GEOCHEMISTRY AND ISOTOPE HYDROLOGY OF REPRESENTATIVE AQUIFERS IN THE GREAT BASIN REGION OF NEVADA, UTAH, AND ADJACENT STATES

REGIONAL AQUIFER-SYSTEM ANALYSIS

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ent of 0.12 ft/ft over about a 500-ft vertical interval exists between the basin-fill and carbonate-rock wells (Berger and others, 1988). This downward head gradient and the isotope value similar to that of average Sheep Range recharge (–93 permil) indicate that recharge from the Sheep Range probably flows primarily through the basin-fill aquifer in Coyote Spring Valley.

The basin-fill aquifer in Coyote Spring Valley is bound on the east by the carbonate rock of the northern Arrow Canyon Range and southern Meadow Valley Mountains. In this area, the carbonate rock that compose these mountains are exposed at land surface, and water in the basin-fill aquifer mixes with water in the carbonate-rock aquifers. This mixed water is observed at Muddy River springs. Water from a well (MX-6; fig. 17) completed in carbonate rock, about halfway between the east edge of the Coyote Spring Valley basin-fill aquifer and Muddy River springs, has a deuterium composition of –97 permil (pl. 2). This isotopic composition is similar to Muddy River springs (–98 permil) and is more evidence supporting the conceptual flow and mixing model: water in the Muddy River springs area is probably a mixture of Sheep Range recharge water and water from the carbonate-rock aquifers beneath Coyote Spring Valley. Using the average deuterium composition of Sheep Range recharge water (–93 permil) and Coyote Spring Valley carbonate-rock aquifer water (–101 permil) to determine the sources of water at Muddy River springs (–98 permil) results in a mixture of 38 percent (14,000 acre-ft/yr) Sheep Range water and 62 percent (22,000 acre-feet/yr) Coyote Spring Valley water.

Water in the carbonate-rock aquifers of Coyote Spring Valley (deuterium composition of –101 permil) can be from two sources, the White River flow system (deuterium composition of –109 permil) and the southern Meadow Valley Wash flow system (deuterium composition of –87 permil; pls. 1 and 2, figs. 16, 17). A mixture of 64 percent (14,000 acre-ft/yr) White River flow-system water and 36 percent (8,000 acre-ft/yr) southern Meadow Valley Wash flow-system water results in water isotopically the same as water in the carbonate-rock aquifers in Coyote Spring Valley.

In summary, water discharging from Muddy River springs is a mixture of 40 percent (14,000 acre-feet/yr) White River flow-system water, 38 percent (14,000 acre-ft/yr) Sheep Range water, and 22 percent (8,000 acre-ft/yr) southern Meadow Valley Wash flow-system water. The 14,000 acre-ft/yr contribution of White River flow-system water to Muddy River springs is significantly less than the 35,000 acre-ft/yr proposed by Eakin (1966) on the basis of water-level data and Maxey-Eakin recharge estimates (Maxey and Eakin, 1949) but is similar to recent estimates by A.H. Welch (U.S. Geological Survey, written commun., 1988) and Kirk and Campana (1990). Welch estimated 18,000 acre-ft/yr of underflow from Pahranagat Valley to Coyote Spring Valley on the basis of the isotopic compositions of empirically derived Maxey-Eakin recharge estimates for the entire White River flow system. Kirk and Campana (1990) calculated a contribution of 16,500 to 19,100 acre-ft/yr for three different flow scenarios for the White River flow system on the basis of Maxey-Eakin recharge estimates and water-level data with a discrete-state compartment model using deuterium to calibrate their models. These flow-system delineations are based on water-level data only, with no consideration of geologic or structural constraints on ground-water flow.

The Sheep Range contribution of 14,000 acre-ft/yr is significantly higher than the estimated 2,000 acre-ft/yr of Eakin (1966), 3,000 acre-ft/yr of A.H. Welch (written commun., 1988), and 5,000 to 6,000 acre-ft/yr of Kirk and Campana (1990). The greater contribution of Sheep Range water compared to previous studies is balanced by not including 6,000–9,800 acre-ft/yr of ground-water from Dry Lake Valley, north of Delamar Valley, because of geologic constraints to ground-water flow (Dettinger and others, 1995) and less underflow from Pahranagat Valley to Coyote Spring Valley. Geologic constraints on Sheep Range water flowing to the west and south, as previously discussed in the section titled "Geologic Framework," indicates that most of the recharge to the Sheep Range probably flows to the northeast toward the Muddy River springs area. The calculated contribution of 14,000 acre-ft/yr of Sheep Range water is higher than the empirical Maxey-Eakin recharge estimate of 11,000 acre-ft/yr, but the amount is reasonable if most of the recharge to the Sheep Range discharges at Muddy River springs. Winograd and Friedman (1972) also postulated, on the basis of deuterium data, that the Sheep Range may be a significant source of water discharging from Muddy River springs.

The 8,000 acre-ft/yr of ground water calculated to flow from the southern Meadow Valley Wash flow system to Muddy River springs agrees with previous estimates by Welch (8,000 acre-ft/yr) and Kirk and Campana (5,500–9,000 acre-ft/yr).

