Chapter 6: Chemical characteristics of water in the aquifer system

Water quality affects the daily lives of everyone and thus is one of the most important topics addressed in water-supply studies. Concerns about the quality and safety of the Nation's water have led to the growth of a large industry devoted to filtering, treating, or bottling water for domestic use and human consumption. Not only is everyone aware of the effects of water quality on taste and plumbing fixtures, water-quality and water-contamination stories are now commonplace in the news media.

Because the Middle Rio Grande Basin Study was primarily concerned with understanding the physical aspects of the ground-water system, water-quality data for the study were collected for this purpose. However, ground- and surface-water sampling for the study has allowed the most complete and areally extensive view of water quality in the Middle Rio Grande Basin to date. The use of water quality for ground-water age dating and the definition of flow paths and traveltimes has made a large contribution to the understanding of the ground-water-flow system (see Boxes *I* and *K*). In addition, water-quality data for the Middle Rio Grande Basin Study adds to our knowledge of whether water in a particular area of the aquifer is suitable for a particular use (including human consumption) and whether human activities may be adversely affecting ground-water quality.

General quality of ground water and what it reveals about the ground-water system

In the same way that the geology of the Santa Fe Group aquifer system varies areally and with depth, so do the chemical properties of ground water in the aquifer. This variation is due to many factors including where water enters the aquifer, the distance it travels and the rock types it contacts within the aquifer, and human activity. Ground-water samples collected from 275 wells and analyzed by Plummer and others (2001) showed significant variation in many water-quality constituents and properties. Concentrations of some chemical constituents or properties in water varied over several factors of 10. This wide variation makes it difficult to generalize water quality in the basin as a whole.

A useful approach to characterizing ground-water quality in the Middle Rio Grande Basin is to divide the basin into zones of different water-quality (or hydrochemical) characteristics (Anderholm, 1988; Logan, 1990; Plummer and others, 2001). Plummer and others (2001) defined 13 hydrochemical zones by using analyses of ground-water samples from 275 different wells and springs (fig. 6.1), resulting in the most areally comprehensive water-quality study to date in the Middle Rio

A small truck-mounted soil-probing machine used in the Middle Rio Grande Basin to sample shallow ground water. The size and portability of this unit allow for the collection of more data with less disturbance.

K

How ground-water chemistry helps us understand the aquifer

L. Niel Plummer,[1] Laura M. Bexfield,[2] and Scott K. Anderholm[2]

Although water is commonly thought of as simply H_2O, literally thousands of other substances are dissolved in water in the environment. Most of these substances occur naturally, and many are present in water in only small quantities. The term "water chemistry" (or water quality) refers to the quantities of these various substances (commonly called solutes) that are present in a particular water sample, making up its chemical composition. In the Santa Fe Group aquifer system of the Middle Rio Grande Basin, patterns in the water chemistry of ground water have helped refine important concepts about the ground-water-flow system, including sources of water, directions of flow, and traveltimes. The water chemistry of a ground-water sample can be thought of as a chemical signature that reflects the sum total of all physical processes and chemical reactions that affected the water from the time it began as dilute rainfall, infiltrated the soil above the water table, passed into the aquifer (ground-water recharge), and traveled, sometimes over great distances and depth, to the point of sample collection or discharge from the aquifer.

Water acquires very small quantities of some solutes from dust and gases when it falls through the atmosphere as precipitation, but water typically acquires the majority of its solutes once it reaches the land surface. Solutes that were already present in the water increase in concentration because of the processes of evaporation and transpiration—processes that, for the most part, remove water while leaving the solutes behind. In some arid environments like New Mexico, plants can withdraw more than 90 percent of the precipitation that has infiltrated into the soil zone. As water infiltrates through the soil zone, it also tends to dissolve carbon dioxide (CO_2) gas that exists in the soil in large quantities (relative to the atmosphere) because of biological activity. When CO_2 dissolves in water in the soil zone, a weak acid is formed. This acid promotes the dissolution of minerals that are present in the soil and rocks, which releases solutes to the water and causes their concentrations to increase. Because of these processes, water in the soil zone can acquire the bulk of its chemistry before it reaches the water table.

