rio Grande at Albuquerque 5/3/1982	2.0	8.00	-0.55	12.09	-0.38	0.07	16.68	4.13	0.87	9.08	-1.12
Rio Grande at Albuquerque 7/15/1986	2.0	8.00	-0.65	12.10	-0.48	0.07	16.69	4.14	0.87	9.08	-1.11
Rio Grande at Albuquerque 11/7/1986	2.0	8.00	-0.40	12.07	-0.23	0.16	16.67	4.13	0.87	9.11	-1.12
Rio Grande at Albuquerque 2/3/1987	2.0	8.00	-0.42	12.07	-0.25	0.16	16.67	4.13	0.87	9.12	-1.12
Rio Grande at Albuquerque 5/11/1988	2.0	8.01	-0.43	12.09	-0.26	0.09	16.67	4.12	0.87	9.11	-1.13
Rio Grande at Albuquerque 11/7/1988	2.0	8.01	-0.22	12.07	-0.05	0.18	16.96	4.41	0.87	9.11	-1.14
Rio Grande at Albuquerque 8/22/1995	2.0	8.01	-0.42	12.29	-0.25	0.12	16.67	4.12	1.48	9.09	-1.13
Rio Grande at Albuquerque 8/16/1971	50.0	7.93	0.40	0.77	0.56	-0.28	21.16	8.66	0.32	9.19	1.64
Rio Grande at Albuquerque 5/3/1982	50.0	7.94	0.08	0.84	0.24	-0.49	21.20	8.70	0.31	9.10	1.67
Rio Grande at Albuquerque 7/15/1986	50.0	7.95	-0.01	0.85	0.15	-0.49	21.21	8.71	0.31	9.10	1.68
Rio Grande at Albuquerque 11/7/1986	50.0	7.93	0.21	0.81	0.38	-0.40	21.18	8.69	0.32	9.13	1.67
Rio Grande at Albuquerque 2/3/1987	50.0	7.93	0.20	0.81	0.36	-0.40	21.18	8.69	0.32	9.14	1.67
Rio Grande at Albuquerque 5/11/1988	50.0	7.94	0.18	0.82	0.35	-0.46	21.18	8.69	0.31	9.13	1.66
Rio Grande at Albuquerque 11/7/1988	50.0	7.92	0.37	0.78	0.54	-0.38	21.45	8.96	0.33	9.13	1.66
Rio Grande at Albuquerque 8/22/1995	50.0	7.94	0.19	1.01	0.36	-0.44	21.18	8.68	0.91	9.11	1.66

Table 8. Saturation indices for selected minerals, as calculated by PHREEQC for selected surface-water compositions.—Continued

Sample source (from table 2)	Simulated temperature (deg. C)	ferrihydrite	goethite	hematite	huntite	lepidocrocite	maghemite	manganite	Mg-ferrite	nsutite	pyrolusite
Rio Grande at Albuquerque 8/16/1971	unaltered	4.49	8.90	22.81	-4.95	8.01	12.38	3.86	14.41	6.73	8.41
Rio Grande at Albuquerque 5/3/1982	unaltered	4.50	8.52	22.00	-7.06	8.02	12.39	5.53	12.59	9.30	10.20
Rio Grande at Albuquerque 7/15/1986	unaltered	4.50	8.35	21.64	-8.08	8.02	12.40	6.28	11.68	10.45	11.00
Rio Grande at Albuquerque 11/7/1986	unaltered	4.50	8.29	21.50	-7.24	8.02	12.39	6.50	11.53	10.81	11.24
Rio Grande at Albuquerque 2/3/1987	unaltered	4.50	8.13	21.16	-7.73	8.02	12.39	7.17	10.78	11.85	11.96
Rio Grande at Albuquerque 5/11/1988	unaltered	4.50	8.73	22.44	-5.87	8.02	12.39	4.65	13.61	7.95	9.26
Rio Grande at Albuquerque 11/7/1988	unaltered	4.50	8.56	22.08	-5.62	8.02	12.39	5.35	12.89	9.03	10.00
Rio Grande at Albuquerque 8/22/1995	unaltered	4.50	8.85	22.71	-5.44	8.02	12.39	4.31	14.20	7.31	8.88
Rio Grande at Albuquerque 8/16/1971	2.0	4.49	8.00	20.88	-7.45	8.01	12.38	7.69	10.31	12.67	12.52
Rio Grande at Albuquerque 5/3/1982	2.0	4.50	8.00	20.90	-8.60	8.02	12.40	7.70	10.21	12.68	12.53
Rio Grande at Albuquerque 7/15/1986	2.0	4.50	8.01	20.90	-9.12	8.02	12.40	7.71	10.10	12.68	12.54
Rio Grande at Albuquerque 11/7/1986	2.0	4.50	8.00	20.90	-8.10	8.02	12.39	7.69	10.22	12.66	12.51
Rio Grande at Albuquerque 2/3/1987	2.0	4.50	8.00	20.90	-8.11	8.02	12.39	7.69	10.21	12.66	12.51
Rio Grande at Albuquerque 5/11/1988	2.0	4.50	8.00	20.89	-7.96	8.02	12.39	7.69	10.30	12.67	12.53
Rio Grande at Albuquerque 11/7/1988	2.0	4.50	8.00	20.89	-7.24	8.02	12.39	7.68	10.34	12.65	12.51
Rio Grande at Albuquerque 8/22/1995	2.0	4.50	8.00	20.90	-7.86	8.02	12.39	7.89	10.32	12.87	12.73
Rio Grande at Albuquerque 8/16/1971	50.0	4.49	9.70	24.52	-3.32	8.01	12.38	0.35	17.95	1.35	4.65
Rio Grande at Albuquerque 5/3/1982	50.0	4.50	9.71	24.54	-4.27	8.02	12.39	0.42	17.93	1.42	4.72
Rio Grande at Albuquerque 7/15/1986	50.0	4.50	9.71	24.54	-4.76	8.02	12.40	0.44	17.83	1.44	4.74
Rio Grande at Albuquerque 11/7/1986	50.0	4.50	9.71	24.53	-3.82	8.02	12.39	0.40	17.92	1.40	4.70
Rio Grande at Albuquerque 2/3/1987	50.0	4.50	9.71	24.53	-3.82	8.02	12.39	0.41	17.91	1.40	4.70
Rio Grande at Albuquerque 5/11/1988	50.0	4.50	9.71	24.53	-3.68	8.02	12.39	0.40	18.00	1.40	4.70
Rio Grande at Albuquerque 11/7/1988	50.0	4.49	9.71	24.53	-3.04	8.01	12.38	0.37	18.01	1.37	4.67
Rio Grande at Albuquerque 8/22/1995	50.0	4.50	9.71	24.53	-3.58	8.02	12.39	0.59	18.01	1.59	4.89

ground-water compositions, rhodochrosite and gibbsite were identified among mineral-precipitate samples from the Authority's current distribution system. Negative SIs for these same minerals for the surface-water compositions indicate that surface water would tend to dissolve these minerals, where present.

The one mineral from table 8 that has positive SIs for most surface-water compositions but negative SIs for most ground-water compositions is $\text{Fe}_3(\text{OH})_8$. If formation of this mineral is kinetically favorable, it could precipitate during delivery of surface water through the Authority's distribution system and subsequently dissolve when the primary source of water reverted to ground water during periods of high demand or drought. The resulting release of Fe into solution could adversely affect water color and taste. The modeling also indicates that at temperatures such as those found in residential water heaters some Mn oxides including birnessite and nsutite would tend to precipitate from surface water but tend to be dissolved by ground water. A change in water source from surface water to ground water could therefore result in the release of Mn into solution, potentially affecting the aesthetic characteristics of the water. Modeling indicates that ground-water compositions also could potentially dissolve Mn oxides even at lower temperatures if the less-oxygenated water from some wells did not become well enough equilibrated with atmospheric conditions to cause the SIs of the Mn oxides to be greater than 0 ± 0.1 .