ASH MEADOWS FLOW SYSTEM

Springs at Ash Meadows discharge 17,000 acre-ft/yr at the distal end of the Ash Meadows flow system (Winograd and Thordarson, 1975). The average deuterium composition of the water from seven springs (the six largest discharging springs plus Scruggs Spring) is –103 permil (Winograd and Pearson, 1976;

appendix A). The sources of water discharging from the springs were determined on the basis of hydraulic gradients in the carbonate-rock aquifers in this area (see section titled "Hydrologic Framework" and pl. 1), the geologic and structural constraints on ground-water flow (see section titled "Geologic Framework" and figs. 17, 18), and the deuterium composition of possible source waters.

The first carbonate-rock aquifer sample site that is upgradient from Ash Meadows springs and has deuterium and water chemistry data is Army Well 1 (fig. 17). Water from Army Well 1 has an average deuterium composition of –104 permil (appendix A). Thus, given the hydrologic position of the well and the isotopic similarity of its water to Ash Meadows springs, water at Army Well 1 is considered representative of water that flows to Ash Meadows. This conclusion was previously reached by Winograd and Friedman (1972), but they also noted that the chemistry at Army Well 1 was more dilute than water discharging at Ash Meadows. At a carbonate-aquifer sample site about halfway between Army Well 1 and Ash Meadows (Amargosa Tracer Well 2; fig. 17), deuterium data are lacking but oxygen-18 data are similar to data from Ash Meadows springs (appendix B). Water chemistry also is similar, although slightly more dilute, so this water also is considered representative of flow to Ash Meadows. The water chemistry from these two sites and how they relate to flow in the Ash Meadows flow system is discussed in the section titled "Water Chemistry."

No water samples from carbonate-rock aquifer sites upgradient from Army Well 1 had deuterium compositions similar to samples from Ash Meadows. Thus, isotopically different waters must be mixing to produce the deuterium composition measured at Ash Meadows and Army Well 1. Given the hydrologic, geologic, and structural constraints (see sections titled "Hydrologic Framework" and "Geologic Framework"), the two nearest carbonate-rock aquifer water sources upgradient from Army Well 1 and Ash Meadows that could mix to produce their deuterium composition are in the area of Well C-1 in south Yucca Flat and Indian Springs (fig. 17, pls. 1 and 2).

A mixture of 33 percent (6,000 acre-ft/yr) Well C-1 water (–111 permil) and 67 percent (11,000 acre-feet/yr) Indian Springs water (–99 permil) is needed to produce the deuterium composition of water at Ash Meadows and Army Well 1 (–103 permil). The source of Indian Springs water is recharge to the Spring Mountains, on the basis of the hydraulic gradient (pl. 1) and deuterium composition of Indian Springs water, which is the same as that of average Spring Mountains recharge (-99 permil). The source of Well C-1 water is less obvious: three possible sources, on the basis of hydrologic, geologic, and structural constraints, are recharge to the Eleana Range (or farther to the west in Pahute Mesa), drainage of paleowater, or White River flow-system water.

The Eleana Range contains 4,000 to 8,000 ft of Devonian to Mississippian noncarbonate rock under the west third of Yucca Flat (Winograd and Thordarson, 1975, "upper clastic aquitard"). Therefore, little precipitation that falls on the Eleana Range probably recharges the carbonate-rock aquifers in the Yucca Flat area. Winograd and Thordarson (1975) estimated the quantity of water flowing into the carbonate-rock aquifers beneath Yucca Flat from both the west (Eleana Range) and northeast (Emigrant Valley) is less than 250 acre-ft/yr. In addition, aeromagnetic interpretations by Bath and Jahren (1984) and recent interpretations of Tertiary extensional tectonics by Guth (1988) indicate that little of the carbonate-rock aquifer underlies the Eleana Formation in this area; instead, the Eleana Formation is probably underlain by noncarbonate basement. Thus, the possibility that water in the volcanic rock of Pahute Mesa, west of the Eleana Range, flows at depth into the carbonate-rock aquifers and then east to Yucca Flat is unlikely. No isotope data exist for the carbonate aquifers beneath the Eleana Range, so the isotopic composition of this water is unknown.

Drainage of water recharged during the last glacial episode is a possible source of water at Well C-1. However, Winograd and Doty (1980) show that water levels in the carbonate-rock aquifers in the Nevada Test Site area have fluctuated less than 100 ft during Wisconsin time, and Jones (1982) shows fluctuations of less than about 150 ft in the northern Frenchman Flat area through most of Quaternary time. Thus, drainage of paleowater is not probable.

White River flow-system water in Pahranagat Valley is isotopically similar (–109 permil) to Well C-1 water (–111 permil) and, on the basis of hydraulic gradients, could be flowing southwest to Yucca Flat (pl. 1). Continuous, thick sequences of carbonate rock provide a flow path for White River flow system water to Frenchman Flat (fig. 17). Thus, of the three possible sources of Well C-1 water, the White River flow system is hydrologically and geologically the most likely.