In ground water, only seven solutes make up nearly 95 percent of all water solutes (Runnells, 1993; Herczeg and Edmunds, 1999). These solutes are calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO_4), and bicarbonate (HCO_3). Although many sources and reactions influence the concentrations of these solutes, the predominant sources of these solutes to ground water in the Middle Rio Grande Basin (Anderholm, 1988) include (1) the dissolution of limestone (calcite, $CaCO_3$) and dolomite ($CaMg(CO_3)_2$) for Ca, Mg, and HCO_3; (2) the dissolution of gypsum ($CaSO_4{\cdot}2H_2O$) and anhydrite ($CaSO_4$) for Ca and SO_4; (3) the dissolution of halite (NaCl) for Na and Cl; and (4) ion exchange reactions on the surfaces of some clay minerals whereby sodium is released to the water in exchange for calcium or magnesium. Sodium also is derived from the dissolution of silicate minerals, such as plagioclase feldspars, which make up some of the sand and gravel that fill the Middle Rio Grande Basin. Potassium is derived from the dissolution of some silicate minerals in granitic rocks and from reactions with some clay minerals. Few reactions remove these seven solutes from ground water. However, some minerals, such as calcite $CaCO_3$, can precipitate from solution to form a solid phase.

In addition to the seven predominant solutes in water, some other solutes known as trace elements typically exist in very small quantities, as do particular isotopes of dissolved constituents (see Box *I*). Processes that affect the concentrations of trace elements and isotopes are not always well understood. However, combined with data on the predominant water-chemistry, trace-element and isotopic data for ground water can provide a powerful tool for tracking ground-water flow.

---

[1] U.S. Geological Survey, Reston, Virginia.

[2] U.S. Geological Survey, Albuquerque, New Mexico.

In a very broad sense, the mineralogy of aquifers can be divided into two groups—those aquifers that contain relatively reactive minerals and those with mostly unreactive minerals. In aquifers composed of reactive rocks and minerals like limestone, dolomite, gypsum, halite, and organic matter, solute concentrations (and isotopic compositions) can change significantly with distance along a ground-water flow path, reflecting extensive chemical reaction. In aquifers composed of mostly unreactive material, like sand and gravel from the chemical and mechanical breakdown of silicate rocks and minerals, solute concentrations change only slightly with distance down a flow path. In these relatively unreactive aquifers, such as the Santa Fe Group aquifer system, water tends to acquire its predominant chemical composition during the process of recharge and retains that composition as it flows through the aquifer.

Much of the ground water in the Middle Rio Grande Basin has acquired its chemical (and isotopic) composition during recharge, either as infiltration of precipitation on the basin margin, as seepage from rivers and arroyos, or as ground-water underflow from adjacent aquifer systems that border the basin. Water chemistry differs depending on the source of water, the degree to which it has been evaporated, the types of rock and mineral it has encountered, and the time it has been in contact with reactive minerals. Therefore, water in the Middle Rio Grande Basin commonly differs in the concentration of any particular solute and the concentration of that solute relative to other solutes. These distinct differences allow for the delineation of areas of the aquifer that have similar chemical "signatures." The spatial extents and configurations of these areas can provide important information about the ground-water-flow system. For example, the chemistry of an area with a particular signature can be compared with the chemistry that might be expected from water moving through a source area with a known rock type or seeping through a river with known surface-water chemistry. The likely source of the ground water can be determined from such comparisons. Boundaries between areas of dissimilar chemical signatures can represent general boundaries between waters from the different sources. The shapes of the areas can also broadly define the directions of ground-water flow. Also, the vertical extent of ground water in the aquifer having a particular chemical signature can indicate how well water is mixing vertically through the aquifer. If this vertical extent is known, the approximate volumes of ground water with different signatures can be calculated and used to estimate the relative amounts of recharge from different sources.