As was done for the ground-water compositions, PHREEQC was used to estimate the likely quantity of mineral that would precipitate from or be dissolved by the simulated surface-water compositions. For each mineral listed in table 6, the maximum quantity that could potentially precipitate or dissolve per kilogram (kg) of water was estimated for all the surface-water compositions that had been simulated to undergo treatment at the treatment plant. Similar to the results for ground water, the simulations indicated that several minerals could potentially form about 5×10^{-3} to 1×10^{-2} mg of precipitate per kg of water. These were mostly the minerals containing Al, Cu, Mn, or Zn. Simulations involving calcite, aragonite, and chalcedony indicated that they could potentially form as much as about 1 to 10 mg of precipitate per kg of water for compositions with positive SIs, or dissolve as much as about 1 to 10 mg of mineral per kg of water for compositions with negative SIs. In contrast to ground water, most of the Fe-containing minerals showed the potential to form about the same magnitude of precipitate as calcite and aragonite, or about 3 orders of magnitude more Fe-containing precipitate than would form from ground water. The Fe-containing minerals could potentially form about 15 to 25 mg of precipitate per kg of water. Chemical modeling indicated that the relatively large potential quantity of Fe precipitates is a result of the addition of ferric chloride for coagulation during surface-water treatment. If such a large increase in the quantity of Fe-containing precipitates forming in the distribution system did occur during surface-water delivery, the ability of the distribution system to convey water could potentially be reduced over time in some areas by a reduction in the effective cross-sectional areas of the conveyance pipes. However, even

at about 30 mg of precipitate per kg of water, hematite would form no more than 5 cubic feet of precipitate per filling of a 6-million-gallon-capacity reservoir, covering a floor 150 feet in diameter to a depth of about 0.0037 inches.

Surface-water compositions simulated to have undergone treatment at the water-treatment plant were used to calculate corrosion indices for comparison with those calculated for ground water (table 7). Dissolved-solids concentrations used in the calculation of the LSIs and RSIs for the surface-water compositions were estimated using the results of the PHREEQC simulations (as opposed to the use of laboratory reported dissolved-solids concentrations for the ground-water compositions). In some cases, these estimated dissolved-solids concentrations may be slightly less than the values that would be measured in a laboratory because not all constituents are modeled in the PHREEQC simulations; however, any differences between estimated and measured dissolved-solids concentrations would have a fairly small effect on the calculated values of the corrosion indices. Two of the indices (LSI and RSI) had a larger range for ground water than they did for surface water. The LSIs for the surface-water compositions varied from -0.5 to 0.2, with all but two values being negative. These indices indicate that most of the surface-water compositions would be considered mildly corrosive—slightly more corrosive than most ground-water compositions. Calcite SIs are negative for 5 of the 8 surface-water compositions after simulation of water treatment, which is generally consistent with the LSI results (table 7). LKIs for the surface-water compositions range from 2.1 to 3.5, and RSIs range from 7.6 to 9.1. Both of these indices indicate that most or all of the surface-water compositions could be mildly to moderately corrosive. Overall, the corrosion indices appear to indicate that surface water could generally be slightly more corrosive than the ground water currently delivered through the Authority's distribution system. However, model simulations indicate that only a relatively small quantity of calcite might be dissolved by any of these surface-water compositions before the water reached equilibrium with calcite. As a result, calcite dissolution might not be sufficient to expose existing pipes to substantially increased corrosion.

Ground-Water/Surface-Water Mixtures

In PHREEQC simulations, each treated surface-water composition was mixed individually with each of the ground-water compositions that had been simulated to represent partial equilibration with atmospheric conditions. For minerals with a reasonable potential to form, the SIs that resulted from selected mixtures of the solutions in ratios of 9 to 1 and 1 to 9 are shown in table 9 (results are not shown for all 160 mixtures). As might be expected, the mixtures have positive SIs for most of the same minerals that the individual ground-water and surface-water compositions do, generally reflecting most closely the water source that makes up 90 percent of the mixture. In particular, mixtures that are mostly surface water tend to show no substantial differences from surface-water compositions in terms of the minerals that have mostly positive or mostly negative SIs (tables 8 and 9).

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.

[All mixtures incorporate ground-water samples simulated to be in partial equilibrium with atmospheric conditions and surface-water samples simulated to have undergone treatment at the proposed treatment plant. deg. C, degrees Celsius]

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	pH	aragonite	birnessite	calcite	chalcedony	cupric			diaspore
									ferrite	ferrite	cuprous ferrite	
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	8.00	0.16	6.26	0.30	0.00	18.86	6.39	1.30	
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	8.00	-0.28	8.57	-0.13	-0.07	17.97	5.49	1.49	
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	8.00	-0.43	9.60	-0.28	-0.02	17.56	5.08	1.39	
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	8.00	-0.24	9.92	-0.08	0.07	17.41	4.93	1.33	
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	8.00	-0.31	10.85	-0.15	0.12	17.02	4.54	1.14	
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	8.00	-0.11	7.36	0.03	-0.11	18.45	5.97	1.45	
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	8.00	0.01	8.32	0.16	0.01	18.33	5.86	1.49	
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	8.00	-0.06	6.79	0.08	-0.13	18.75	6.28	1.94	
Charles 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	8.06	0.16	6.80	0.30	0.09	15.99	4.71	1.25	
Charles 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	8.06	0.11	7.05	0.25	0.09	15.89	4.61	1.27	
Charles 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	8.07	0.10	7.16	0.24	0.09	15.85	4.57	1.27	
Charles 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	8.07	0.11	7.19	0.26	0.10	15.83	4.56	1.28	
Charles 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	8.07	0.11	7.28	0.25	0.11	15.79	4.52	1.28	
Charles 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	8.06	0.13	6.92	0.27	0.08	15.94	4.66	1.26	
Charles 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	8.06	0.14	7.02	0.28	0.09	16.02	4.74	1.27	
Charles 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	8.06	0.13	6.90	0.27	0.08	15.98	4.70	1.42	
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0	8.03	-0.16	12.04	0.01	0.28	16.53	4.04	0.86	
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0	8.01	-0.49	12.05	-0.32	0.10	16.55	4.06	0.86	
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0	8.01	-0.58	12.05	-0.41	0.10	16.56	4.06	0.86	
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0	8.00	-0.37	12.03	-0.20	0.18	16.55	4.06	0.86	
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0	8.00	-0.38	12.03	-0.21	0.18	16.55	4.06	0.86	
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0	8.01	-0.39	12.04	-0.22	0.12	16.54	4.05	0.86	
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0	8.01	-0.21	12.03	-0.04	0.19	16.83	4.34	0.86	
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0	8.02	-0.38	12.24	-0.22	0.14	16.55	4.05	1.44	
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0	7.92	0.41	0.72	0.57	-0.27	21.03	8.59	0.30	
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0	7.94	0.13	0.79	0.29	-0.46	21.07	8.63	0.30	
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0	7.94	0.05	0.81	0.21	-0.46	21.08	8.64	0.30	
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0	7.93	0.24	0.77	0.41	-0.38	21.05	8.61	0.31	
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0	7.93	0.23	0.77	0.39	-0.38	21.05	8.61	0.31	
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0	7.94	0.22	0.77	0.38	-0.44	21.05	8.61	0.30	
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0	7.92	0.38	0.74	0.55	-0.36	21.32	8.88	0.31	
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0	7.94	0.22	0.96	0.39	-0.42	21.05	8.61	0.88	

