CHAPTER 4 – MIMBRES BASIN

INTRODUCTION

This chapter emphasizes the relationship between groundwater flow and the hydrogeologic framework of the Mimbres Basin aquifer system. The chapter concludes with an overview of groundwater quality in the context of hydrogeologic controls on the basin-system's groundwater-flow regime. As previously noted, the term "system" simply stresses the physiographic, geologic, and hydrogeologic complexity of the large area that makes up the Mimbres Basin watershed, and "basin-fill aquifer system" refers to all water-bearing deposits emplaced during Late Cenozoic filling of structural basins in the region. The bulk of this intermontane-basin fill consists of unconsolidated to partly indurated alluvial deposits, with some interbedded lacustrine and eolian sediments. Locally, the fill also includes important aquifer zones made up of igneous rocks (primarily basaltic flows and intrusions) emplaced during the interval of Basin and Range extension. Basin-fill aquifers are unconfined where deposits are unconsolidated, relatively coarse-grained, and located in the upper part of the zone of saturation. However, semiconfined to confined hydrologic conditions occur where fine-grained or partly indurated lithofacies are present. Major boundaries for the individual aquifer systems include bedrock–basin-fill contacts, fault zones, laterally extensive confining units, and inter-basin divides between regional groundwater-flow domains.

LOCATION AND PHYSIOGRAPHIC SETTING

Overview

The Mimbres Basin system is an interconnected group of geohydrologic subbasins that covers an area of about 13,300 km^2 (5,140 mi^2), and includes parts of the United States and the Republic of Mexico. Approximately 11,400 km^2 (4,410 mi^2) of the basin system is in southwestern New Mexico, including parts of Grant, Luna, Doña Ana and Sierra counties (Figure 4-1). Most of the area lies within the Mexican Highland section of the Basin and Range physiographic province, which is characterized by isolated north to northwest-trending mountain ranges rising from extensive bolson plains (Hawley 1969, 1975, 1986). The northernmost part of the basin system extends into the Mogollon-Datil section of the Transition Zone and is dominated by high volcanic plateaus and north to northwest-trending mountain ranges. One of the best sources of supplemental information on geomorphic features, surficial deposits, and soils in the Chihuahua part of the study area is still Morrison's (1969) reconnaissance mapping based on his interpretation of photographs taken from the Gemini and Apollo spacecrafts. Field observations by Hawley (1969) in the northern Chihuahua region were made during cooperative investigations of soil-geomorphic and hydrogeologic conditions by the USDA-SCS and the Secretaria de Recursos Hidraulicos, Dirección de Agrologia (Flores M. 1970).

The Mimbres surface-water basin is bounded on the north and west by the Continental Divide, which crosses parts of the Piños Altos and Black ranges, and the Big Burro uplift (Figure 4-1). At 3,051 m (10,011 ft) above sea level, Reeds Peak in the Black Range is the northernmost and highest point of the basin. This peak is located near the southeastern edge of the Datil-Mogollon section. The Black Range and Mimbres Mountains to the southeast decrease in altitude southward and are separated from the Cookes Range (Cookes Peak elevation 2,563 m; 8,410 ft) by a broad saddle. The east-central part of the basin is bounded by the Goodsight Mountains, the Sierra de las Uvas, the Sleeping Lady-Aden Hills uplift, and the basalt flows and cinder cones of the West Potrillo volcanic field. Basalts of the West Potrillo area cap a large variety of bedrock and basin-fill units including Precambrian, Paleozoic and Mesozoic rocks, Lower Tertiary igneous intrusive and extrusive units, and Sante Fe Group basin-fill (Seager 1989, 1995). The Rio Grande Valley and Mesilla Bolson lie to the east of these upland areas. As will be noted in the next section, a small part of the basin system watershed, located in the saddle between the Uvas-Sleeping Lady and Aden-West Potrillo uplifts (most of Mason Draw drainage basin), contributes recharge to the Mesilla Basin aquifer system.

The entire southern boundary of the Mimbres Basin system (from the West Potrillo uplift to Sierra Alta) is poorly defined in terms of both surface and subsurface-flow regimes. Subbasins east and southeast of the Columbus-Palomas area merge southward with (1) the extensive ephemeral-lake plains (*vadose* and *phreatic playas*) of the northwestern Bolson de los Muertos, and (2) the fan-delta complex of the terminal Rio Casas Grandes that presently flows into the *closed* and *undrained* basin of Laguna Guzman (Figure 3-1). The oldest exposed part of the fluvial-deltaic sequence was deposited by the ancestral Rio Casas Grandes when it emptied into pluvial Lake Palomas about 10 to 25 thousand years ago (ka) at the end of the Pleistocene Epoch. At its highest stands, this lake inundated the entire lower (Mimbres and Casas Grandes) basin area to an elevation of about 1,225 m (4,020 ft) above mean sea level (Reeves 1969, Hawley 1969, 1993, Morrison 1969, Table 3-1). Coarse-grained sediments of the fan-delta complex form a broad, but very low topographic divide between the present regional *sink* of the Rio Casas Grandes at Laguna Guzman (minimum elevation of 1,185 m; 3,890 ft), and lowest drainageways in the Mimbres Basin system east of Columbus and Palomas (also about the same elevation).
The Bolson de los Muertos (Hawley 1969, Reeves 1969) is the regional sink for the *open* and *partly drained* Mimbres Basin system. The bolson floor includes the ephemeral-lake plains of "El Barreal" (Figure 3-1) and Salinas de la Union (south of map area). Extensive parts of the bolson plain are also veneered with eolian deposits that partly cover older lacustrine sediments of pluvial Lake Palomas (Plate 1). As already noted, the term "Barreal" is correctly spelled *Barrial* in Spanish-American usage and denotes areas of mudflats. The term is generally synonymous with *vadose playa* in the American Southwest (Ordóñez 1936, Hawley 1969, Morrison 1969). The lowest part of the Bolson de los Muertos in the study area ("El Barreal," Figure 3-1) is about 1,175 to 1,180 m (3,855 to 3,870 ft) above mean sea level. This is about 50 m (165 ft) above the inner valley of the Rio Grande at El Paso-Cuidad Juárez (80 km, 50 mi to the northeast).

The Palomas volcanic field and Sierra Alta (mostly in Chihuahua), the Carrizalillo Hills, and the northwest-trending Cedar Mountains form the southwestern boundary of the basin system. A poorly defined surface-water and groundwater divide also separates the southwestern Mimbres Basin system from the lower basin of the Rio Casas Grandes in the southern part of the Palomas volcanic field (east of Boca Grande, Chihuahua). Basin fill and bedrock relationships in this area are obscured by Pliocene basalts of the Palomas field. Moreover, evidence of young fault scarps, cutting (Mid-to Late-?) Quaternary deposits in parts of the area extending from the eastern piedmont of Sierra Alta, across to the lower Casas Grandes valley, and to Laguna Guzman and Laguna Santa Maria (Figure 3-1, Plate 1) indicate that there may be a neotectonic component that influences some of the boundary shifts between the lower Mimbres and Casas Grandes fluvial-deltaic systems.

North of the Cedar Mountains, the western edge of the basin system follows the Continental Divide across the "Antelope Plains" area west of Deming, and continues up a slope of coalescing alluvial fans on the southeastern flank of the Big Burro Mountains. As will be noted in the next section, some underflow from a narrow zone west of the Divide contributes to groundwater in the western Mimbres Basin system (China Draw section of Lordsburg Subbasin - Chapter 7). The northwestern boundary crosses the topographic gap between the Burro uplift and the Pinos Altos Range. This short segment of the Continental Divide includes the Silver City-Tyrone area and part of the southern Mangas structural basin. The eastern flanks of the Pinos Altos Range and the western slopes of the Black Range form the headwaters of the Mimbres River, while the crests of these ranges mark the eastern boundary of the Gila River watershed.

The only major perennial stream in the Mimbres Basin system is the upper reach of the Mimbres River (Figure 4-1).
From its headwaters, the river flows south to the vicinity of Black Mountain (15 km, 9.5 mi. NW of Deming), where it turns to the east and flows north of Deming and the Little Florida Mountains. Although it contains perennial reaches in the 40 km (25 miles) upstream from the Grant County-Luna County border, the Mimbres River flows past Deming only during infrequent intervals. A well-defined river channel terminates about 16 km (10 mi) east of Deming. The area includes a small structural depression occupied by "Florida Lake," which is located just west of a buried bedrock constriction beneath the saddle between the Cooke's Range and Little Florida Mountains (Darton 1916, 1917). To the east, "paleo-flood flows" have produced a complex fluvial fan on the basin floor (Seager 1995, Love and Seager 1996). Darton (1916) reported flood peaks of 3 to 4.5 m (10 to 15 ft) during spring or early summer near Deming, and he noted that these discharge conditions could last up to a few days and recur two or three times a year.