Interpretations of water-chemistry data are most reliably made within a conceptual framework of the ground-water system that has been derived from several additional types of hydrologic and geologic data, such as water levels, that indicate general directions of ground-water flow (see Box *F*). In combination with the multitude of hydrologic and geologic data obtained as part of the USGS Middle Rio Grande Basin Study, water-chemistry data have improved the understanding of the aquifer through recognition of ground-water sources, delineation of flow paths, and determination of ground-water traveltimes calculated using isotopic data (see Box *I*).

Ground-water sampling at the 98th Street well. Because monitoring wells typically do not contain pumps, a portable sampling pump must be lowered into the well.

Specific conductance is an indicator of how mineralized a sample of water is. It is measured in microsiemens per centimeter (µS/cm) at a specified temperature, usually 25 degrees Celsius. Pure water is a poor conductor of electricity, but minerals dissolve in water, and the resulting ions conduct electricity. In general, the larger the value of specific conductance the greater the concentration of dissolved solids in the water sample and the poorer the water quality. The specific conductance of seawater is about 50,000 µS/cm, whereas the specific conductance of distilled water is approximately 1 µS/cm (Heath, 1983; Hem, 1985).

The concentration of *dissolved oxygen* is a general indicator of how recently ground water entered the aquifer. In general, recently recharged water has a dissolved-oxygen concentration similar to surface water (which has relatively large values in comparison to most ground water), and concentration tends to decrease as ground water moves away from the point of recharge. The presence of organic material in the aquifer can cause more rapid oxygen depletion. However, in the Santa Fe Group aquifer system, some recently recharged river water has small values of dissolved oxygen because of organic material within inner-valley sediments, and some very old (greater than 10,000 years) ground water has relatively large values of dissolved oxygen. (See Hem [1985] for a general discussion of dissolved oxygen in ground water.)

Grande Basin. Because their sampling relied primarily on existing production wells, results are not applicable to deeper areas of the aquifer beneath the production zone. Boundaries between the water-quality zones may not be vertical as implied by a two-dimensional map (fig. 6.1). The reader is referred to Plummer and others (2001) for a complete description, but general characteristics of the regions shown in figure 6.1 are summarized in table 6.1.