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	pH	aragonite	birnessite	calcite	chalcedony	cupric ferrite	cuprous ferrite	diaspore
Duranes 6	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	8.01	0.21	6.30	0.35	0.05	18.86	6.39	1.29
Duranes 6	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	8.02	-0.22	8.62	-0.07	0.01	17.96	5.49	1.48
Duranes 6	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	8.02	-0.36	9.65	-0.21	0.06	17.55	5.07	1.39
Duranes 6	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	8.02	-0.18	9.97	-0.03	0.14	17.40	4.92	1.33
Duranes 6	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	8.02	-0.25	10.90	-0.10	0.19	17.02	4.54	1.14
Duranes 6	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	8.02	-0.06	7.40	0.08	-0.03	18.44	5.97	1.44
Duranes 6	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	8.02	0.06	8.36	0.20	0.08	18.32	5.85	1.49
Duranes 6	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	8.02	-0.01	6.82	0.13	-0.06	18.74	6.27	1.92
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	8.21	0.50	7.41	0.64	0.41	15.92	4.67	1.13
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	8.22	0.47	7.68	0.61	0.42	15.81	4.57	1.15
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	8.22	0.46	7.80	0.60	0.42	15.77	4.53	1.16
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	8.22	0.47	7.82	0.61	0.43	15.75	4.52	1.16
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	8.22	0.46	7.92	0.61	0.43	15.71	4.48	1.17
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	8.21	0.48	7.54	0.62	0.41	15.87	4.62	1.14
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	8.21	0.48	7.64	0.62	0.42	15.94	4.70	1.15
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	8.21	0.48	7.49	0.62	0.41	15.90	4.66	1.30
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	2.0	8.34	0.36	12.16	0.53	0.64	13.99	2.78	0.67
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	2.0	8.35	0.33	12.16	0.50	0.63	13.99	2.78	0.67
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	2.0	8.35	0.33	12.16	0.50	0.63	13.99	2.79	0.67
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	2.0	8.34	0.34	12.15	0.51	0.63	13.99	2.79	0.67
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	2.0	8.34	0.34	12.14	0.51	0.63	13.99	2.79	0.67
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	2.0	8.34	0.34	12.16	0.51	0.63	13.99	2.78	0.67
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	2.0	8.34	0.35	12.14	0.52	0.63	14.11	2.90	0.67
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	2.0	8.35	0.34	12.19	0.51	0.63	13.99	2.78	0.84
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	50.0	7.96	0.65	0.37	0.82	0.08	18.61	7.35	0.09
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	50.0	7.97	0.63	0.38	0.79	0.07	18.61	7.36	0.09
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	50.0	7.97	0.63	0.38	0.79	0.07	18.61	7.36	0.09
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	50.0	7.97	0.64	0.37	0.80	0.08	18.61	7.36	0.09
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	50.0	7.97	0.64	0.37	0.80	0.08	18.61	7.36	0.09
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	50.0	7.97	0.64	0.38	0.80	0.07	18.61	7.35	0.09
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	50.0	7.96	0.65	0.37	0.81	0.08	18.72	7.47	0.09
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	50.0	7.97	0.64	0.42	0.80	0.07	18.61	7.35	0.26

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	pH	aragonite	birnessite	calcite	chalcedony	cupric ferrite	cuprous ferrite	diaspore
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	8.01	0.17	6.15	0.31	-0.01	18.90	6.44	1.27
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	8.01	-0.27	8.46	-0.13	-0.08	18.01	5.54	1.49
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	8.01	-0.43	9.49	-0.28	-0.03	17.61	5.13	1.41
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	8.01	-0.23	9.81	-0.08	0.06	17.45	4.97	1.35
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	8.01	-0.31	10.74	-0.15	0.11	17.07	4.59	1.17
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	8.01	-0.11	7.25	0.03	-0.12	18.49	6.02	1.43
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	8.01	0.02	8.21	0.16	0.00	18.37	5.90	1.49
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	8.01	-0.06	6.69	0.08	-0.14	18.79	6.32	1.91
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	8.18	-0.13	5.99	0.01	0.01	16.34	5.10	1.00
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	8.19	-0.28	6.26	-0.14	0.00	16.24	5.00	1.03
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	8.20	-0.33	6.37	-0.19	0.01	16.20	4.96	1.04
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	8.19	-0.26	6.39	-0.12	0.02	16.18	4.95	1.05
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	8.20	-0.28	6.48	-0.14	0.02	16.14	4.91	1.07
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	8.19	-0.25	6.12	-0.11	0.00	16.29	5.05	1.01
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	8.19	-0.19	6.22	-0.06	0.01	16.37	5.13	1.03
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	8.19	-0.26	6.11	-0.12	0.00	16.33	5.08	1.17
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0	8.03	-0.16	12.05	0.01	0.28	16.53	4.04	0.86
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0	8.01	-0.49	12.06	-0.32	0.10	16.55	4.06	0.86
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0	8.01	-0.59	12.07	-0.42	0.10	16.56	4.06	0.86
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0	8.01	-0.37	12.04	-0.20	0.17	16.54	4.05	0.86
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0	8.01	-0.39	12.04	-0.22	0.17	16.54	4.06	0.86
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0	8.02	-0.40	12.06	-0.23	0.12	16.54	4.05	0.86
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0	8.02	-0.21	12.04	-0.04	0.19	16.83	4.34	0.86
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0	8.02	-0.39	12.25	-0.22	0.14	16.54	4.05	1.44
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0	7.93	0.41	0.73	0.58	-0.28	21.02	8.58	0.30
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0	7.95	0.13	0.80	0.29	-0.46	21.06	8.62	0.29
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0	7.95	0.04	0.82	0.20	-0.46	21.07	8.63	0.29
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0	7.94	0.24	0.78	0.40	-0.38	21.05	8.61	0.30
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0	7.94	0.22	0.78	0.39	-0.38	21.04	8.61	0.30
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0	7.94	0.21	0.78	0.38	-0.44	21.05	8.61	0.29
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0	7.93	0.38	0.75	0.54	-0.37	21.32	8.88	0.31
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0	7.95	0.22	0.97	0.38	-0.42	21.05	8.60	0.87

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of		Simulated temperature (deg. C)	Fe(OH) _{2,7} Cl _{0,3}	Fe ₃ (OH) ₈	ferrihydrite	goethite	hematite	huntite	lepidocrocite	
		ground water to	surface water								maghemite	
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered		9.12	0.17	4.45	8.83	22.67	-4.97	7.97	12.29
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered		9.03	-0.38	4.45	8.49	21.95	-6.82	7.97	12.30
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered		9.03	-0.62	4.46	8.34	21.62	-7.73	7.98	12.31
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered		9.06	-0.72	4.45	8.28	21.50	-7.01	7.97	12.30
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered		9.06	-0.95	4.45	8.14	21.19	-7.45	7.97	12.30
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered		9.06	-0.08	4.45	8.67	22.34	-5.77	7.97	12.30
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered		9.06	-0.33	4.45	8.52	22.01	-5.56	7.97	12.30
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered		9.04	0.11	4.45	8.79	22.58	-5.39	7.97	12.30
Charles 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered		8.00	-2.75	3.50	7.69	20.37	-5.33	7.02	10.39
Charles 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered		7.97	-2.81	3.50	7.66	20.29	-5.52	7.02	10.39
Charles 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered		7.97	-2.83	3.50	7.64	20.25	-5.62	7.02	10.39
Charles 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered		7.97	-2.84	3.50	7.63	20.24	-5.55	7.02	10.39
Charles 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered		7.97	-2.87	3.50	7.62	20.21	-5.59	7.02	10.39
Charles 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered		7.97	-2.78	3.50	7.68	20.33	-5.41	7.02	10.39
Charles 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered		7.98	-2.80	3.50	7.66	20.30	-5.39	7.02	10.39
Charles 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered		7.97	-2.76	3.50	7.69	20.36	-5.37	7.02	10.39
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0		9.11	-1.28	4.45	7.95	20.79	-7.41	7.97	12.29
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0		9.03	-1.25	4.45	7.96	20.81	-8.40	7.97	12.30
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0		9.03	-1.24	4.46	7.96	20.81	-8.87	7.98	12.31
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0		9.06	-1.25	4.45	7.96	20.81	-7.99	7.97	12.30
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0		9.06	-1.24	4.45	7.96	20.81	-8.00	7.97	12.30
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0		9.06	-1.26	4.45	7.96	20.80	-7.84	7.97	12.30
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0		9.05	-1.26	4.45	7.95	20.80	-7.22	7.97	12.30
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0		9.03	-1.26	4.45	7.96	20.80	-7.76	7.97	12.30
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0		9.14	1.52	4.45	9.66	24.43	-3.30	7.97	12.29
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0		9.05	1.54	4.45	9.67	24.45	-4.10	7.97	12.30
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0		9.05	1.55	4.46	9.67	24.45	-4.54	7.98	12.31
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0		9.08	1.54	4.45	9.66	24.44	-3.74	7.97	12.30
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0		9.08	1.55	4.45	9.66	24.44	-3.74	7.97	12.30
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0		9.08	1.53	4.45	9.66	24.44	-3.59	7.97	12.30
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0		9.08	1.53	4.45	9.66	24.44	-3.04	7.97	12.29
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0		9.06	1.54	4.45	9.66	24.44	-3.51	7.97	12.30