San Vicente Arroyo drains the northwest part of the basin and it is one of the sites of catastrophic channel incision in the 1890-1910 period (Darton 1916, Plate VI B, Paige 1916, Rich 1911). The Silver City to Faywood reach of this arroyo contains an intermittent stream and receives effluent from wastewater treatment plants and mine-mill

Figure 4- 1. Land use in the Mimbres Basin.

processing sources (Hanson et al. 1994). Other drainageways in the basin contain ephemeral streams (arroyos, draws, dry washes) that flow only in response to intense rainstorms. Major arroyo systems include Seventysix Draw in the southern Deming Subbasin (Palomas Arroyo of Darton 1916), which discharges through the Columbus-Palomas area; and Macho Draw, which is the axial stream in the northern Florida Subbasin that includes the large watershed east of the Cookes Range.

Land Use

The Mimbres Basin system represents a wide array of land use/landcover, with forest areas prevalent in the higher elevations in the north and rangeland in the transition zone to drier, lower-elevation areas to the south. Lowlands contain a mix of irrigated farmland, rangeland and alkali-flats (Figure 4-1). Rangeland accounts for the majority of the area. Major urban areas include Deming, Silver City, and Hurley, with a few smaller rural communities scattered, such as Columbus, throughout the basin. The Silver City-Hurley area has been one of the largest metallic-mineral producing centers of the American Southwest for more than a century. Copper remains the top mineral commodity, but the region has also been the site of significant amounts of lead, zinc, and silver production (Orris et al. 1993). It includes the enormous open-pit mines at Tyrone and Santa Rita as well as large related mineral-processing centers at Hurley and Tyrone.

Most of the irrigated cropland is located in the area south of Deming and along the Mimbres River. Cropped acreage in the basin was reported at 14,222 ha (35,141 acres) irrigated acres in 1998. The principal crops were pasture 4,939 ha (12,204 acres), chile 2,700 ha (6,671 acres), cotton 2,582 ha (6,380 acres), and small grains 2,193 ha (5,420 acres) (Hawkes and Libbin 1999). Water use was not reported by hydrologic area for 1998, however, in 1995 the water depletions for irrigated agriculture in the basin were reported at 7.9 x10^7 m^3 (64,242 acre-feet) (Wilson 1998). This included 1.4 x10^7 m^3 (11,657 acre-feet) from surface water sources and 6.4 x10^7 m^3 (52,585 acre-feet) from groundwater sources. Hanson and others (1994, p 11-13) report that during the 1975 to 1985 period, about 77% of water use in the Mimbres Basin was for irrigated agriculture, with about 16-17% being used for mineral extraction and processing, and less than 4% for urban use. Groundwater provided about 75% of the developed water resources during this time.

Climate

The Mimbres Basin is typical of the arid southwest, with mostly clear skies and limited rainfall and humidity. Average annual precipitation varies from less than 25.4 cm (10 in) per year in low lying portions of the basin to as much as 76.2 cm (30 in) per year at higher elevations. Annual rainfall at the Deming station (elevation 1,321 m; 4,332 ft) averaged 23.4 cm (9.22 inches) over the 1948-1995 period. The average for Columbus (elevation 1,268 m; 4,160 ft) for the same period was 24.4 cm (9.59 inches). The station at Gage (elevation 1,344 m; 4,410 ft), which is about 32 km (20 mi) west of Deming, reported an average of 26.1 cm (10.28 in) over the period 1948-1995. White Signal (elevation 1,850 m; 6,070 ft), which is just a few miles southwest of Silver City, averaged 37.8 cm (14.89 in) for the period 1949-1994. In the upper reach of the Mimbres River at the Mimbres Ranger Station (elevation 1,904 m; 6,247 ft), the average was 43.3 cm (17.05 inches) for the period 1948-1995. Nearly half of the annual precipitation is from thunderstorms that occur from July through September. The station as Pinos Altos (elevation 2,134 m; 7,000 ft) reported an average of 49.5 cm (19.5 in) for the period 1948-1973. Average snow depth for the same period was 89 cm (35.18 in) (NCDC 1999).

Temperatures are generally warm to hot during the summer and mild in the winter in the lower elevations of the basin. In the higher elevations, summer temperatures are mild and winter temperatures cold. The annual mean air temperature at Deming for the period 1948-1995 is reported at 15.8° C (60.6° F). Chart 3-5 shows the average monthly minimum and maximum air temperatures. During the summer months (June, July, and August) the maximum temperatures are above 32° C (90° F) and minimum temperatures have been above 13.9° C (57° F) in June and above 16.6° C and (62° F) during July and August. During the winter months (December, January, and February) the maximum temperatures reach about 14.4° C (58° F) and minimum temperatures drop to about -2.2° C (28° F). Mean annual temperatures are similar at the other stations in the lower elevations: Columbus 16.8° C (62.3° F), Gage 15.2° C (59.4° F), and Florida 14.9° C (58.9° F). In the higher elevations, temperatures are cooler, with the maximum summer temperatures at the Mimbres Ranger Station below 30° C (86° F) (see Chart 3-6). Winter minimum temperatures in the higher elevations are much colder with the Mimbres Ranger Station average at about -7° C (20° F), (NCDC 1999). Large diurnal changes in temperature are common throughout the basin with a range of about 17° C (30° F), (NCDC 1999).

Records of pan evaporation are only available for the Florida station where the annual total class A pan evaporation (1948-1992) was 261 cm (103 in), (NCDC 1999).

HYDROGEOLOGIC FRAMEWORK

Introduction

In terms of deep crustal structure, the Mimbres Basin system is part of three overlapping tectonic provinces. The northern portion is in the southern Mogollon-Datil volcanic field, and the southwestern area lies within the Basin and Range province (Seager et al. 1982, Drewes et al. 1985). East of the Florida Mountains, a deep north-trending graben (called the Florida basin by Hanson et al. 1994) is considered to be part of the Rio Grande rift, a structural subbasin of the eastern Basin and Range region (Seager and Morgan 1979). However, province-scale tectonic features appear to have little or no effect on the relatively shallow groundwater-flow systems that are of primary concern in this report. Emphasis here will be on intra-basin-scale structures at shallower depth that demonstrably influence the groundwater flow in major basin-fill aquifers described in the following sections.

Structural Boundary and Bedrock Components

The thickness, character, and extent of the basin-fill in the Mimbres Basin system are determined by the Late Cenozoic history of individual subbasin components of this "system." The four major compilations of geologic information on the area are the reports, maps and structural cross-sections by Clemons (1998), Drewes and others (1985), Seager and others (1982) and Seager (1995). Geologic and geohydrologic information on the basin-system in Mexico was compiled from DGGTN (nd, a, b) maps of the Ciudad Juárez (2°) Sheet, and from Córdoba and others (1969). Klein's (1995) interpretation of seismic velocity sections in southwestern New Mexico is another important source of information on internal structure of basins and thickness of unconsolidated fill deposits. Unpublished estimates of basin-fill density and thickness based on isostatic-residual gravity interpretations by Heywood (1992, work in progress) have also been very valuable in preparing the hydrogeologic sections (Plate 1, AA' to EE') for this report. The basic hydrogeologic framework of the Mimbres Basin is shown in Figures 4-2a and 4-2b.

The bedrock and structural components of the basin system are discussed here in terms of basin-boundary properties and partitioning effects in intra-basin areas. As emphasized in Chapter 3, proper identification of structural and lithologic boundary conditions, and description of hydrostratigraphic units and lithofacies assemblages provide a sound basis for compiling the maps and cross sections that characterize the hydrogeologic framework of any given basin. The longitudinal profiles on Figure 4-2b illustrate the relation between structure and hydrostratigraphy along dominant groundwater-flow paths through the central part of the basin, and in combination with the cross-sections on Plate 1, they can be used to establish reasonable limits in groundwater-flow calculations. As already noted, the Mimbres Basin system is quite complex in terms of deep geologic structure. This complexity is reflected in the distribution pattern of major subbasin units and intra-basin structural highs described in this section, as well as in the hydrostratigraphic-unit and lithofacies-assemblage unit properties discussed in more detail below.