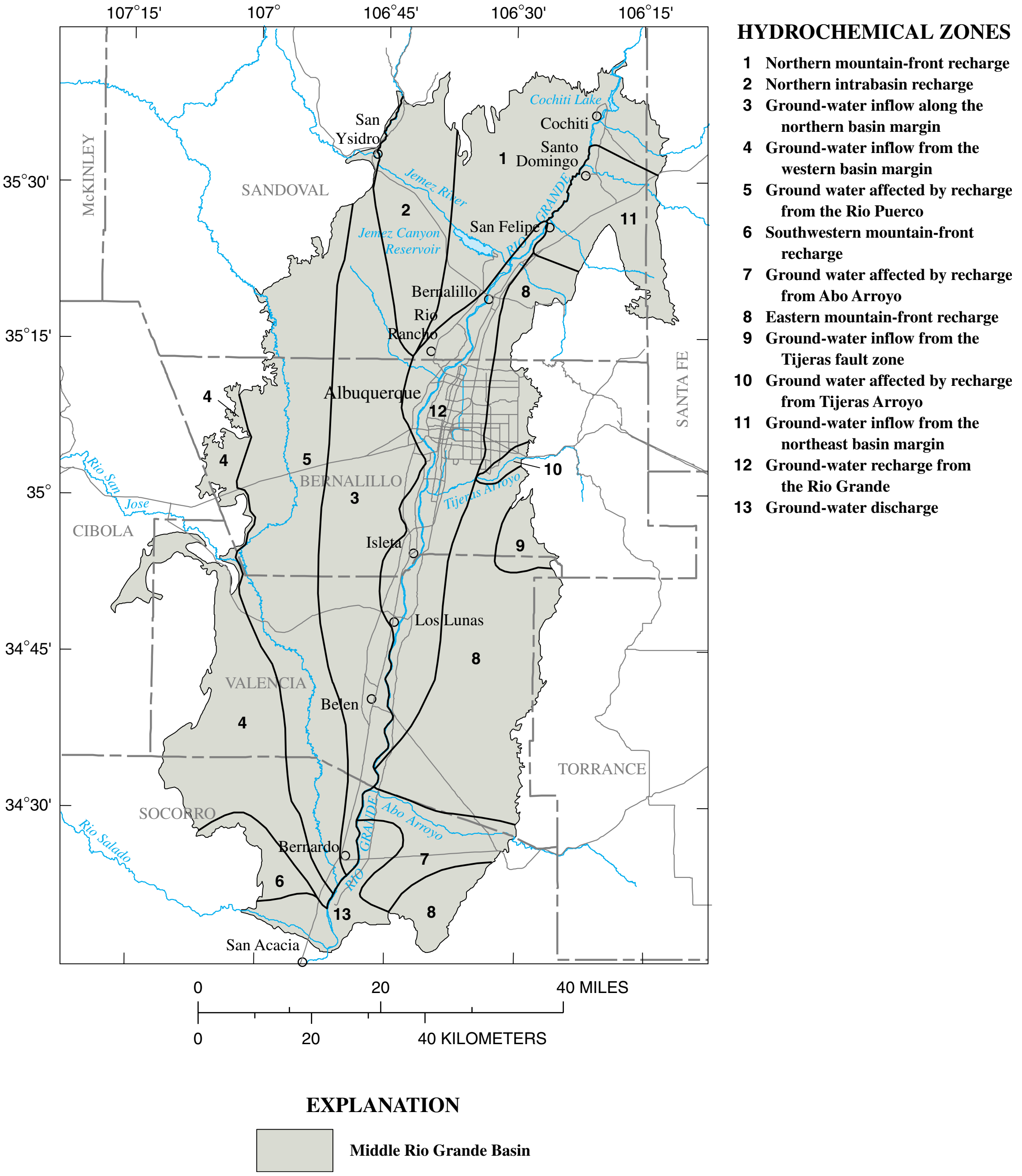
Not only can hydrochemical zones be used to characterize ground-water quality in different parts of the Middle Rio Grande Basin, they can also be used to delineate probable sources of recharge and their relative contributions, determine ground-water flow paths within the aquifer system, and provide an estimate of the sustainability of current ground-water pumping. Probable recharge sources for each of the hydrochemical zones defined by Plummer and others (2001) are listed in table 6.1. (Zone 13 is thought to represent a convergence of flow from multiple zones in the basin and does not represent a single recharge source.) For example, zone 4 contains the oldest ground water in the basin (based on carbon-14 age; see Box *N*), and the strongly negative values of deuterium (see Box *I*) suggest that this water originated as precipitation at a higher elevation. These data, in combination with other water-quality information, led to the interpretation that zone 3 represents “recharge from the Jemez Mountains north of the basin, primarily during the last glacial period” (Plummer and others, 2001).

Because these hydrochemical zones were defined on the basis of a limited number of samples, the characteristics listed in table 6.1 are only generalizations. A well within one of the zones may contain water with substantially different chemical characteristics from those represented by the median, or typical, values for the zone.

Naturally occurring substances that limit the use of ground water

Current (2002) U.S. Environmental Protection Agency (USEPA) and State of New Mexico drinking-water standards and the significance of selected constituents are shown in table 6.2, along with the significance of each constituent for human health and (or) the esthetic properties of water. This listing is limited to constituents or properties listed in the preceding discussion of the ground-water-quality regions defined by Plummer and others (2001).