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water		Simulated temperature (deg. C)		Fe(OH) _{2.7} Cl _{0.3}	Fe ₃ (OH) ₈	ferrihydrite	goethite	hematite	huntite	lepidocrocite	maghemite
Duranes 6	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	9.11	0.17	4.45	8.83	22.67	-4.69	7.97	12.29		
Duranes 6	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	9.03	-0.38	4.45	8.49	21.94	-6.44	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	9.02	-0.63	4.45	8.34	21.61	-7.29	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	9.05	-0.72	4.45	8.28	21.50	-6.67	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	9.06	-0.95	4.45	8.14	21.19	-7.10	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	9.05	-0.09	4.45	8.67	22.33	-5.45	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	9.05	-0.33	4.45	8.52	22.01	-5.29	7.97	12.29		
Duranes 6	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	9.03	0.10	4.45	8.79	22.58	-5.08	7.97	12.30		
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	7.93	-2.86	3.46	7.66	20.30	-2.93	6.98	10.32		
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	7.90	-2.93	3.46	7.62	20.21	-3.04	6.98	10.31		
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	7.90	-2.96	3.46	7.60	20.17	-3.09	6.98	10.31		
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	7.91	-2.96	3.46	7.59	20.16	-3.08	6.98	10.31		
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	7.91	-2.99	3.46	7.58	20.13	-3.11	6.98	10.31		
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	7.91	-2.89	3.46	7.64	20.26	-2.98	6.98	10.31		
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	7.91	-2.92	3.46	7.62	20.22	-2.99	6.98	10.32		
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	7.91	-2.87	3.46	7.65	20.29	-2.95	6.98	10.32		
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	2.0	7.83	-4.17	3.40	6.91	18.71	-4.42	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	2.0	7.81	-4.17	3.40	6.90	18.70	-4.45	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	2.0	7.81	-4.17	3.40	6.90	18.70	-4.47	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	2.0	7.82	-4.16	3.40	6.91	18.71	-4.45	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	2.0	7.82	-4.16	3.40	6.91	18.71	-4.45	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	2.0	7.81	-4.17	3.40	6.91	18.70	-4.43	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	2.0	7.82	-4.16	3.40	6.91	18.71	-4.41	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	2.0	7.81	-4.17	3.40	6.91	18.70	-4.42	6.92	10.20		
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	50.0	8.05	-1.07	3.50	8.72	22.55	-1.39	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	50.0	8.02	-1.06	3.50	8.72	22.55	-1.41	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	50.0	8.02	-1.06	3.50	8.72	22.55	-1.43	7.02	10.41		
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	50.0	8.03	-1.06	3.50	8.72	22.55	-1.40	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	50.0	8.03	-1.06	3.50	8.72	22.55	-1.40	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	50.0	8.03	-1.07	3.50	8.72	22.55	-1.39	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	50.0	8.03	-1.07	3.50	8.72	22.55	-1.37	7.02	10.40		
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	50.0	8.02	-1.07	3.50	8.72	22.55	-1.39	7.02	10.40		

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	Fe(OH) _{2.7} Cl _{0.3}	Fe ₃ (OH) ₈	ferrihydrite	goethite	hematite	huntite	lepidocrocite	maghemite
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	9.12	0.19	4.45	8.85	22.71	-4.90	7.97	12.29
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	9.03	-0.35	4.45	8.51	21.98	-6.74	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	9.03	-0.59	4.46	8.36	21.66	-7.67	7.98	12.31
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	9.06	-0.69	4.45	8.30	21.54	-6.94	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	9.06	-0.92	4.45	8.16	21.23	-7.38	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	9.06	-0.06	4.45	8.69	22.37	-5.69	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	9.06	-0.30	4.45	8.54	22.05	-5.49	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	9.04	0.13	4.45	8.81	22.62	-5.33	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	7.97	-2.59	3.47	7.82	20.64	-6.16	6.99	10.33
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	7.94	-2.66	3.46	7.78	20.56	-6.60	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	7.94	-2.68	3.46	7.76	20.52	-6.90	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	7.95	-2.69	3.46	7.76	20.51	-6.58	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	7.95	-2.71	3.46	7.74	20.48	-6.64	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	7.95	-2.62	3.46	7.80	20.60	-6.34	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	7.95	-2.64	3.46	7.78	20.57	-6.20	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	7.95	-2.60	3.46	7.81	20.63	-6.33	6.98	10.32
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0	9.11	-1.28	4.45	7.95	20.79	-7.38	7.97	12.29
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0	9.03	-1.25	4.45	7.96	20.81	-8.37	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0	9.03	-1.24	4.46	7.96	20.81	-8.87	7.98	12.31
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0	9.06	-1.25	4.45	7.96	20.80	-7.97	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0	9.06	-1.25	4.45	7.96	20.81	-7.99	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0	9.06	-1.26	4.45	7.95	20.80	-7.81	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0	9.05	-1.26	4.45	7.95	20.80	-7.20	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0	9.03	-1.26	4.45	7.96	20.80	-7.74	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0	9.14	1.52	4.45	9.66	24.43	-3.27	7.97	12.29
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0	9.05	1.54	4.45	9.67	24.45	-4.08	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0	9.05	1.55	4.46	9.67	24.45	-4.54	7.98	12.31
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0	9.08	1.54	4.45	9.66	24.44	-3.72	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0	9.08	1.55	4.45	9.66	24.44	-3.73	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0	9.08	1.54	4.45	9.66	24.44	-3.56	7.97	12.30
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0	9.08	1.53	4.45	9.66	24.44	-3.02	7.97	12.29
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0	9.06	1.54	4.45	9.66	24.44	-3.49	7.97	12.30