Hanson and others (1994, Figures 4 and 8) based much of their conceptual model of the basin's groundwater-flow system on the inferred distribution of seven subbasin units and intervening "structural highs," which they provisionally identified on the basis of interpretations of isostatic-residual gravity anomalies (Charles Heywood, USGS, personal communication, 1999) and seismic velocity profiles (e.g., Klein 1995). These major intra-basin structural features have been independently recognized by Seager (1995) and Seager and others (1982). However, they use different location designations for most of the subbasin units identified by Hanson and others (1994). The following list provides general information on location and suggested names of these subbasin and intra-basin features (Figure 4-2a inset):

1. Upper Mimbres Subbasin: Mimbres trench of Hanson and others (1994); Mimbres half graben of Seager and others (1982). West-tilted basin between the Black Range uplift (to east) and the Cobre uplift (Santa Rita area). The headwaters of the Mimbres River is in this area. This is one of two areas in the basin system where volcanics in or below the Lower (Gila) basin-fill sequence (map unit Tba) are locally major aquifers. *Note that the (upper) Mimbres structural basin continues southeastward into the Rio Grande rift to the east of the Cooke's Range (horst) block and is transitional to the Florida Subbasin (Plate 1).*
2. San Vicente Subbasin: Mangas trench of Hanson and others (1994); San Vicente half graben of Seager and

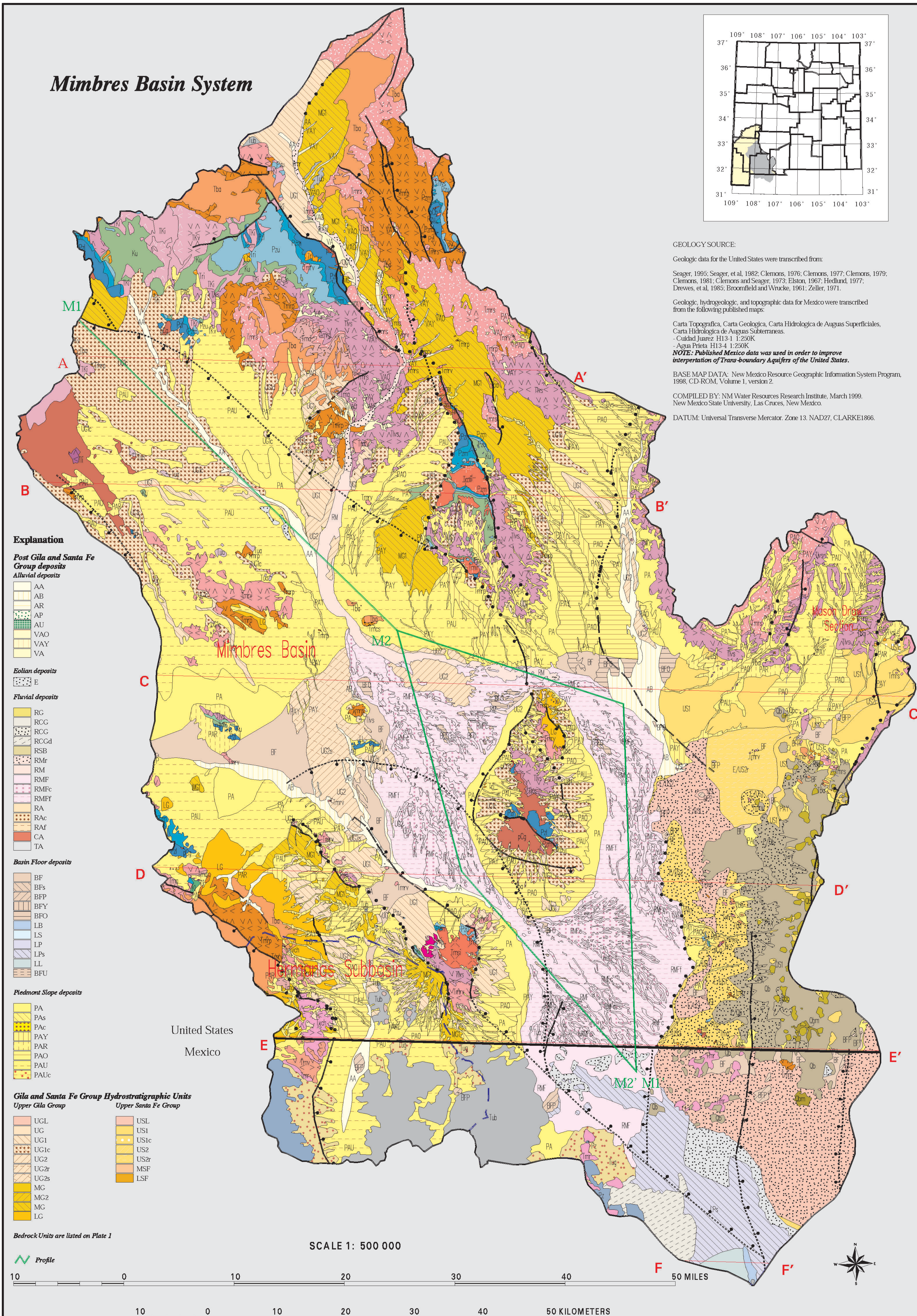
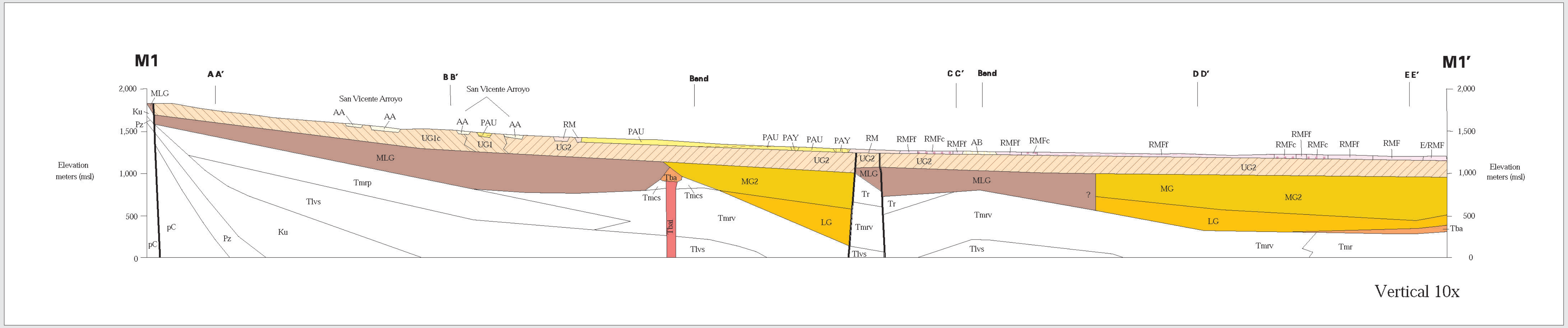


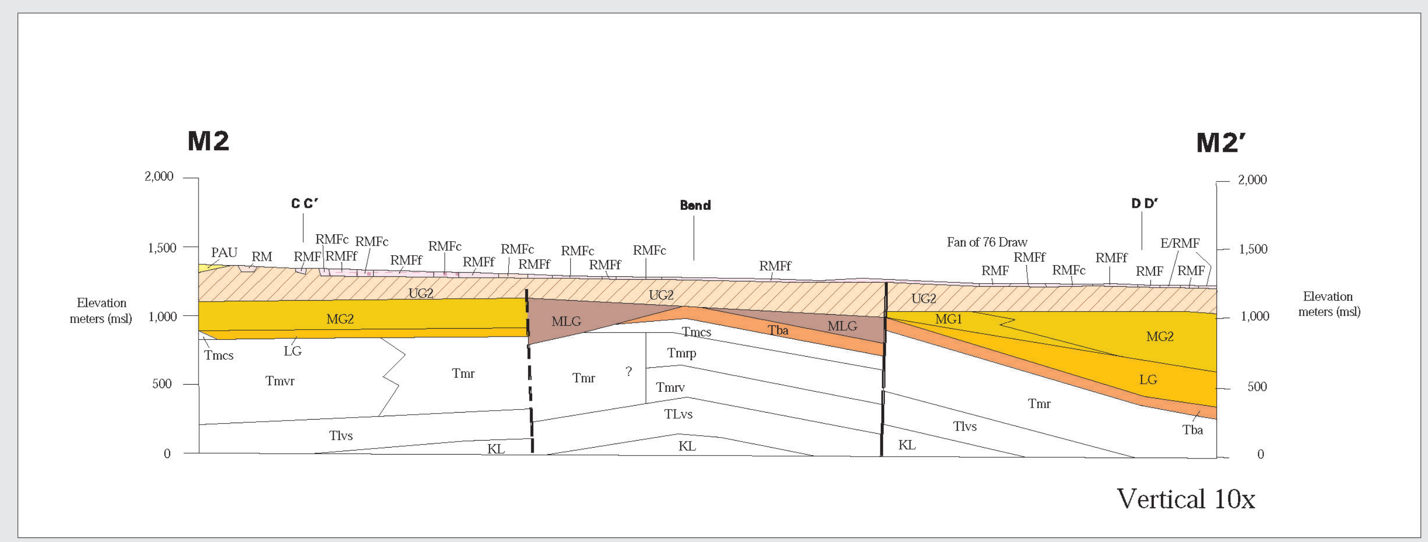
Figure 4- 2a. Hydrogeologic map of the Mimbres Basin System.