USEPA drinking-water standards are of two types: primary and secondary. *Primary standards* are the “maximum permissible level of a contaminant in water which is delivered to any user of a public water system” (U.S. Environmental Protection Agency, 2002). The standards are enforceble, in contrast to *secondary standards*, which are nonenforceble. Constituents covered by secondary standards may cause cosmetic or esthetic effects. The presence in drinking water of chemical constituents regulated by drinking-water standards does not necessarily pose a health risk. Many constituents that are essential for good health at low concentrations may pose a health risk at higher concentrations.



HYDROCHEMICAL ZONES

1 Northern mountain-front recharge
2 Northern intrabasin recharge
3 Ground-water inflow along the northern basin margin
4 Ground-water inflow from the western basin margin
5 Ground water affected by recharge from the Rio Puerco
6 Southwestern mountain-front recharge
7 Ground water affected by recharge from Abo Arroyo
8 Eastern mountain-front recharge
9 Ground-water inflow from the Tijeras fault zone
10 Ground water affected by recharge from Tijeras Arroyo
11 Ground-water inflow from the northeast basin margin
12 Ground-water recharge from the Rio Grande
13 Ground-water discharge

EXPLANATION

▨ **Middle Rio Grande Basin**

Figure 6.1.—*Hydrochemical regions of the Middle Rio Grande Basin as defined by Plummer and others (2001).*

Table 6.1.—Median values of selected parameters of the 13 hydrochemical zones delineated for the Santa Fe Group aquifer system of the Middle Rio Grande Basin

[Plummer and others (2001); years BP, years before present; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

	Hydrochemical zone and recharge source						
	1	2	3	4	5	6	7
	Northern mountain-front recharge	Northern intrabasin recharge	Ground-water inflow along the northern basin margin	Ground-water inflow from the western basin margin	Ground water affected by recharge from the Rio Puerco	Southwestern mountain-front recharge	Ground water affected by recharge from Abo Arroyo
Number of samples	16	10	44	10	12	2	5
Deuterium (parts per thousand) [1]	–79	–63	–97	–64	–63	–64	–64
Carbon-14 age (years BP)	8,800	8,800	19,500	20,400	8,100	7,700	9,400
Specific conductance (µS/cm)	380	390	590	3,300	2,400	590	920
pH (standard units)	7.5	7.8	8.3	7.6	7.5	8.0	7.4
Dissolved oxygen (mg/L)	5.1	6.8	3.1	4.9	3.0	3.7	5.6
Chloride (mg/L)	9.5	6.2	12	[2] 530	180	26	24
Sulfate (mg/L)	25	35	95	[2] 670	[2] 980	80	[2] 310
Bicarbonate (mg/L)	150	140	170	250	180	230	170
Nitrate (mg/L)	0.6	5.2	1.3	1.1	1.5	0.6	1.4
Calcium (mg/L)	39	29	10	130	170	39	91
Sodium (mg/L)	26	47	100	450	280	44	49
Potassium (mg/L)	5.4	6.2	4.1	14	12	3.2	3.4
Silica (mg/L)	47	28	28	21	26	14	22
Arsenic (mg/L)	0.0051	0.0096	[3] 0.021	0.0018	0.0011	0.0011	0.0026

	Hydrochemical zone and recharge source						
	8	9	10	11	12	13	
	Eastern mountain-front recharge	Ground-water inflow from the Tijeras fault zone	Ground water affected by recharge from Tijeras Arroyo	Ground-water inflow from the northeast basin margin	Ground-water recharge from the Rio Grande	Ground-water discharge	Average for all zones
Number of samples	47	8	6	7	105	3	275
Deuterium (parts per thousand) [1]	–81	–74	–75	–69	–95	–91	–90
Carbon-14 age (BP)	5,200	16,200	3,200	10,000	4,600	17,900	8,100
Specific conductance (µS/cm)	380	1,300	620	1,300	430	2,500	470
pH (standard units)	7.5	7.1	7.4	7.6	7.7	7.7	7.7
Dissolved oxygen (mg/L)	5.5	4.1	6.7	6.6	0.1	0.1	1.9
Chloride (mg/L)	7.7	87	29	22	16	[2] 680	16
Sulfate (mg/L)	34	150	110	[2] 400	63	[2] 290	67
Bicarbonate (mg/L)	170	290	220	170	160	160	160
Nitrate (mg/L)	0.4	1.0	3.3	1.9	0.1	0.4	0.5
Calcium (mg/L)	48	130	80	100	42	93	41
Sodium (mg/L)	22	87	29	87	29	210	44
Potassium (mg/L)	2.0	4.6	3.5	4.4	6.7	11	5.3
Silica (mg/L)	26	23	23	31	53	29	33
Arsenic (mg/L)	0.0017	0.002	0.001	0.0022	0.0055	0.008	0.005

