

APPENDIX 8—Mixing of different water sources

MIXING OF DIFFERENT WATER SOURCES

We determined that dedolomitization is the primary control on the general water chemistry. The high mountain aquifer system is a recharge zone, and therefore the primary water source is local precipitation. However, saline groundwater has been observed in the high mountains. The Cloudcroft Apache Replacement well, located approximately two miles east of the Village of Cloudcroft, was drilled to a total depth of 1,644 feet below ground level, and was completed in the Yeso Formation (Street and Peery, 2007). Water from this well was high in sodium chloride (NaCl) and had a very high total dissolved solids

(TDS) concentration of 260,000 mg/L. It is probable that small amounts of this saline water could mix with fresh groundwater in this system. Although the Pecos Slope aquifer appears to be recharged mainly by the high mountains aquifer system, some deeper groundwater may be forced up into the shallow system along faults in the area.

We investigated the mixing of fresh water derived from precipitation in the mountains and saline waters found deeper in the subsurface by examining chloride/bromide (Cl/Br) ratios. Cl/Br ratios have been used to distinguish atmospheric Cl contribution from other origins

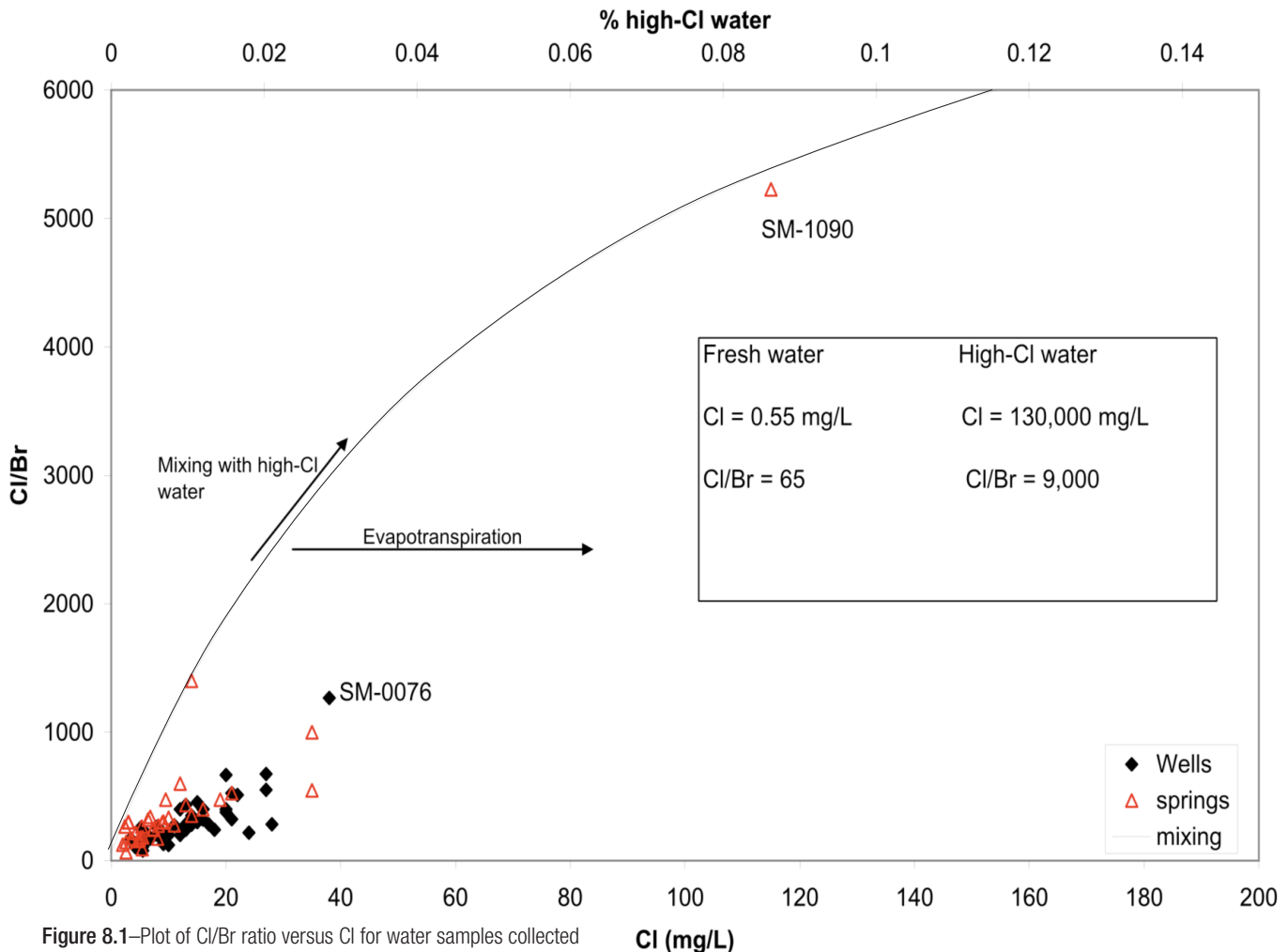
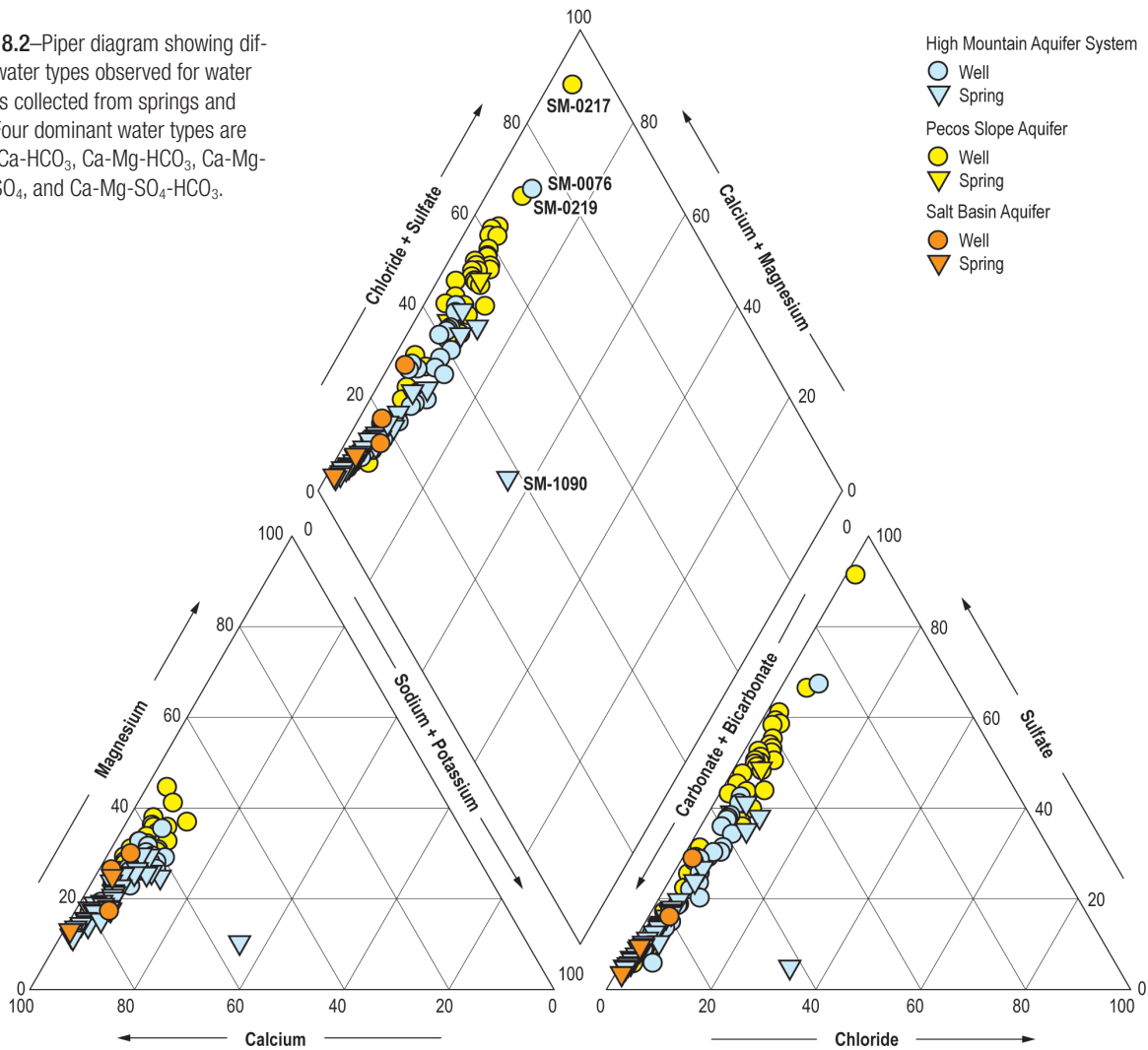


Figure 8.1—Plot of Cl/Br ratio versus Cl for water samples collected from springs and wells, along with hypothetical mixing model.

Figure 8.2—Piper diagram showing different water types observed for water samples collected from springs and wells. Four dominant water types are found: Ca-HCO₃, Ca-Mg-HCO₃, Ca-Mg-HCO₃-SO₄, and Ca-Mg-SO₄-HCO₃.



in groundwater (Alcala and Custodio, 2008; Davis et al., 1998; Freeman, 2007; Sonney and Vuataz, 2010). The Cl/Br ratio works well as a tracer of salinity because both Cl and Br behave conservatively in groundwater under most circumstances. Therefore, a significant change in the Cl/Br ratio is usually due to the mixing of two source waters with different Cl/Br ratios. In general, precipitation is characterized by a Cl/Br ratio of 200 or less. Cl/Br ratios for most shallow groundwater with low Cl concentrations range between 80 and 160, and Cl/Br ratios in groundwater tend to increase with increasing Cl concentrations. Most high chloride waters, specifically those that have been affected by halite dissolution, can have Cl/Br ratios well above 1000 (Davis et al., 1998; Alcala and Custodio, 2008).