Profile Explanation

- AA - Alluvial deposits in axial arroyo channel systems; facies ***b*** (like ***5a***)
- AB - Unchanneled alluvial deposits of axial basin floodways; facies ***b and c*** (like ***3***)
- PAU - Older and younger piedmont-slope deposits and correlative Upper Gila (UG1) and Upper Santa Fe piedmont facies (***5 to 8***), undivided
- PAY - Younger piedmont-slope deposits of late Quaternary age; mostly facies ***5***
- RM - Channel, floodplain and low terrace deposits of the Lower Mimbres River; mostly facies ***a*** and ***b***
- RMF, E/RMF - Fluvial-fan deposits of the ancestral and modern Mimbres River, undivided; up to 20 m thick and primarily in vadose zone; facies ***a***
- RMFc - Fluvial-fan deposits of the Mimbres River, course-grained facies; mostly facies ***a2***
- RMFf - Fluvial-fan deposits of the Mimbres River, fine-grained facies; ***mostly lithofacies a3 and c;*** includes extensive gypsiferous and alkali impregnated sediments in the Florida subbasin
- UG1, UG1c - Proxiaml to distal, Upper Gila Hydrostratigraphic Units, piedmont slope facies, undivided; mostly facies ***5***
- UG2 - Upper Gila HSUs, undifferentiated fine to medium grained basin-floor deposits; including those of ancestral Mimbres and Rio Santa Barbara systems; mostly facies ***3***
- MG - Upper Tertiary: Middle Gila HSUs, undivided (includes MG1 and MG2); primarily facies ***7 and 8*** (mostly in zone of saturation in central basin areas)
- LG - Upper Tertiary, Lower Gila Hydrostratigraphic Units (HSUs), undivided piedmont and basin-floor facies ***4, 7, 8, 9, and 10.*** ***Note that unit is mostly buried in central basin area and is saturated***
- MLG - Middle and Lower Gila undivided HSUs, only on cross-sections
- Tbai - Middle-Upper Tertiary: Basaltic Andesite-intrusive masses
- Tba - Oligocene: Basaltic andesites interbedded with and underlying LG

Note that non-colored units are listed on Figure 4-2a and Plate 1.



SCALE 1: 500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

Figure 4-2b. Hydrogeologic profile for the Mimbres Basin.

others (1982). East-tilted structural basin west of the southern Cookes Range horst and the Cobre-Pinos Altos uplift (Silver City-Santa Rita area) to northeast. The subbasin's eastern boundary is the Treasure Mountain fault zone. To the northwest (Tyrone-Silver City area), it merges with the Mangas Subbasin, which extends northward to the Gila River Valley (Chapter 8). The headwaters and main channel of San Vicente Arroyo form the major drainage system in this subbasin. *Note that the Mangas-San Vicente Subbasin merges southward with the central part of the Mimbres Basin system in the Deming Subbasin area (unit 5), where fill thickness is as much as 1,300 m (4,265 ft) (Figure 4-2b and Plate 1, cross-sections AA' and BB').*

3. Dwyer Subbasin: Cross graben of Hanson and others (1994); unnamed by Seager and others (1982). Southwest-trending half-graben west of the Cookes Range uplift and southeast of the Cobre uplift, which connects the Upper Mimbres and Mangas-San Vicente subbasins. The middle reach of the Mimbres River is in this subbasin. *Note that the mostly perennial upper and middle reaches of the Mimbres River start recharging the major Mimbres basin-fill aquifer system where the river crosses the Dwyer-San Vicente Subbasin boundary zone, which is controlled by the (down to west) Treasure Mountain fault zone of Seager and others (1982) (Taylor fault of Hanson et al. 1994) (refer to Plate 1, cross-sections AA' and BB').*
4. Florida Subbasin: Florida graben of Hanson and others (1994); includes part of Mimbres Subbasin of Seager (1995) and Seager and others (1982). Graben and (east-tilted) half-graben complex between the Cookes Range and Goodsight Mountains to the north, and the Florida and West Potrillo (Camel Mountain) uplifts to the south. The Subbasin extends into Mexico where it merges southward with the Bolson de los Muertos at the ephemeral-lake plain of "El Barreal." Seager (1995) identifies two "Mimbres Subbasins" (here termed *sections*) where basin fill is very thick (1 km). Seager's *Akela section* is crossed by I-10 east of Deming, and the very deep (~ 1.5 km; 5,000 ft) *Mesquite Lake section*, which is located southeast of the Florida Mountains (Plate 1, EE'). The *Akela* structural depression in the central Florida Subbasin merges eastward with a broad saddle between the Sierra de las Uvas-Sleeping Lady Hills area (north) and the Aden Hills-West Potrillo uplift (south) that contains the watershed of Mason Draw (Figure 4-1). *Note that the present lower valley of the Mimbres River terminates in the western Akela section after crossing a broad structural (and bedrock) high that connects the Cooke's Range and Florida Mountain horst blocks and constricts groundwater flow. Refer to Plate 1, cross-sections BB' - EE', and profile M1M1' (Figure 4-2b).*
5. Deming Subbasin: Deming basin of Seager (1995) includes parts of southern Mangas and Seventysix subbasins of Hanson and others (1994). According to Seager (1995), this subbasin is transitional northeastward to the San Vicente "half graben" which is bounded on the east by the southern Cookes Range and Little Florida uplifts. Fill thickness is as much as 1.3 km (4,250 ft). The southern part of the Deming Subbasin was originally designated the Iona subbasin by Seager (1995). It is bounded on the north by the northwest-trending Snake Hills fault zone and generally coincides with the Seventysix basin of Hanson and others (1994). The southern border of this depression is the northwest-trending Seventysix fault zone and the Burdick Hills-Tres Hermanas horst. A saddle in this horst near Midway Butte (about 28 km, 18 mi SSW of Deming) is a local zone of interconnection with the Hermanas Subbasin (6). The central part of the Deming Subbasin, west of the main Florida uplift, was also the major site of "lower Rio Mimbres" fluvial deposition for much of Quaternary time. As this area aggraded, spill-out zones of the ancestral river occurred at two major locations: (a) in the broad saddle between the Florida and Cooke's Range uplifts (from the San Vicente to the central Florida [*Akela*] Subbasin); and (b) in the gap between the Florida and Tres Hermanas uplifts (from the southern Deming [*Iona-Seventysix*] to the southern Florida and Columbus Subbasins). *Refer to Plate 1, cross-sections CC' and DD', and Figure 4-2b, as well as Blanford and Wilson (1987, Figure 7).*
6. Hermanas Subbasin: Hermanas basin of Seager (1995); Tres Hermanas graben of Hanson and others (1994). A northwest-trending structural depression between the Burdick Hills-Tres Hermanas horst (Seager 1995) and the Cedar Mountains uplift (Cedar arch of Hanson et al. 1994). South of the Carrizalillo Hills, this east-tilted half graben to symmetric full graben extends into Mexico, where it is bounded on the west by the Sierra Alta frontal fault zone. The southern end of the subbasin includes the Palomas volcanic field (primarily Pliocene basalt flows) and the playa-lake basin of Laguna Polvaredones. The Hermanas structural subbasin appears to merge southward with the lower basin of the Rio Casas Grandes east of Boca Grande. *Note that most of the fill of this depression comprises units in the Middle to Lower part of the Gila Group, which are dominated by conglomerates and sandstones (see section on groundwater flow). (Refer to Plate 1, cross-sections DD' and EE', and Figure 4-2a).*
7. Columbus Subbasin: A narrow graben structure, located east of the Tres Hermanas uplift and bounded on the east by the Columbus fault zone of Seager (1995). It connects southward with the Palomas depression in Mexico and is transitional eastward with the southern Florida (*Mesquite Lake*) Subbasin. Basaltic volcanics (map units Tub and Tba?) are important components of the basin-fill aquifer system. *Refer to Plate 1, cross-sections DD' and EE', and Figure 4-2b, as well as Blanford and Wilson (1987, Figures 7-9). Note that this subbasin is not specifically named by Hanson and others (1994, Figure 4), but they do show it as a separate unit in their map (Figure 8), with estimated average thickness of the basin-fill aquifer in the < 300 m (550-1,000 ft) range.*

Two of the above listed subbasins (5 and 6) have small, but significant areas where surface- and subsurface-flow divides do not coincide. A narrow strip of land, 4-8 km (2.5-5 mi) wide and 50 km (30 mi) long west of the Continental Divide, is underlain by aquifers that drain to contiguous parts of the Upper Deming and Hermanas Subbasins (China Draw section of Lordsburg Subbasin - Chapter 7). The total surface area that contributes recharge to the Mimbres Basin system, however, is only about 315 km² (122 mi²), with each subbasin getting about half of the very small amount of estimated underflow (see discussions in following sections). Another part of the Mimbres Basin system where surface- and subsurface-flow divides do not coincide is east of the central Florida Subbasin in the broad saddle connecting the Uvas-Sleeping Lady and the Aden-West Potrillo uplifts. Here, about 470 km² (185 mi²) of the Mason Draw (surface) watershed overlies a shallow saturated zone that drains eastward into the Mesilla Basin aquifer system (King et al. 1971). Surface flow from the Mason Draw *section* (Figure 4-1) currently terminates in small *vadose playas* near I-10 just east of the Florida Subbasin.