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	manganite	Mg-ferrite	nsutite	pyrolusite
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	3.93	14.20	6.85	8.48
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	5.44	12.56	9.16	10.09
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	6.11	11.74	10.19	10.80
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	6.30	11.61	10.51	11.02
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	6.90	10.95	11.44	11.66
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	4.65	13.48	7.94	9.25
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	5.27	12.83	8.91	9.91
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	4.35	14.01	7.38	8.91
Charles 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	4.26	11.34	7.38	8.63
Charles 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	4.44	11.16	7.64	8.81
Charles 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	4.51	11.07	7.75	8.89
Charles 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	4.53	11.06	7.78	8.91
Charles 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	4.59	10.99	7.87	8.97
Charles 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	4.35	11.26	7.51	8.72
Charles 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	4.41	11.19	7.61	8.79
Charles 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	4.36	11.32	7.49	8.73
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0	7.66	10.20	12.63	12.48
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0	7.67	10.11	12.63	12.49
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0	7.68	10.01	12.64	12.50
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0	7.66	10.12	12.62	12.47
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0	7.65	10.11	12.61	12.47
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0	7.66	10.20	12.63	12.49
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0	7.65	10.24	12.61	12.47
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0	7.86	10.21	12.83	12.68
Charles 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0	0.32	17.83	1.31	4.61
Charles 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0	0.39	17.82	1.38	4.68
Charles 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0	0.41	17.72	1.40	4.69
Charles 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0	0.37	17.80	1.35	4.65
Charles 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0	0.37	17.80	1.35	4.65
Charles 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0	0.37	17.89	1.36	4.66
Charles 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0	0.34	17.89	1.33	4.62
Charles 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0	0.55	17.90	1.55	4.85

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	manganite	Mg-ferrite	nsutite	pyrolusite
Duranes 6	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	3.96	14.26	6.88	8.51
Duranes 6	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	5.48	12.63	9.20	10.14
Duranes 6	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	6.15	11.83	10.23	10.85
Duranes 6	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	6.35	11.68	10.55	11.06
Duranes 6	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	6.95	11.02	11.49	11.71
Duranes 6	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	4.69	13.54	7.98	9.29
Duranes 6	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	5.31	12.89	8.95	9.95
Duranes 6	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	4.38	14.07	7.41	8.95
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	4.88	11.94	8.00	9.25
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	5.07	11.78	8.27	9.44
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	5.14	11.71	8.38	9.52
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	5.16	11.68	8.41	9.54
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	5.22	11.62	8.51	9.61
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	4.97	11.87	8.13	9.35
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	5.04	11.80	8.23	9.41
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	4.94	11.93	8.07	9.32
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	2.0	8.01	8.92	12.74	12.60
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	2.0	8.02	8.92	12.75	12.60
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	2.0	8.02	8.92	12.75	12.60
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	2.0	8.01	8.92	12.73	12.59
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	2.0	8.01	8.92	12.73	12.58
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	2.0	8.02	8.92	12.75	12.60
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	2.0	8.01	8.92	12.73	12.59
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	2.0	8.05	8.93	12.78	12.64
Duranes 6	Rio Grande at Albuquerque 8/16/1971	9:1	50.0	0.21	16.20	0.96	4.26
Duranes 6	Rio Grande at Albuquerque 5/3/1982	9:1	50.0	0.22	16.21	0.97	4.27
Duranes 6	Rio Grande at Albuquerque 7/15/1986	9:1	50.0	0.22	16.21	0.97	4.27
Duranes 6	Rio Grande at Albuquerque 11/7/1986	9:1	50.0	0.21	16.21	0.96	4.26
Duranes 6	Rio Grande at Albuquerque 2/3/1987	9:1	50.0	0.21	16.21	0.95	4.25
Duranes 6	Rio Grande at Albuquerque 5/11/1988	9:1	50.0	0.22	16.21	0.97	4.27
Duranes 6	Rio Grande at Albuquerque 11/7/1988	9:1	50.0	0.21	16.21	0.96	4.26
Duranes 6	Rio Grande at Albuquerque 8/22/1995	9:1	50.0	0.25	16.22	1.00	4.30

Table 9. Saturation indices for selected minerals, as calculated by PHREEQC for selected ground-water/surface-water mixtures.—Continued

Ground-water sample source (from table 1)	Surface-water sample source (from table 2)	Simulated ratio of ground water to surface water	Simulated temperature (deg. C)	manganite	Mg-ferrite	nsutite	pyrolusite
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	unaltered	3.86	14.27	6.74	8.41
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	unaltered	5.37	12.63	9.05	10.02
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	unaltered	6.04	11.80	10.08	10.73
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	unaltered	6.24	11.68	10.40	10.94
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	unaltered	6.83	11.02	11.32	11.58
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	unaltered	4.58	13.55	7.84	9.18
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	unaltered	5.20	12.91	8.80	9.84
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	unaltered	4.29	14.08	7.27	8.84
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	9:1	unaltered	3.83	11.70	6.58	8.15
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	9:1	unaltered	4.01	11.47	6.84	8.34
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	9:1	unaltered	4.09	11.33	6.96	8.42
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	9:1	unaltered	4.10	11.39	6.98	8.43
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	9:1	unaltered	4.16	11.32	7.07	8.49
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	9:1	unaltered	3.92	11.62	6.71	8.24
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	9:1	unaltered	3.98	11.58	6.80	8.30
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	9:1	unaltered	3.93	11.67	6.70	8.25
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	2.0	7.67	10.20	12.64	12.49
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	2.0	7.68	10.10	12.65	12.50
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	2.0	7.69	9.99	12.65	12.51
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	2.0	7.67	10.11	12.63	12.48
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	2.0	7.67	10.10	12.62	12.48
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	2.0	7.68	10.19	12.64	12.50
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	2.0	7.66	10.23	12.62	12.48
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	2.0	7.87	10.20	12.84	12.69
Leavitt 2	Rio Grande at Albuquerque 8/16/1971	1:9	50.0	0.32	17.82	1.32	4.61
Leavitt 2	Rio Grande at Albuquerque 5/3/1982	1:9	50.0	0.40	17.80	1.38	4.68
Leavitt 2	Rio Grande at Albuquerque 7/15/1986	1:9	50.0	0.42	17.70	1.40	4.70
Leavitt 2	Rio Grande at Albuquerque 11/7/1986	1:9	50.0	0.38	17.79	1.36	4.66
Leavitt 2	Rio Grande at Albuquerque 2/3/1987	1:9	50.0	0.38	17.79	1.36	4.66
Leavitt 2	Rio Grande at Albuquerque 5/11/1988	1:9	50.0	0.38	17.88	1.37	4.67
Leavitt 2	Rio Grande at Albuquerque 11/7/1988	1:9	50.0	0.34	17.89	1.33	4.63
Leavitt 2	Rio Grande at Albuquerque 8/22/1995	1:9	50.0	0.56	17.89	1.55	4.85

As a result of these similarities, the list of minerals that might reasonably dissolve or newly precipitate as the result of a change in water source between a ground-water/surface-water mixture and ground water or surface water alone is the same as the list previously discussed for a change between ground water and surface water. That is, aragonite, calcite, chalcedony, and perhaps $\text{Fe}_3(\text{OH})_8$ appear to be the primary minerals that might dissolve or newly precipitate within the distribution system when the source of water is changed. Again, of these minerals, only aragonite and calcite have been positively identified among mineral precipitates present in the Authority's current distribution system. When heated to 50°C , the ground-water/surface-water mixtures also have positive SIs for some Mn oxides that have negative SIs for ground-water compositions at this temperature. Therefore, precipitation of Mn oxides (followed by dissolution upon a change in water source) could potentially occur if kinetics of the reactions were favorable.

PHREEQC was used to estimate the likely quantity of mineral that would precipitate from or be dissolved by the simulated ground-water/surface-water compositions. Model simulations indicated that the quantity of most minerals precipitated from or dissolved by a ground-water/surface-water mixture compared to ground water or surface water alone would likely be somewhat larger (about one-half to one order of magnitude). For the iron minerals, the quantity precipitated from any mixture would be closer to the quantity precipitated from surface water alone than from ground water alone; for mixtures that are mostly surface water, the quantity precipitated could be as much as one order of magnitude higher than for surface water alone.