[1] Deuterium values can be negative because they are expressed as parts per thousand differences relative to an ocean-water standard.

[2] These values exceed the U.S. Environmental Protection Agency secondary water-quality standards in table 6.2.

[3] This value exceeds the U.S. Environmental Protection Agency primary water-quality standard for arsenic in table 6.2.

Table 6.2.—Current drinking-water standards and significance of constituents commonly found in ground water in the Middle Rio Grande Basin

[USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; --, no standard exists or no effects known]

Constituent	USEPA drinking-water standard maximum contaminant level (mg/L)[1]		State of New Mexico drinking-water standard maximum contaminant level (mg/L) [2]	Significance
	Primary standard	Secondary standard		
Arsenic	0.01	--	0.05	Skin damage; circulatory system problems; increased cancer risk.[1]
Boron	--	--	--	--
Calcium	--	--	--	In large amounts, increases corrosiveness of water. In combination with sodium, gives water a salty taste.[3]
Chloride	--	250	--	In large amounts, increases corrosiveness of water. In combination with sodium, gives water a salty taste.[3]
Fluoride	4	2	4	Bone disease (pain and tenderness of the bones); children may get mottled teeth.[1]
Manganese	--	0.05	--	Dark brown-black stains; bitter, metallic taste.[3,4]
Nitrate (measured as nitrogen)	10	10	10	Methemoglobinemia (“Blue baby syndrome”).[1]
pH (in standard units)	--	6.5–8.5	--	Values less than 4 indicate corrosive water that tends to dissolve metals and other substances that it contacts. Values greater than 8.5 indicate alkaline water that, on heating, tends to form scale in pipes and boilers.[3]
Potassium	--	--	--	In combination with sodium can cause foaming, corrosion, and scale formation in boilers.[5]
Silica	--	--	--	In combination with calcium and magnesium forms scale in pipes and boilers.[5]
Sodium	--	--	--	See chloride, potassium; in large concentrations, may affect people with cardiac difficulties, hypertension, and certain other medical conditions. In combination with calcium and magnesium may be detrimental to certain irrigated crops.[3]
Sulfate	--	250	--	Medicinal taste; laxative effect. In combination with calcium forms scale in pipes and boilers.[3,4]

[1] U.S. Environmental Protection Agency (2002).

[2] New Mexico Environment Department (1996).

[3] Heath (1983).

[4] National Water Quality Association (2002a, b).

[5] Todd (1980).

Concentrations of chemical constituents in water are typically reported as *milligrams per liter* (mg/L) or *micrograms per liter* (µg/L), which are essentially equal to parts per million and parts per billion, respectively. An example of 1 part per million is 1 ounce of a substance dissolved in 7,500 gallons of water (Heath, 1983). “Four drops of ink in a 55-gallon barrel of water would produce an “ink concentration” of 1 part per million” (Kimball, 2002). Similarly, 1 part per billion is 1 ounce of a substance dissolved in 7.5 million gallons of water, or one drop of ink in one of the largest tanker trucks used to haul gasoline (Kimball, 2002).