Basin-Fill Aquifer System

Major Hydrostratigraphic Subdivisions

Lithostratigraphic units in the Mimbres Basin system range in age from Quaternary to Precambrian (Figure 4-2 and Plate 1). Quaternary to Neogene (Mio-Pliocene) basin-fill and local interbedded volcanics comprise the most extensive aquifer system, and they are subdivided into the major hydrostratigraphic-unit classes described in Chapter 3 (Figure 3-5, Tables 3-2 and 3-3). Previous workers have lumped much of this material into an undivided "bolson-fill" aquifer, or they have attempted to broadly correlate basin-fill deposits with the Santa Fe Group (eastern edge of study area) or the Gila Group (in most of the Mimbres Basin-system area). As emphasized in Chapter 3 (Figure 3-5), Santa Fe and Gila lithostratigraphic terminology varies greatly throughout the region (cf. Trauger 1972, Seager et al. 1982, 1987, Seager 1995, Drewes et al. 1985, and Clemons 1998). However, most investigators have made a clear distinction between (1) an upper, poorly-consolidated basin-fill unit, with thicknesses in the 100 to 300 m range (330 to 990 ft), and (2) a lower conglomeratic zone that is locally as much as 1,000 m (3,280 ft) thick. The lower, partly indurated zone is commonly designated the Gila Conglomerate even though much of the unit is made up of sandstones and mudstones (e.g., QTg map-unit of Hanson et al. 1994). Clemons (1982, 1984, 1998) recommended that the bulk of the upper basin-fill (which is mostly poorly consolidated alluvium of Pliocene to Early Pleistocene age) be included in an informal Upper Gila Group mapping unit, the Mimbres Formation, while Seager (1995) maps this formation as a formal lithostratigraphic unit. Trauger (1972, p 40-43) also recognized informal "upper and lower parts" of the Gila Conglomerate, with the upper unit comprising poorly-consolidated, younger basin-fill that appears to correlate with Seager's (1995) Mimbres Formation.

The hydrostratigraphic-unit classification of the Gila and Santa Fe groups used in this report (including HSUs: LG, MG, UG, MLS, MSF, US) provides a logical mechanism for subdividing basin-fill deposits into mappable units, thus facilitating geohydrologic characterization of basin-fill deposits and determination of their aquifer potential. The surficial layer of Upper Quaternary valley fill associated with larger stream systems (including deposits of the Upper Mimbres River and San Vicente Arroyo) is also recognized by most workers. This shallow aquifer unit, with saturated thicknesses of up to 30 m (100 ft), is locally a very important recharge zone. Hydrostratigraphic units RM, RMF, AA and BF are the major components of surficial alluvial deposits designated Qal and (upper) Qab by Hanson and others (1994).

The major limitation on proper recognition of hydrostratigraphic units and lithofacies assemblages (discussed below) in all the basin systems of the study area is the essential absence of borehole geophysical logging information. This type of subsurface data has been a key quality-control element in the hydrogeologic framework models developed in the Rio Grange Rift basins to the north and east (Hawley and Haase 1992, Hawley and Lozinsky 1992, Hawley et al. 1995, and Connell et al. 1998).

Major Lithofacies Assemblages

Lithofacies assemblages described in Chapter 3 (Figure 3-6, Tables 3-4 to 3-6) are the basic building blocks of the individual hydrostratigraphic units that form the basin-fill aquifer system. The explanation of Plate 1 provides a key to the lithofacies composition of the hydrostratigraphic units that are schematically depicted on hydrogeologic maps and cross sections in this report. As mapped on Figure 4-2a (and Plate 1), coarser-grained piedmont-slope facies assemblages (*5-8*) in hydrostratigraphic units: UG1, MLG, and LG dominate much of the northern and western part of the basin system (e.g., most of the Upper Mimbres, Dwyer, San Vicente, northern Florida and Hermanas subbasins); and sandy to clayey basin-floor facies (*1-4, 9, 10*) in hydrostratigraphic units: UG2, MG2, MLG, and LG form most of the basin-fill in the Deming, central and southern Florida, and Columbus subbasins.

Emphasis here is on the fact that the upper part of the basin-fill sequence (primarily Middle and Upper Gila hydrostratigraphic units and overlying surficial deposits of the Mimbres fluvial system) includes a gradually increasing amount of fluvial (facies *1-3*), eolian (*4*) and playa lake (*9, 10*) deposits as one moves southward along the dominant groundwater-flow paths toward the international border (Figure 3-4, Figure 4-2b). Furthermore, with the exception of local aquifers in basaltic volcanics, overall permeability of the entire basin-fill sequence decreases with depth, primarily due to increases in consolidation and cementation, and increasing proportion of fine-grained material (e.g., transition from facies assemblages *1* and *2*, through *3* and *4*, to *9* and *10*; and gradation from facies *5* and *6* to *7* and *8*). Permeability decreases are also associated with lateral transitions from basin-floor to piedmont-slope facies assemblages (e.g., facies *1-4* to *5* and *7*). This subject will be further discussed in the following sections.

Hydraulic Properties of Major Aquifer-System Components

Recent works by Hanson and others (1994, Figure 9) and Wilkins (1998, Figure 18, Table 7) show that even preliminary analyses of drillers' logs and well performance data (e.g., specific capacity determinations) can be powerful tools in documenting spatial variability in the hydraulic properties of major aquifer zones (Figure 4-3). For example, the analysis by Hanson and others (1994) of variation in specific capacity with depth for 278 wells completed in the basin-fill aquifer system shows that most wells (60%) with highest average specific-capacity values (232 - 304 m^3/d/m; 13-17 gpm/ft) are completed in the upper 100 m (330 ft) of saturated basin-fill. An additional 33% of the wells had average specific capacities between 143-214 m^3/d/m (8-12 gpm/ft), and were completed at depths between 100 and 200 m (330 and 660 ft). Wells with average values of 125 to 161 m^3/d/m (7 to 9 gpm/ft) were completed between 200 and 300 m (660 and 980 ft) and represent only 5% of the sampled population. Below that depth to 450 m (1,500 ft), specific capacities of 6 reported wells (2%) had average values of less than 107 m^3/d/m (6 gpm/ft).

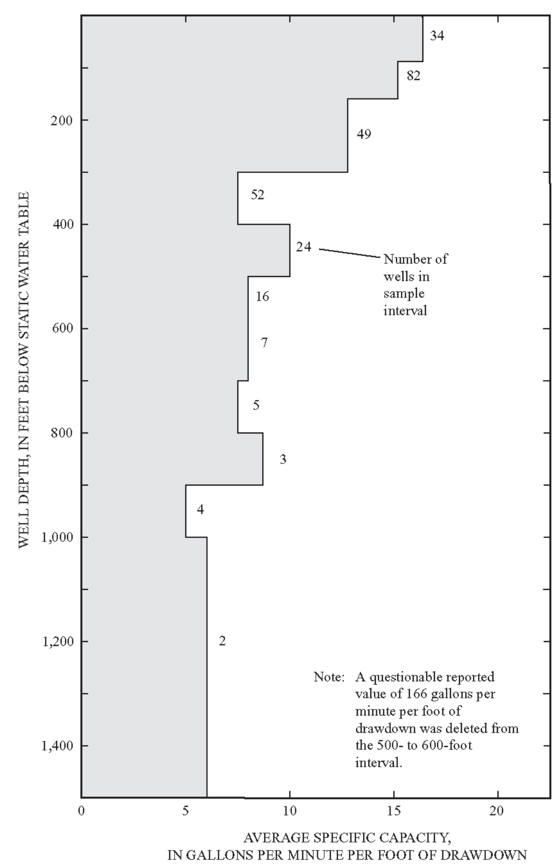


Figure 4-3. Specific capacities for selected Mimbres Basin wells (from Hanson et al. 1994)

Wilkins (1998) has evaluated percentage ranges of broad textural and induration classes using available drillers' logs in several parts of the basin system (also to maximum depths of 950 m; 3,100 ft). He (p. 30) finds that most wells "penetrate [Gila] conglomerate in the first 60 m (200 feet) of saturated sediments in the upper reaches of the Mimbres River and San Vicente Arroyo." Fine-grained and/or poorly sorted sediments are the dominant textural groups in weakly consolidated basin-fill of central and northwestern parts of the basin. Moreover, deposits with less than 20% fines or cemented zones comprise no more than 25% of the saturated fill anywhere in the basin, and such materials are not documented in driller logs at depths below 200 to 300 m (660 to 1,000 ft). In this report, the interpretation of the hydrostratigraphic-unit distribution patterns (and associated facies assemblages) shown on cross-sections AA' to FF' (Plate 1), and flow-line sections along subbasin axes (Figure 4-2a, b) agree with the general observations on both vertical and horizontal variation in aquifer properties made by Hanson and others (1994) and Wilkins (1998).