Corrosion indices calculated for selected ground-water/surface-water mixtures are shown in table 7. Dissolved-solids concentrations for calculation of the LSIs and RSIs were estimated from PHREEQC output. As expected, the values of all corrosion indices for the mixtures are within the range of values obtained for ground-water and surface-water compositions alone. The values calculated for the mixtures closely reflect the values calculated for the type of water composing the bulk of the mixture. Because most surface-water compositions were found to have corrosion indices indicating a slightly greater potential for corrosion compared to most ground-water compositions, most ground-water/surface-water mixtures also have corrosion indices indicating a slightly greater corrosion potential compared to most ground-water compositions. The calcite SIs simulated for the mixtures in table 7 are consistent with this conclusion.

Potential Chemical Effects of Changes in the Source of Water Supply on the Distribution System

Based on modeled SIs and kinetic considerations, solid phases that appear most likely to either dissolve or newly precipitate under assumed distribution-system conditions when

surface water or ground-water/surface-water mixes are delivered through the current distribution system are carbonates (particularly aragonite and calcite). Other types of minerals with some potential to dissolve or newly precipitate are a form of silica, the Fe-containing mineral $\text{Fe}_3(\text{OH})_8$, and an aluminum hydroxide (gibbsite or diaspore). Dissolution of most of these minerals (except the Fe-containing minerals) is not likely to substantially affect trace-element concentrations or aesthetic characteristics of delivered water and would probably be of concern only if the quantities of material precipitated were large enough to clog pipes or fixtures. PHREEQC calculations do indicate that somewhat larger masses of material would precipitate from surface water or ground-water/surface-water mixtures compared to ground water alone. Dissolution of the increased mass of Fe-containing minerals precipitated in the system could potentially result in discoloration of delivered water and even have some effect on trace-element concentrations, depending on the elements that co-precipitated with or sorbed to the minerals.

Under some conditions (particularly, when water is heated), Mn oxides might newly precipitate from surface water or ground-water/surface-water mixtures and subsequently re-dissolve when ground water is the primary source of supply, possibly affecting both trace-element concentrations and aesthetic characteristics of delivered water. X-ray diffraction data did not show the presence of Mn oxides in any parts of the current distribution system (even at temperatures at which SIs for manganese oxides in ground water are positive). However, the presence of Mn oxides may not be evident from x-ray diffraction, making it unclear whether precipitation of these minerals is kinetically favored under the conditions present. One Mn-containing mineral, rhodochrosite, was identified in the current distribution system despite having negative SIs for all ground-water compositions. This mineral would tend to dissolve when the primary source of supply changed to surface water.

Based on modeled SIs for calcite combined with calculations of corrosion indices, treated San Juan-Chama water from the Rio Grande does not appear likely to be highly corrosive under most conditions, although some samples have corrosion indices indicative of mild to moderate corrosivity. The results for ground-water/surface-water mixes were similar to those for surface water; the calcite SIs in particular indicated that the mixtures would not be likely to result in substantial calcite dissolution.

Summary

Chemical modeling was used by the U.S. Geological Survey, in cooperation with the Albuquerque Bernalillo County Water Utility Authority, to estimate the potential chemical effects that could occur in the Authority's water distribution system as a result of changing the source of water used for municipal and industrial supply. A variety of water samples selected to represent the chemistry of ground water currently (2005) delivered by the Authority and of surface water that will be delivered starting in 2008 were modeled in

the software package PHREEQC. The samples were modeled under a variety of conditions (particularly temperature and atmospheric-gas pressures) assumed to be present in various parts of the distribution system. The surface-water samples also were modeled to undergo the treatment processes projected to occur at the new water treatment plant. Minerals identified as having positive SIs for the simulated ground-water compositions were compared with minerals identified in precipitate samples collected from pipes, reservoirs, and one water heater associated with the current distribution system. Minerals identified as having positive SIs also were compared between the simulated ground-water and surface-water compositions, and among these compositions and ground-water/surface-water mixtures modeled using them. Analysis focused on minerals that were kinetically favored to form. Quantities of potential precipitate formation and indicators of corrosion potential also were compared among ground-water compositions, surface-water compositions, and ground-water/surface-water mixtures.

For the simulated ground-water compositions, minerals that included at least one positive SI and had favorable kinetics for forming substantial quantities of precipitate within the Authority's distribution system were:

- calcium carbonate (aragonite or calcite); and
- a form of iron oxide or hydroxide (ferrihydrite, goethite, hematite, lepidocrocite, maghemite).

Other minerals with positive SIs but uncertain kinetics of formation were a form of silica (chalcedony), a calcium/magnesium carbonate (huntite), an aluminum hydroxide (gibbsite or diaspore), and various forms of Mn, Cu, and Zn. Minerals with positive SIs that were unlikely to form because of known kinetic limitations included feldspars, zeolites, clays, and crystalline silica. Of the minerals simulated to have positive SIs, the ones identified in mineral-precipitate samples from the Authority's distribution system were aragonite, calcite, goethite, hematite, and lepidocrocite. Also identified were amorphous forms of Fe or Fe oxyhydroxides. Two minerals, rhodochrosite and gibbsite, that did not have positive SIs for the simulated ground-water compositions also were identified in the distribution system; these minerals may have been transported into the system.

The minerals with positive SIs for the simulated surface-water compositions and the simulated ground-water/surface-water mixtures were quite similar to the minerals with positive SIs for the simulated ground-water compositions. Therefore, based on the modeled SIs and kinetic considerations, minerals that appear most likely to either dissolve or newly precipitate under assumed distribution-system conditions when surface water or ground-water/surface-water mixtures are delivered through the current distribution system are carbonates (particularly aragonite and calcite). Other types of minerals with some potential to dissolve or newly precipitate are a form of silica (particularly chalcedony), the Fe-containing mineral $\text{Fe}_3(\text{OH})_8$, an aluminum hydroxide (gibbsite or diaspore), and a Mn oxide (particularly birnessite or nsutite). Dissolution of most of these minerals (except the Fe- or Mn-containing minerals) is

not likely to substantially affect trace-element concentrations or aesthetic characteristics of delivered water, except perhaps hardness. These minerals would probably be of concern only if the quantities of material precipitated were large enough to clog pipes or fixtures. Some Fe-containing minerals that were identified in the Authority's distribution system were associated with relatively high contents of some metals, including As, Cr, Cu, Mn, Pb, and Zn. However, these Fe-containing minerals were not identified as minerals likely to dissolve when the source of water was changed from ground water to surface water or a ground-water/surface-water mixture.

PHREEQC calculations indicate that somewhat larger masses of material would precipitate from surface water or ground-water/surface-water mixtures compared to ground water alone. If dissolution of the increased mass of Fe-containing minerals precipitated in the system was to occur, aesthetic characteristics and trace-element concentrations of delivered water could potentially be adversely affected.

Based on modeled SIs for calcite and additional calculations of corrosion indices (the Langelier Saturation Index, Ryznar Stability Index, and Larson-Skold Index), ground water, surface water, and ground-water/surface-water mixtures are likely to differ only slightly in corrosion potential. Most corrosion indices indicate that surface water and ground-water/surface-water mixtures could be somewhat more corrosive in general than ground-water compositions. However, simulated calcite SIs show that there should not be a great potential for surface water or ground-water/surface-water mixtures to dissolve large quantities of existing calcite and expose pipes to substantially increased corrosion.

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Appendix

Appendix

TITLE Master model

#This file shows PHREEQC input for at least one example of every type of model calculation conducted for the study:

#-Representative surface-water (SW) compositions (numbers 11-18) are defined

#-Representative ground-water (GW) compositions (numbers 80-89) are defined

#-Treatment of representative SW samples is simulated as described in specifications for the proposed SW plant

#-GW samples are simulated at conditions closer to atmospheric equilibrium

#-A selected GW sample near atmospheric equilibrium is mixed with all treated SW samples using a specified ratio

#-Resulting water mixtures are heated and cooled

#-Mixtures are brought into equilibrium with a selected mineral to determine the maximum quantity of precipitate

#

#Selected output for all model calculations is shown, including saturation indices (SIs) for selected minerals.