An examination of the median values of selected water-quality parameters by the hydrochemical zones in table 6.1 shows that three constituents exceeded at least one of the three standards listed in table 6.2 (USEPA primary or secondary standard or New Mexico standard). The median arsenic concentration of 0.021 mg/L in zone 3 exceeded the USEPA primary standard of 0.010 mg/L. The median concentrations of chloride in zones 4 and 13, 530 and 680 mg/L, respectively, exceeded the USEPA secondary standard of 250 mg/L. Concentrations of sulfate in zone 4 (670 mg/L), zone 5 (980 mg/L), zone 7 (310 mg/L), zone 11 (400 mg/L), and zone 13 (290 mg/L) exceeded the USEPA secondary standard of 250 mg/L.

The results reported in Plummer and others (2001) were a summary of a comprehensive suite of chemical analyses, not all of which were reported in the paper. In addition, the median concentration of manganese was 0.05 mg/L in zone 4, which is equivalent to the USEPA secondary standard (L.M. Bexfield, U.S. Geological Survey, written commun., 2001).

An additional two points should be made about the chemical analyses of ground water and the applicability of Federal and State standards. First, water samples analyzed by Plummer and others (2001) were untreated samples obtained directly from wells. Because such water is not being delivered directly to the consumers of a municipal supply, the standards do not strictly apply. However, the comparison is provided to give an indication of untreated source water. Second, even though the median values presented in table 6.1 may not exceed a water-quality standard, individual samples from the zone may. Conversely, even though the median values in table 6.1 may exceed a water-quality standard, individual samples from the zone may not.

The naturally occurring water-quality constituent of most concern in ground water of the Middle Rio Grande Basin has been arsenic. In 1991, seven City of Albuquerque well fields had at least one well producing water with more than 0.030 mg/L of arsenic (CH2M Hill, 1991). Generally, by blending water from different wells in each well field, water of an acceptable concentration was delivered and the water supply was not affected; however, arsenic concentrations in the Don well field (fig. *B.1A*) were too large for such dilution, causing the entire field to be taken out of production (CH2M Hill, 1991). Concerns also have been raised about arsenic concentrations in the discharge of treated wastewater to the Rio Grande. Because essentially all of this wastewater originates as ground water and because the wastewater-treatment process does not remove arsenic, water with arsenic concentrations larger than the naturally occurring concentrations in the river could be conveyed to the Rio Grande. A study by Wilcox (1997) found that mean dissolved-arsenic concentrations in Rio Grande water generally increased downstream from 0.002 mg/L at San Felipe Pueblo to 0.004 mg/L at Los Lunas. Mean dissolved-arsenic concentrations in treated wastewater from the Bernalillo, Rio Rancho, and Albuquerque wastewater-treatment plants ranged from 0.008 mg/L to 0.016 mg/L. Mean dissolved-arsenic concentration in the Jemez River below Jemez Reservoir was 0.018 mg/L.

In October 2001, the USEPA issued a final arsenic primary standard of 0.010 mg/L for drinking water and extended compliance beyond community water systems to all systems that serve at least 25 of the same people more than 6 months per year (U.S. Environmental Protection Agency, 2001a). Annual compliance costs for New Mexico are estimated at $49–$60 million to meet the primary standard of 0.010 mg/L of arsenic (Bitner, Thomson, and Chwirka, 2001).

Contaminants of human origin and ground water

Human contamination of ground water in the Middle Rio Grande Basin, though severe in some localities, is not widespread and does not affect a large quantity of water in the aquifer. Most of the ground water in the basin has a "low susceptibility to contamination because the depth to water is greater than 100 feet and there is virtually no natural mechanism for [direct] recharge to the ground-water system" (Anderholm, 1987). An exception is the basin- and valley-fill deposits of the inner valley of the Rio Grande, which have a "relatively high susceptibility to contamination because the depth to water is generally less than 30 feet and there are many types of recharge to the ground-water system" (Anderholm, 1987). Among the facilities or activities that are potential sources of ground-water contamination in the Middle Rio Grande Basin are military and industrial operations, leaking underground-storage tanks, landfills, agricultural activities, and domestic septic systems.