Facies assemblages with moderate (saturated horizontal) hydraulic conductivities (values in the 3 to 10 m/d (10 to 33 ft/d) range; Table 3-5) are restricted to Upper Gila Hydrostratigraphic Units (primarily UG2 map-units on Plate 1, Figure 4-2b) that have maximum thicknesses in the 10 to 100 m (30 - 330 ft) range. In marked contrast, silty-clay and conglomeratic units that characterize Middle and Lower Gila Hydrostratigraphic Units (MG, LG, MLG; Plate 1, Figure 4-2b) are assigned hydraulic conductivity values, ranging from extremely low to no more than 1 m/day (3 ft/d) (Table 3-5, facies *7-10*). As recognized by Hanson and others (1994, p. 73), a major limitation to the two-dimensional groundwater-flow model used in their study, was the requirement that full thicknesses of bolson-fill deposits be simulated as single hydrologic units. Three-dimensional modeling approaches, such as those used by Frenzel and Kaehler (1992) and Kernodle and others (1995), would definitely be appropriate for the Mimbres Basin based on the present investigation and the above-cited studies (cf. Kernodle 1992a, and concluding part of following section).

Hanson and others (1994) estimated transmissivity values for the basin-fill aquifer based on aquifer tests, specific capacities of wells (Figure 4-3), and lithologic logs of wells. They also reported (Hanson 1994, Table 4) that transmissivity values determined from aquifer tests at wells completed in basin-fill aquifers range from 1 to 4,650 m^2/d (10 to 50,000 ft^2/d). Most of these tests were short-duration, single-well tests in boreholes that penetrated only a small part of the total aquifer thickness. The wide range in transmissivity values may be caused partly by limitations in the testing methods and by the heterogeneity of sediments that comprise the basin-fill aquifer (Hanson et al. 1994).

Another factor that must be considered with respect to aquifer hydraulic properties is the potential for consolidation, land subsidence and earth-fissure formation in areas of substantial groundwater withdrawal from the basin-fill aquifer system. Land subsidence and earth-fissure formation have already been well documented in the central Deming Subbasin (Contaldo and Mueller 1988, Haneberg and Friesen 1995) and has been reported near Columbus.

MAJOR COMPONENTS OF THE GROUNDWATER-FLOW SYSTEM

Surface-Water Components

Surface flow in the Mimbres Basin system has four major components that directly interface with groundwater flow: (1) perennial and intermittent flow in reaches of the upper Mimbres River and San Vincente Arroyo; (2) intermittent mountain streams; (3) ephemeral streams in arroyos; and (4) widely scattered springs and seeps.

Perennial Streams

The Mimbres River, flowing southward from its headwaters in the Black Range and Pinos Altos Range, is the largest stream in the Mimbres Basin (Figure 4-4). In the Upper Mimbres Subbasin (Figure 4-1), the channel of the Mimbres River usually has perennial flow from about 11 km (7 mi) north of the village of Mimbres to the Grant-Luna county line (Trauger 1972, p. 50). However, during the irrigation season, diversions to the ditches may cause parts of the channel to be dry in this reach (Hanson et al. 1994). As already noted, occasional large flood flows also extend into the central Florida Subbasin east of the Little Florida Mountains. Two exceptionally large floods from December 1904 through May 1905, and from January through April 1906 resulted in flows that almost reached to the U.S./Mexico border (Darton 1916, p.111).

The surficial layer of alluvium that underlies the floor of the Mimbres River Valley includes partly saturated channel deposits, mapped as RMr and RM in the "upper" and "lower" parts of the valley upstream from the Deming area. Downstream from the incised channel reach, fluvial-fan deposits, mapped as RMF, RMFf, and RMFc, cover the floors of the Deming and Florida subbasins (Figures 4-2a, 4-2b and Plate 1). These distributary channel deposits are discussed in detail by Love and Seager (1996). The RMr unit of the perennial to intermittent upper Mimbres River is

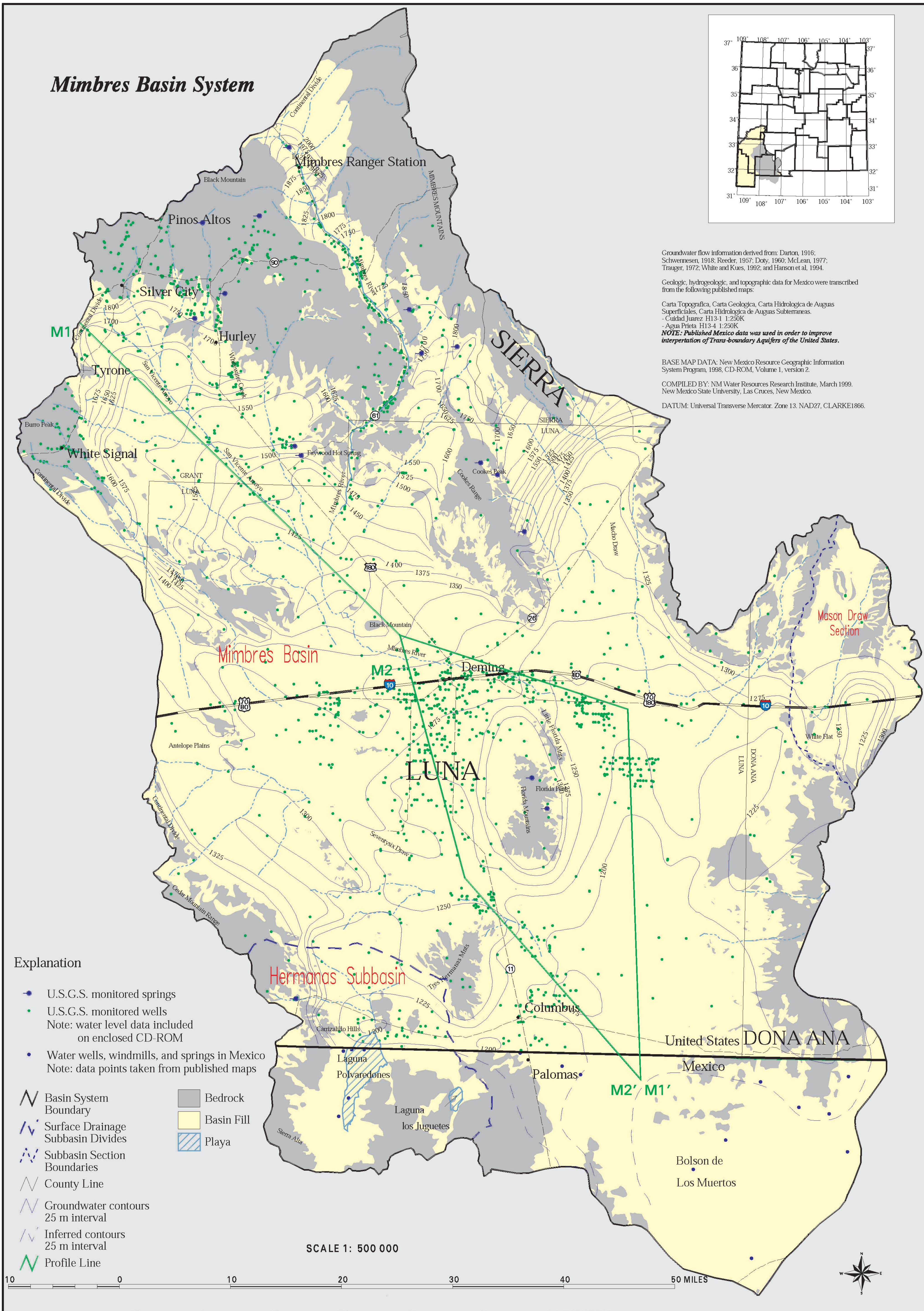


Figure 4-4. Mimbres Basin groundwater contours, flow direction, and stream- aquifer relationships

an important local aquifer that provides recharge to the underlying Gila Group and contiguous bedrock units in places where hydraulic head decreases with depth (Figure 4-2a, 4-2b and Plate 1). Gaining reaches of the upper Mimbres channel also serve as conduits for recharge from upper basin highlands. The fill of the lower Mimbres River Valley (unit RM) overlies the upper hydrostratigraphic unit UG2 (Figures 4-2a, 4-2b and Plate 1) and provides significant recharge to these coarse-grained fluvial deposits (facies *1* and *2*) between Faywood and Deming (Figures 4-1, 4-2a, b and Plate 1).

Intermittent Streams

Intermittent streams, with very short perennial reaches and commonly associated with small springs and seeps, are primarily restricted to the high mountain ranges (Black and Pinos Altos) that form the northern boundary of the Mimbres Basin system. Many of these streams are in the upper drainage basins of San Vicente Arroyo and the Mimbres River, and they contribute directly or indirectly to flood and base flow of these two streams.