Chloride concentrations for water samples collected from springs ranged from 2 mg/L to 115 mg/L with a median value of 7 mg/L, and Cl/Br ratios ranged from 65 to 5000, with a median value of 286. Water collected from wells exhibited Cl concentrations, ranging from 2 mg/L to 125 mg/L, with a median value of 12.5 mg/L and Cl/

Br ratios ranging from 79 to 1953 with a median value of 260. Figure 8.1 shows a plot of Cl/Br ratios as a function of Cl concentration for all spring and well samples, along with a hypothetical two end-member mixing curve. Note that the mixing curve shown in Figure 8.1 is a hypothetical mixing curve due to uncertainties in end-member Cl concentrations and Cl/Br ratios. We chose end-member values that produced a curve that enveloped all data points, and therefore they were controlled by the spring samples with the highest Cl/Br ratios. The Cl concentration observed for the water in the Apache Replacement well near Cloudcroft (130,000 mg/L) was used for the saline water end-member. A value of 9000 was used as the Cl/Br ratio for the saline water end-member. The actual Cl/Br ratio for water from the Cloudcroft Apache Replacement well is not known, as Br was below the detection limit. However, with such low Br concentrations and extremely high Cl concentrations, the Cl/Br ratio is clearly well above 1000. If the increase in Cl concentration is only due to the mixing of these two end-members, then the data will plot along the mixing line. For water that undergoes evaporation, the Cl concentration

will increase but the Cl/Br ratio will not change. It can be seen that for most springs and wells, Cl concentrations are relatively low, and Cl/Br ratios are generally below 300. However, several water samples have significantly higher Cl concentrations and Cl/Br ratios and plot along or below the mixing curve, indicating that the increase in Cl concentrations is a result of evapotranspiration (ET) and the mixing of fresh meteoric water with a saline water source that has a higher Cl/Br ratio. Note that even for the data point that plots furthest along the mixing curve (SM-1090), the proportion of saline water is less than 0.1%.

Most of the data points that stand out in Figure 8.1 are the same water samples that were recognized as outliers on the Piper diagram (Fig. 8.2). Spring water sample SM-1090 plots very close the hypothetical mixing curve, and is located at the top of the mountain range near the approximate location of a fault. This spring appears to be affected by addition of a saline water source with a high Cl/Br ratio. There may be pockets of the same high-Cl water present near this fault that are mixing with fresh meteoric waters and discharging at these springs or the high Cl/Br ratios may be due to anthropogenic contamination.

The well sample that stands out in Figure 8.1 is SM-0076, and it is located near the Mayhill fault that runs along a reach of the Rio Peñasco. Therefore, the elevated Cl/Br ratio may be due to upwelling water from depth along this fault.

REFERENCES

- Alcala, Franciso J. and Emilio Cusodio, 2008, *Using the Cl/Br ratio as a tracer to identify the origin of salinity in aquifers in Spain and Portugal*, Journal of Hydrology, Volume 359, p. 189-207.
- Davis, S. N., Whittemore, D. O., Fabryka-Martin, J., 1998, *Uses of Chloride/Bromide Ratios in Studies of Potable Water*, Ground Water, Vol. 36, No. 2, p. 338-350.
- Freeman, James T., 2007, *The use of bromide and chloride mass ratios to differentiate salt-dissolution and formation brines in shallow groundwaters of the Western Canadian Sedimentary Basin*, Hydrology Journal, Vol. 15, p 1377-1385.
- McLean W, and J. Jankowski, 2000, *Groundwater quality and sustainability in an alluvial aquifer, Australia*, in Sililo et al (eds) Proceedings of the XXX IAH congress on groundwater: Past Achievements and Future Challenges Cape Town South Africa, 26th November–1st December 2000. A. A. Balkema, Rotterdam.
- Nkotagu, H, 1996, *The groundwater geochemistry in a semi-arid, fractured crystalline basement area of Dodoma, Tanzania*, Journal of African Earth Sciences, Volume 23(4), p. 593–605.
- Street, J. B., and Peery, R., 2007, *Well report: Village of Cloudcroft, Apache replacement well PN-409-S-6, Cloudcroft, New Mexico*, John Shomaker & Associates, INC. Report prepared for US Bureau of Reclamation and the Village of Cloudcroft, 40 p.
- Sonney, Romain, and Francois-D. Vuataz, 2010, *Use of Cl/Br Ratio to Decipher the Origin of Dissolved Mineral Components in Deep Fluids from the Alps Range and Neighboring Areas*. Proceedings World Geothermal Congress, 2010, Bali, Indonesia, p. 1-13.