The USEPA currently (2002) lists five Superfund sites in the Middle Rio Grande Basin (U.S. Environmental Protection Agency, 2001b). One of these sites was removed from the priority list after contaminated soil was removed from the site, and another was removed from the priority list after site investigation. The remaining three sites have ground water contaminated with organic chemicals and are currently undergoing remediation.

The New Mexico Environment Department (NMED) currently (2002) lists about 700 former and present leaking underground-storage-tank sites in the Middle Rio Grande Basin (New Mexico Environment Department, 2001), though not all these leaks resulted in ground-water contamination. Most of these tanks stored some form of fuel.

Currently (2002), three RCRA (**R**esource **C**onservation and **R**ecovery **A**ct of 1976) sites are in the Middle Rio Grande Basin (U.S. Environmental Protection Agency, 1999). Two of these sites, Kirtland Air Force Base and Sandia National Laboratories, are composed of a number of individual sites on large installations. These individual sites represent activities such as landfilling, fire training, and explosives testing. Potential ground-water contaminants are organic chemicals, radioactive elements, and metals. The third RCRA site has ground water contaminated with organic chemicals from electronics manufacturing. All three sites are undergoing remediation.

A study by Anderholm (1997), intended to examine the effects of land use on water quality at the water table, sampled and analyzed ground water from 24 monitoring wells having total depths within 20 feet of the water table in the basin- and valley-fill deposits in the Albuquerque area. This study found that "human activities have affected shallow ground-water quality." Organic chemicals (pesticides, solvents, metal degreasers, and a gasoline additive) were detected in water from 11 of the 24 wells sampled, though no concentrations were equal to or greater than applicable drinking-water standards (not all chemicals had standards) (Levings and others, 1998). Other water-quality constituents indicated that "infiltration from septic-system effluent . . . has affected the shallow ground-water composition" in parts of the inner valley in the Albuquerque area (Anderholm, 1997). A later study by Bexfield and Anderholm (1997)

Basalt flows exposed in Boca Negra Canyon. Arsenic in ground water is commonly associated with volcanic rocks in the subsurface.

One of the typical steps in producing a ground-water-flow model is model *calibration*. Inevitably, some of the values used in creating the model are estimated. Calibration is the process of changing these model-input values to reduce model error by varying the estimated values over a range of probable values until there is an acceptable match between simulated and observed data (Leake, 1997; Spitz and Moreno, 1996).

examined the chemical quality of ground water being used for domestic supply in an area susceptible to contamination. Water from 14 domestic supply wells was sampled and analyzed. These wells had total depths ranging from 45 to 350 feet below the water table, which included wells completed in basin- and valley-fill as well as Santa Fe Group deposits. Bexfield and Anderholm (1997) concluded, "no strong evidence was found of effects on ground-water chemistry from human activities."

Kues and Garcia (1995) sampled 81 water-supply wells in four unincorporated areas of Bernalillo County during 1990–93. Three of these areas were in the Middle Rio Grande Basin and included 61 wells of varying depth: the inner valley of the Rio Grande both north and south of Albuquerque and an area northeast of Albuquerque. Pesticide concentrations were greater than detection limits in three wells in the inner valley. Concentrations of detergent additives (indicating the presence of domestic sewage) were greater than detection limits in four wells: three in the inner valley and one in the northeast area.

All municipal and community water systems are required to periodically test their water to ensure that it meets applicable drinking-water standards and to report the results to water users. In Albuquerque, ground-water samples from each well in the distribution system are analyzed on a regular basis to ensure compliance with drinking-water standards (City of Albuquerque, 2000). The results from this compliance monitoring are periodically mailed to water-utility customers. The City of Albuquerque has voluntarily collected and analyzed additional ground-water samples from its production wells to better characterize the ground-water resource. These data, which were not collected for compliance purposes, are summarized by Bexfield, Lindberg, and Anderholm (1999).