San Vicente Arroyo, which originates on the southwest slopes of the Pinos Altos Range and the western slopes of the Cobre uplift, is the principal drainage for the northwest part of the basin system. Its major (ephemeral to intermittent) tributaries are Rio de Arenas, Cameron Creek, and Whitewater Creek (Trauger 1972). Throughout most of its length, San Vicente Arroyo is an ephemeral to intermittent stream, however, an estimated perennial discharge of 11 to 16 m^3/d (20 to 30 gpm) flows in the channel for a short distance downstream from the gage at Silver City. This flow is primarily due to upstream groundwater contributions, return seepage from urban irrigation, and probably line losses from the city water system (Trauger 1972, p. 51). The sewage treatment plant located about 8 km (5 mi) downstream from Silver City also discharges approximately 7.6 m^3/d (1.4 cfs) of treated effluent to San Vicente Arroyo (Hanson et al. 1994). The surficial alluvial deposits associated with the arroyo's axial channel are mapped on Figure 4-2a and Figure 4-2b as hydrostratigraphic unit AA. Partly saturated channel fills of hydrostratigraphic unit AA overlie the Upper Gila Group piedmont and basin-floor deposits (map units UG1c, UG1, and UG2; facies *5, 7, 1,* and *2*), and at least locally provide significant recharge to the basin-fill aquifer system.

Ephemeral Streams

Cow Springs and Seventysix Draw are the two major ephemeral streams draining the western slopes of the basin system head in the White Signal area southwest of Burro Peak. Cow Springs Draw terminates in the broad basin-floor area of the north-western Deming Subbasin. Seventysix Draw (Palomas Arroyo of Darton 1916), which also receives runoff from the Cedar Mountains uplift, continues southeastward along the boundary zone between the Deming and Hermanas subbasins, and finally terminates in the Columbus-Palomas area near the boundary between the Columbus and southwestern Florida subbasins. Most of the runoff from the southern Cedar Mountains uplift, western Tres Hermanas Mountains, and Carrizalillo Hills flows through a system of distributary channels of Hermanas Draw in the southern part of the Hermanas Subbasin, and ultimately discharges into the Laguna Povaredones (*vadose playa*) depression at the west edge of the Palomas volcanic field. However, at least some groundwater discharge from this *closed basin* appears to drain eastward to the Columbus Subbasin (cf. following discussion and Figure 4-4a).

The other major ephemeral stream contributing to the Mimbres River system is Macho Creek, which receives surface runoff from almost the entire Florida Subbasin area north of Interstate Highway 10. A complex of distributary channels marks its confluence with the lower Mimbres River in the central (*Akela*) part of the Florida Subbasin. The easternmost large stream in the Mimbres Basin system is Mason Draw, which is the *trunk* arroyo that receives most of the storm runoff from the southern slopes of Sierra de las Uvas. This axial drainageway terminates in an area of closed depressions located in the broad saddle between the West Potrillo and Uvas-Goodsight volcanic fields. Small *vadose playas* in this area would ultimately spill to the *Akela section* of the Florida Subbasin in extreme flood events. As already noted, previous work (King et al. 1971, Wilson et al. 1981) indicates that most groundwater flow from the 470 km^2 (185 mi^2) Mason Draw watershed drains eastward into the Mesilla Basin aquifer system. *Note that this part of the Mimbres Basin system is informally designated the Mason Draw section in this report (Figures 3-1, 4-1).*

Springs and Seeps

In the context of groundwater-flow in basin-fill aquifers described herein, nearly all springs and seeps are components of "mountain-front recharge" that contribute to the groundwater reservoir in the Mimbres Basin system. Locations of various springs in the area are shown on Figure 4-4. This is not a complete listing of springs in the basin. Additional information for the springs shown on Figure 4-4 can be found in the USGS Open-File Report 92-118 (White and Kues 1992).

According to Hanson and others (1994, p. 20), "thirty-three springs and an unknown number of seeps are scattered through the Mimbres Basin. Most springs discharge from fractured bedrock in the mountainous areas of the basin, or represent underflow in alluvial channels that is forced to the surface by shallow bedrock, often volcanic dikes." Springs with the highest historically documented discharge (Apache Tejo - 3,260 m^3/d, 1,350 gpm; Warm - not reported; Lindauer - 245 m^3/d (45 gpm); and Faywood Hot Springs - 165 m^3/d, 30 gpm) are aligned along the Treasure Mountain Fault zone at the eastern edge of the San Vicente Subbasin. Prior to extensive well development early in the 20th century, these springs tapped fractured bedrock aquifers with large recharge areas in the Cobre uplift and possibly part of the Pinos Altos Range. Nearby well fields have subsequently intercepted most of the groundwater flow that originally contributed to the discharge of the larger springs in the basin system. It is also important to note that there is no historical record of any large springs in the International Boundary area between Faywood Hot Springs and the lower reach of the Rio Casas Grandes near Laguna Guzman, Chihuahua. This is well documented in reports of the early boundary and railroad surveys, and accounts relating to the "Mormon Battalion" expedition and the Butterfield Trail (Bailey 1963, Conkling and Conkling 1947, and James 1969). For example, the 1854 - A.B. Gray Survey for the Texas Western Railroad (Bailey 1963) found no reliable water supply near the 32nd parallel between El Paso and the Animas Basin except for a moderately large spring at the Carrizalillo site (in the southern Hermanas Subbasin). Estimated historic discharge of this spring was probably less than 100 m^3/d (20 gpm), and much of the water was used to supply a former route of the Southern Pacific Railroad (SPRR) at nearby Hermanas Station (Darton 1916, 1933).

Recharge

The Mimbres Basin system is typical of most arid to semiarid regions in that only a very small percentage of basinwide precipitation and surface runoff contributes to groundwater recharge. Data compiled herein and interpretations by Hanson and others (1994, p. 41) indicate that this contribution is less than 2% of the average annual precipitation or about 7.8 x 10^7 m^3 (62,245 ac-ft). Using the "mountain-front-runoff method" of Hearne and Dewey (1988), with adjustment for surface outflow from the Upper Mimbres River Subbasin, Hanson and others (1994) estimated the mountain-front component of annual recharge at about 6.82 x $10^7 m^3$ (55,300 ac-ft).

From a basinwide perspective, all major upland areas with relatively high precipitation-runoff (and low temperature and evapotranspiration) regimes are located in the northern part of the basin system (north of 32° 30' latitude, and near the Luna-Grant County line). Sections AA' and BB' on Plate 1 illustrate the topographic setting in profile. Moreover, there is general agreement that most of the recharge to the basin-fill aquifer is in that area, with the exception of a narrow corridor of effective recharge extending south along the Mimbres Valley between Faywood gaging station and Deming (Darton 1916, Trauger 1972, Hanson et al. 1994). Estimates of the distribution of mountain-front recharge throughout the basin system by Hanson and others (1994, Table 6), which compare areas north and south of their Section AA' (near Latitude 32° 15'), also indicate that most recharge to the basin-fill aquifer system is derived from the highland areas and Upper Mimbres River Subbasin (including the San Vicente Arroyo system) north of Deming. In fact, there may be little or no effective recharge contribution from many upland areas in the southern part of the basin system, excluding the largest watersheds in the Florida, Tres Hermanas, Cedar Mountains, and Sierra Alta uplifts.

From a more local (subbasin) perspective, the most effective zones of recharge to basin-fill aquifers occur in four major settings:

1. Along losing reaches of the upper Mimbres River channel downstream from the Faywood gaging station (in the Dwyer Subbasin near the Luna-Grant county line).
2. Percolation losses from saturated zones in channels of major arroyos, such as the reach of San Vicente Arroyo starting about 8 km (5 mi) downstream from Silver City.
3. Areas of direct groundwater discharge from bedrock aquifer systems in highland areas to (lower pressured) basin-fill aquifers. This component of mountain-front recharge may be very large, particularly near valleys and canyons draining high-mountain terrains. *Note that "discharge" from large springs such as Apache, Tejo, Lindauer and Faywood Hot Springs along the Treasure Mountain fault zone at the eastern edge of the San Vicente Subbasin) is part of this basin-fill recharge (see proceeding discussion).*
4. Underflow (groundwater draining) from adjacent basins, mostly from the *China Draw section* of the Lordsburg Subbasin (Chapter 7) *(see Figures 3-1, 3-2 and 4-1).*

The hydrogeologic map and cross sections (Figures 4-2a, 4-2b, Plate 1) also illustrate the importance of shallow buried bedrock highs that locally restrict groundwater flow. Such constrictions influence not only movement and discharge (discussed below), but also recharge. From a recharge perspective, the buried bedrock constrictions near Faywood gaging station forces much of the underflow in the Upper Mimbres and Dwyer subbasins to either the surface or the shallow subsurface. In the losing (Faywood to Deming) channel reach downstream from this constriction, the situation is reversed, and there are major contributions of both surface water and shallow groundwater to the deeper aquifer zones of the San Vicente and Deming subbasins. The major aquifer component in the latter area is the Upper Gila HSU-UG2 (facies *1-3*). Hanson and others (1994, Table 6) estimate that as much as 19.7 x 10^6 m^3 (16,000 ac-ft) is annually contributed to basin-fill recharge in this very local area. Channel losses in the upper reaches of the San Vicente Arroyo system, infiltration from the large springs (Apache Tejo-Lindauer-Faywood) along the Treasure Mountain fault zone, and other sources of mountain-front recharge all contribute some recharge to the basin-fill aquifer near the confluence of the Mimbres River and San Vicente Arroyo near the Grant-Luna county line. This contribution however, probably does not exceed 12.3 x 10^6 m^3/yr (10,000 ac-ft/yr). Hanson and others (1994, p 43, 62) originally estimated that about 10.4 x 10^6 m^3/yr (8,400 ac-ft/yr) might enter the San Vicente Subbasin as underflow from the Mangas “trench” area north of the Continental Divide. However, they subsequently concluded (as is recognized in our report) that this Divide segment separates the upper Gila and northern Mimbres basins in terms of both surface-water and groundwater flow.