Another possibility is that little water flows from the Yucca Flat area to Ash Meadows. Winograd and Thordarson (1975, p. 94) estimated the total flow within the carbonate-rock aquifers beneath Yucca Flat to the south to be less than 350 acre-ft/yr. A likely alternative is that water from Pahranagat Valley flows through the Frenchman Flat area south of Well C-1 and mixes with Spring Mountains water, producing the water at Ash Meadows. This interpretation is reasonable because the central core of thick, continuous carbonate rock extends from Pahranagat Valley to Ash Meadows (fig. 17). Using the average isotope value of Pahranagat Valley water (–109 permil) and Indian Springs water (–99 permil) to produce Ash Meadows water (–103 permil) results in a mixture of 40 percent (7,000 acre-ft/yr) Pahranagat Valley water and 60 percent (10,000 acre-ft/yr) Spring Mountains water. The 40 percent contribution of Pahranagat Valley water to Ash Meadows spring discharge is in good agreement with the 35 percent estimated by Winograd and Friedman (1972) and Winograd and Thordarson (1975).

The Spotted, Pintwater, Desert, and Groom Ranges are assumed to contribute little water to the carbonate-rock aquifers (fig. 17). This assumption agrees with previous work by Winograd and Friedman (1972) and Winograd and Thordarson (1975). These mountains, with the exception of the Groom Range, are less than 7,100 ft in altitude and, therefore, do not receive large amounts of winter precipitation that could become available to recharge the carbonate-rock aquifers. The Groom Range is composed mostly of Precambrian basement rock and is not underlain by carbonate-rock aquifers (M.D. Dettinger, U.S. Geological Survey, oral commun., 1989); therefore, little precipitation in the Groom Range recharges the carbonate-rock aquifers. In addition, any potential recharge water in these ranges generally is isotopically heavy; median deuterium composition of 13 samples from the Pintwater and Groom Ranges is –90 permil (pl. 2; B.F. Lyles, Desert Research Institute, written commun., 1986) compared with recharge water in the Spring Mountains (–99 permil) and water in the White River flow system (–109 permil). This heavy deuterium composition severely limits the possibility that any significant recharge to these mountains contributes to Ash Meadows discharge.

As previously discussed, recharge to the Sheep Range probably contributes little to spring discharge at Ash Meadows due to geologic and structural constraints. The relatively heavy deuterium composition of Sheep Range water (–93 permil), as compared with Ash Meadows spring water (–103 permil), also limits the percentage of Sheep Range water that could mix with Spring Mountains and Pahranagat Valley water to produce the deuterium composition measured at Ash Meadows.

In summary, a mixture of 40 percent (7,000 acre-ft/yr) Pahranagat Valley water and 60 percent (10,000 acre-ft/yr) Spring Mountains water discharging at Ash Meadows springs is geologically, hydrologically, and isotopically the most likely alternative. Previous work by Winograd and Friedman (1972), Winograd and Thordarson (1975), Winograd and Pearson (1976), Welch and Thomas (1984), and Kirk and Campana (1990) postulated a 24 to 35 percent input of Pahranagat Valley water to Ash Meadows, which is similar to the 40 percent proposed by this isotopic mixing model. The 60 percent Spring Mountains contribution also is reasonable, if the previous estimate of about 65 percent Spring Mountains plus Sheep Range water (Winograd and Friedman, 1972; Winograd and Thordarson, 1975; Winograd and Pearson, 1976) is assumed to be mostly Spring Mountains water. This assumption seems reasonable because the previous studies assumed that the Spring Mountains and Sheep Range were isotopically the same and no flow barriers existed between the Sheep Range and Ash Meadows springs. Other evidence to support the concept that recharge from the Spring Mountains contributes 60 percent of Ash Meadows springs discharge is as follows:

1. A Maxey-Eakin recharge estimate, which assumes that only precipitation above 6,000 ft becomes recharge, for the part of the Spring Mountains that topographically drains to the Ash Meadows flow system is 7,000 acre-ft/yr. This estimate is lower than the 10,000 acre-ft/yr estimated by the isotope mixing model, but ground-water flow modeling studies of Las Vegas and Pahrump Valleys (Harrill, 1976, 1986) indicate that Maxey-Eakin recharge estimates for the Spring Mountains underestimate recharge by about 20 to 35 percent.
2. Winograd and Thordarson (1975) suggest on the basis of structural disposition that some recharge south of the topographic divide in the Spring Mountains flows northward into Indian Springs Valley rather than southwestward into Pahrump Valley.
3. In a recharge area such as the Spring Mountains, which contains well-mixed water, as indicated by the lack of isotopic depletion with increased altitude (fig. 21), topographic divides probably have less effect on the areas of recharge than in a recharge area that contains less well-mixed water.

LAS VEGAS VALLEY

Isotopic composition of ground water in the basin-fill aquifers of Las Vegas Valley indicates that the aquifers are supplied almost entirely by recharge to the Spring Mountains. This conclusion agrees with ground-water flow modeling studies by Harrill (1976) and Morgan and Dettinger (1996). The average deuterium composition of water from 10 wells and springs in northern Las Vegas Valley is –98 permil, ranging from –101 to –96 permil (pl. 2). This average value is similar