#chemical parameters needed to perform corrosion calculations, and precipitate mass from equilibrium calculations

#

#The user needs to specify the selected GW solution for mixing, the desired mixing ratio,

#and the selected mineral for equilibration and subsequent output of mass precipitated

#

SOLUTION_SPREAD

-units mg/l

-redox O(0)/O(-2)

Number	Alkalinity		As	Ca	Cl	F	Fe	eh	pH	temperature		K	Mg	
	Mn	Na	N(5)	Si	S(6)	Al	Cu	Zn	O(0)	pe	Description			
11	163	0.003	70	37	0.7	0.012		7.7	25.5	5.9	9	0.004	60	
28	150	0.005	0.002	0.005	7	12.8640	RGABQ8/16/1971							
12	110	0.002	37	5.6	0.4	0.009		8.3	15	2.9	6.7	0.004	16	
17	68	0.005	0.002	0.005	8.3	13.1808	RGABQ5/3/1982							
13	99	0.003	28	4.5	0.2	0.02		7.8	10.5	3.1	4.9	0.004	17	
17	45	0.005	0.002	0.005	7.6	14.0767	RGABQ7/15/1986							
14	135	0.003	42	12	0.4	0.014		8.05	9	3.4	7	0.004	27	
21	59	0.005	0.002	0.003	9.6	13.9901	RGABQ11/7/1986							
15	134	0.003	39	14	0.4	0.012		7.9	5	2.8	6.9	0.004	23	
21	61	0.005	0.002	0.005	11.5	14.5351	RGABQ2/3/1987							
16	143	0.003	41	13	0.5	0.01		8.7	20.5	2.6	8.5	0.004	32	
18	76	0.005	0.002	0.005	7.9	12.2968	RGABQ5/11/1988							
17	183	0.004	53	13	0.4	0.01		8.46	16	3.8	9.7	0.004	33	
22	73	0.005	0.004	0.005	8.3	12.9325	RGABQ11/7/1988							
18	141	0.003	37	7.6	0.4	0.012		7.81	24	3.2	8.3	0.006	24	
19	57	0.02	0.002	0.001	7	12.8783	RGABQ8/22/1995							
80	135	0.002	41.07	11.3	0.58	0.007	0.176	7.64	19	1.64	3.9	0.001	23.32	
0.44	31.41	35.7	0.003	0.0005	0.0066			Charles2						
81	205	0.004	51.58	14.1	0.46	0.021	0.131	7.48	19	9.51	12.09	0.003	42.5	
0.05	69.62	96	0.003	0.0005	0.001			Duranes6						
82	179	0.033	4.42	18.2	1.44	0.003	0.185	8.85	23.8	1.18	0.49	0.001	102.4	
1.28	29.1	65	0.003	0.0005	0.001			Leavitt2						
83	133	0.002	37.91	24.3	0.6	0.010	0.161	7.73	22.7	2.81	2.98	0.001	26.9	
0.32	28.1	19.4	0.003	0.0005	0.001			Love5						
84	130	0.021	33.63	37.8	0.74	0.011	0.138	7.76	25.7	7.39	7.42	0.001	40.14	
0.22	67.24	43.6	0.003	0.0005	0.0067			Miles1						
85	182	0.002	49.4	11.5	0.58	0.003	0.204	7.35	22.5	2.11	7.6	0.001	28.67	
0.87	28.2	55.4	0.003	0.0005	0.001			Ridgecrest1						
86	157	0.006	60.99	62.4	0.51	0.018	0.067	7.45	23.3	3	4.71	0.009	40.84	
0.18	35.18	31.3	0.003	0.0005	0.012			Thomas6						
87	123	0.008	47.12	19.6	0.48	0.003	0.180	7.91	18	2.67	5.69	0.001	18.25	
0.72	36.7	50.4	0.003	0.0005	0.001			VolAndia3						
88	174	0.036	39.54	87.4	1.19	0.013	0.109	7.75	28.7	4.83	5.63	0.018	77.3	
0.05	41.5	37.2	0.003	0.0005	0.001			Walker2						
89	158	0.014	20.15	9.33	0.72	0.003	0.206	7.88	24.3	6.43	3.37	0.001	58.02	
0.86	70.1	54.6	0.003	0.0005	0.001			Zamora1						

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SELECTED_OUTPUT

```
-file AllOutput.txt
#
#Output of SIs for all minerals with SI greater than 0.1 for at least one GW or SW composition
#
-si      albite(low) analbite analcime annite aragonite birnessite bixbyite\
        Ca-nontronite calcite chalcedony chrysotile CO2(g) cristobalite\
        CupricFerrite CuprousFerrite diaspore diopside dolomite Fe(OH)2.7Cl0.3\
        Fe3(OH)8 ferrihydrite gibbsite(C) goethite halloysite hausmannite\
        hematite huntite jarosite-K K-nontronite kaolinite laumontite leonhardite\
        lepidocrocite maghemite magnesite magnetite manganite Mg-ferrite Mg-nontronite\
        microcline montmorillonite muscovite Na-nontronite nsutite O2(g)\
        pyrolusite pyrophyllite quartz rhodochrosite sanidine(H) sepiolite(c) talc tremolite willemite ZnSiO3
#
#Output for calculating corrosion indices
#
-ph      true
-temperature      true
-alkalinity      true
-ionic_strength   true
-totals   Al As C Ca Cl Cu F Fe K Mg Mn N Na S Si Zn
-molalities      Ca+2 Cl- SO4-2
#
#Output for determining mass of precipitate
#
-equilibrium_phases      calcite
```

PHASES

```
Fix_H+
H+ = H+
log_k 0
```

#Simulate treatment plant processes

```
#
#Add ferric chloride to SW at quantity indicated by design plans (avg 30 mg/L),
#along with sulfuric acid sufficient to bring the pH down to 6
#
```

```

USE SOLUTION 11
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 21
END

```

```

USE SOLUTION 12
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 22
END

```

```

USE SOLUTION 13
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 23
END

```

```

USE SOLUTION 14
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 24
END

```

```

USE SOLUTION 15
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 25
END

```

```

USE SOLUTION 16
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 26
END

```

```

USE SOLUTION 17

```

```

REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 27
END

```

```

USE SOLUTION 18
REACTION 1 Add ferric chloride
    FeCl3
    0.185 mmol
EQUILIBRIUM_PHASES
    Fix_H+ -6.0 H2SO4 10.
SAVE SOLUTION 28
END

```

```

#
#Add 1.5 mg/L of O3, plus avg. H2O2 dose of 0.2 mg/L, plus
O2 sufficient to
#bring largest DO up near 24 mg/L (as indicated in design
plans). Also add
#some organic matter to oxidize (about 0.6 mg/L)
#

```

```

USE SOLUTION 21
REACTION 2 Add O3, O2, H2O2 and organic matter
    O2
    H2O2 .017
    O3 .086
    CH2O .056
    0.360 mmol
SAVE SOLUTION 31
END

```

```

USE SOLUTION 22
REACTION 2 Add O3, O2, H2O2 and organic matter
    O2
    H2O2 .017
    O3 .086
    CH2O .056
    0.360 mmol
SAVE SOLUTION 32
END

```

```

USE SOLUTION 23
REACTION 2 Add O3, O2, H2O2 and organic matter
    O2
    H2O2 .017
    O3 .086
    CH2O .056
    0.360 mmol
SAVE SOLUTION 33
END

```

```

USE SOLUTION 24
REACTION 2 Add O3, O2, H2O2 and organic matter

```

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O2
H2O2 .017
O3 .086
CH2O .056
0.360 mmol
SAVE SOLUTION 34
END

USE SOLUTION 25
REACTION 2 Add O3, O2, H2O2 and organic matter
O2
H2O2 .017
O3 .086
CH2O .056
0.360 mmol
SAVE SOLUTION 35
END

USE SOLUTION 26
REACTION 2 Add O3, O2, H2O2 and organic matter
O2
H2O2 .017
O3 .086
CH2O .056
0.360 mmol
SAVE SOLUTION 36
END

USE SOLUTION 27
REACTION 2 Add O3, O2, H2O2 and organic matter
O2
H2O2 .017
O3 .086
CH2O .056
0.360 mmol
SAVE SOLUTION 37
END

USE SOLUTION 28
REACTION 2 Add O3, O2, H2O2 and organic matter
O2
H2O2 .017
O3 .086
CH2O .056
0.360 mmol
SAVE SOLUTION 38
END

#Allow CO2 removal from SW assuming 75% efficiency as
indicated by design plans,
#and drop O2 back to near 10 mg/L

USE SOLUTION 31
EQUILIBRIUM_PHASES 1
CO2(g) -1.85

O2(g) -0.52
SAVE SOLUTION 41
END

USE SOLUTION 32
EQUILIBRIUM_PHASES 1
CO2(g) -2.09
O2(g) -0.52
SAVE SOLUTION 42
END

USE SOLUTION 33
EQUILIBRIUM_PHASES 1
CO2(g) -2.15
O2(g) -0.52
SAVE SOLUTION 43
END

USE SOLUTION 34
EQUILIBRIUM_PHASES 1
CO2(g) -2.04
O2(g) -0.52
SAVE SOLUTION 44
END

USE SOLUTION 35
EQUILIBRIUM_PHASES 1
CO2(g) -2.07
O2(g) -0.52
SAVE SOLUTION 45
END

USE SOLUTION 36
EQUILIBRIUM_PHASES 1
CO2(g) -1.97
O2(g) -0.52
SAVE SOLUTION 46
END

USE SOLUTION 37
EQUILIBRIUM_PHASES 1
CO2(g) -1.88
O2(g) -0.52
SAVE SOLUTION 47
END

USE SOLUTION 38
EQUILIBRIUM_PHASES 1
CO2(g) -1.92
O2(g) -0.52
SAVE SOLUTION 48
END

#

#Add NaOCl at 4 mg/L, H₂SiF₆ at 1 mg/L, and hydrated lime sufficient to bring pH to 8

#

USE SOLUTION 41

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 51

END

USE SOLUTION 42

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 52

END

USE SOLUTION 43

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 53

END

USE SOLUTION 44

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 54

END

USE SOLUTION 45

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 55

END

USE SOLUTION 46

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 56

END

USE SOLUTION 47

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 57

END

USE SOLUTION 48

REACTION 3 Add NaOCl and H₂SiF₆

NaOCl

H₂SiF₆ 0.130

0.054 mmol

EQUILIBRIUM_PHASES

Fix_H+ -8.0 Ca(OH)₂ 10.

SAVE SOLUTION 58

END

#

#Bring GW samples closer to equilibration with atmospheric conditions

#

USE SOLUTION 80

EQUILIBRIUM_PHASES 1

CO₂(g) -3.0

O₂(g) -5.0

SAVE SOLUTION 90

END

USE SOLUTION 81

EQUILIBRIUM_PHASES 1

CO₂(g) -3.0

O₂(g) -5.0

SAVE SOLUTION 91

END

USE SOLUTION 82

EQUILIBRIUM_PHASES 1

CO₂(g) -3.0

O₂(g) -5.0

SAVE SOLUTION 92

END

USE SOLUTION 83

EQUILIBRIUM_PHASES 1

CO₂(g) -3.0

O₂(g) -5.0

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SAVE SOLUTION 93
END

USE SOLUTION 84
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 94
END

USE SOLUTION 85
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 95
END

USE SOLUTION 86
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 96
END

USE SOLUTION 87
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 97
END

USE SOLUTION 88
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 98
END

USE SOLUTION 89
EQUILIBRIUM_PHASES 1
CO2(g) -3.0
O2(g) -5.0
SAVE SOLUTION 99
END

#Mix treated SW with selected GW

MIX 1 Mixing treated RGABQ8/16/1971 with Charles 2
51 9.0
90 1.0
SAVE SOLUTION 201
END

MIX 2 Mixing treated RGABQ5/3/1982 with Charles 2
52 9.0
90 1.0

SAVE SOLUTION 202
END

MIX 3 Mixing treated RGABQ7/15/1986 with Charles 2
53 9.0
90 1.0

SAVE SOLUTION 203
END

MIX 4 Mixing treated RGABQ11/7/1986 with Charles 2
54 9.0
90 1.0

SAVE SOLUTION 204
END

MIX 5 Mixing treated RGABQ2/3/1987 with Charles 2
55 9.0
90 1.0

SAVE SOLUTION 205
END

MIX 6 Mixing treated RGABQ5/11/1988 with Charles 2
56 9.0
90 1.0

SAVE SOLUTION 206
END

MIX 7 Mixing treated RGABQ11/7/1988 with Charles 2
57 9.0
90 1.0

SAVE SOLUTION 207
END

MIX 8 Mixing treated RGABQ8/22/1995 with Charles 2
58 9.0
90 1.0

SAVE SOLUTION 208
END

#Heat SW/GW mixture
#

USE SOLUTION 201
REACTION_TEMPERATURE 1
50.0

SAVE SOLUTION 301
END

USE SOLUTION 202
REACTION_TEMPERATURE 1
50.0

SAVE SOLUTION 302


```

END

USE SOLUTION 203
REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 303
END

USE SOLUTION 204

REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 304
END

USE SOLUTION 205
REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 305
END

USE SOLUTION 206
REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 306
END

USE SOLUTION 207
REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 307
END

USE SOLUTION 208
REACTION_TEMPERATURE 1
    50.0
SAVE SOLUTION 308
END

#
#Cool SW/GW mixture
#
USE SOLUTION 201
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 401
END

USE SOLUTION 202
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 402
END

USE SOLUTION 203
REACTION_TEMPERATURE 1

```

```

    2.0
SAVE SOLUTION 403
END

USE SOLUTION 204

REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 404
END

USE SOLUTION 205
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 405
END

USE SOLUTION 206
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 406
END

USE SOLUTION 207
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 407
END

USE SOLUTION 208
REACTION_TEMPERATURE 1
    2.0
SAVE SOLUTION 408
END

#
#Calculate mass of selected precipitate for heated mix
#
USE SOLUTION 301
EQUILIBRIUM_PHASES 4
    calcite 0.0
SAVE SOLUTION 501
END

USE SOLUTION 302
EQUILIBRIUM_PHASES 4
    calcite 0.0
SAVE SOLUTION 502
END

USE SOLUTION 303
EQUILIBRIUM_PHASES 4
    calcite 0.0
SAVE SOLUTION 503
END

```

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USE SOLUTION 304
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 504
END

USE SOLUTION 305
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 505
END

USE SOLUTION 306
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 506
END

USE SOLUTION 307
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 507
END

USE SOLUTION 308
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 508
END

#Calculate mass of selected precipitate for cooled mix
#

USE SOLUTION 401
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 601
END

USE SOLUTION 402
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 602
END

USE SOLUTION 403
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 603
END

USE SOLUTION 404
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 604
END

USE SOLUTION 405
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 605
END

USE SOLUTION 406
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 606
END

USE SOLUTION 407
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 607
END

USE SOLUTION 408
EQUILIBRIUM_PHASES 4
 calcite 0.0
SAVE SOLUTION 608
END

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