Movement and Discharge

The direction and amount of groundwater-flow are at best an estimate due to the uncertainties in the hydraulic gradient, aquifer thickness, and hydraulic conductivity. Groundwater in the Mimbres Basin system generally moves from the northern highlands to the interior basins and southward toward the U.S./Mexico border (Figure 4-4). Isolated interior mountains also locally modify the regional flow pattern by adding minor amounts of recharge and altering the width and depth of the basin-fill aquifer. Hanson and others (1994) constructed a predevelopment groundwater contour map based on work done by McLean (1977), and data presented by Darton (1916, 1917). The predevelopment map indicates an estimated annual groundwater flow from New Mexico into Chihuahua of about 8 x 10^6 m^3 (6,500 ac-ft). However, extensive groundwater development has currently altered the directions of groundwater-flow in the basin-fill aquifer toward local pumping centers near Deming and Columbus (Blandford and Wilson 1987, Hanson et al. 1994). Groundwater-flow across the U.S./Mexico border has currently been altered to a south to north direction.

The predevelopment interpretation of major sites of groundwater discharge, based on the synthesis of previous work by Hanson and others (1994, Table 6), shows that most losses from the flow system (as much as 8.8 x 10^7 m^3, 71,000 ac-ft) were due to evapotranspiration from (1) alluvial flats and playa lakes in the northern Deming and west-central Florida subbasins (about 5.3 x10^7 m^3, 43,000 ac-ft); and (2) evaporation from playa lakes and alkali flats in the Chihuahua portion of the basin system (as much as 3.5 x 10^7 m^3, 28,000 ac-ft). Other discharge components including evaporation loss from lakes, streams and rivers, transpiration from native vegetation, and underflow across the southern basin boundary are very minor compared to above-mentioned evapotranspiration losses in the central and southern part of the basin system prior to the historic period of intensive groundwater use by irrigated agriculture and mine-mill activity.

In the context of modern exploitation of the basin-fill aquifer system, pumping of groundwater for irrigation currently captures a significant proportion of the water resource that was previously discharged by evapotranspiration in the natural geohydrologic setting that has existed since the end of the Pleistocene (glacial-pluvial) Epoch about 10,000 years ago. Wilson (1997) reports that current groundwater depletions for irrigated agriculture in the Luna and Grant county areas are about 6.9 x 10^7 m^3 (56,000 ac-ft) (>96% in Luna County). This groundwater use alone is slightly more than the total amount of recharge estimated for aquifers throughout the Mimbres Basin system (Hanson et al. 1994, this report).

CONCEPTUAL MODEL OF GROUNDWATER FLOW

The conceptual model of groundwater flow in the Mimbres Basin aquifer system needs to be examined in terms of the hydrogeologic constraints placed on the flow regime by structural-boundary, hydrostratigraphic, and lithofacies conditions, which are either well documented or reasonably inferred. The interpretations of the information presented in this report are graphically presented or tabulated in Plate1; Figures 4-2a, 4-2b; and Tables 3-2 to 3-6. The “Summary of U.S. Geological Survey Ground-Water-Flow Models of Basin-Fill Aquifers in the Southwestern Alluvial Basins Region...” by J.M. Kernodle (1992a) sets the tone for this section: “As a rule, identifiable geologic features that affect groundwater flow paths, including geologic structure and lithology of beds, need to be represented in the model (p. 65).” According to Kernodle (p. 66) major categories of geohydrologic boundaries in alluvial basins include: “1) internal boundaries that alter flow paths, including small-permeability beds, fissure-flow volcanics and faults; 2) recharge boundaries, primarily around the perimeter of basins (mountain-front recharge), and along the channels of intermittent streams, arroyos, and washes (tributary recharge); [and] 3) recharge and discharge boundaries associated with semipermanent surface-water systems in the flood plains of major streams...” Finally, in terms of numerical modeling strategies, Kernodle (p. 59) states that: “Although the two-dimensional models may successfully reproduce selected responses of the aquifer, they often fail to accurately mimic the function of the system.” In addition (p. 60): “In comparison with two-dimensional groundwater flow models, three-dimensional models may more accurately portray the flow system of the basin-fill aquifer system by simulating the vertical components of flow. However, the worth of the model is still a function of the accuracy of the hydrologist’s concept of the [hydrogeologic, and geohydrologic] workings of the aquifer system.”

Limitations of recent two-dimensional modeling efforts in the Mimbres Basin system are clearly recognized by the modelers themselves (Hanson et al. 1994, p. 35, 73, 76, 89). Modern and predevelopment estimates of basinwide recharge and discharge appear to be reasonably well constrained, and relevant information on climatic, surface-water, and vegetation is adequately presented. The general properties of the shallow groundwater-flow system and topography of the potentiometric “water-table” surface also are well documented, primarily due to pioneering work by Darton (1916, 1917) and Trauger (1972), and recent studies by McLean (1977), and Hanson and others (1994). The exhaustive compilation of available hydrogeologic information during the present study and its presentation in a three-dimensional format on Plate 1, and Figures 4-2a and 4-2b further demonstrates that two-dimensional portrayals of the groundwater-flow regime just will not work. A reasonable assumption can be made that most of the presently available groundwater resource is very old water of very uncertain quality, much of which will be difficult to develop in terms of both economics and production life. *Note that this observation applies to all basin systems covered in this report, except for the Gila River Basin (Chapter 8).*

While the basin-fill aquifer system is more than 1,000 m (3,300 ft) thick in deeper subbasin areas, the thickness of the groundwater production zone rarely exceeds 200 m (660 ft) and is commonly less than 100 m (330 ft). A liberal estimate of available water of good quality in storage is no more than 3.78 x 10^{10} m^3 (37.8 km^3, 3.06 x 10^7 ac-ft). This assumes an average saturated thickness of basin-fill of about 100 m (330 ft) in five of the seven major subbasin areas described in this chapter (San Vicente, Florida, Deming, Hermanas, and Columbus) and specific yield value of 0.1. However, at many localities, much of the upper 100 m (330 ft) of saturated basin fill is either fine grained or partly indurated, and semiconfined to confined conditions appear to better characterize the aquifer system.

Groundwater-flow calculations must always incorporate the physical constraints placed on the system by the structural framework of individual subbasins that are separated by (often shallowly) buried bedrock highs (Figure 4-2b, Plate 1 sections CC’, DD’, EE’). The most important buried constrictions or sills that influence the groundwater-flow regime are located beneath the broad topographic saddles that separate (1) the Florida and Cookes Range uplifts, and (2) the southern Florida and Tres Hermanas mountains. The constriction north of the Little Florida Mountains may actually be the most effective barrier of the two, but this would have to be confirmed by detailed test drilling and geophysical surveys (cf. cross sections in Figure 4-2b).

As shown originally by Darton (1916, Hanson et al. 1994, Figure 11), these constrictions effectively “ponded” groundwater in the deep Deming and southern San Vicente subbasins prior to and during early stages of groundwater-irrigation development. Seventysix Draw contributed some recharge to this *partly drained* groundwater flow system (Figure 3-3), but the bulk of the recharge clearly came from the upper Mimbres River and San Vicente Arroyo drainage basins (cf. preceding discussion of recharge). The broad bedrock high (Tres Hermanas-Burdick [Hills] uplift), which separates the southwestern Deming Subbasin from the Hermanas Subbasin, appears to be overtopped by thin hydrostratigraphic unit UG deposits in a shallowly buried saddle near Midway Butte (about 28 km, 18 mi SSW of Deming). This fill is partly saturated as the result of groundwater “ponding” in the Deming Subbasin, however, there is no evidence that spillage (underflow) from the Deming Subbasin aquifer system to the Hermanas Subbasin has been a significant contribution to groundwater flow along the International Boundary (near the *closed* depression of Laguna Polvaredones).

Special emphasis in this report, and in the "preliminary simulation of groundwater flow in the Mimbres Basin …" by Hanson and others (1994), is on development of a better conceptual model of the hydrogeologic controls on the groundwater-flow systems in the International Boundary Zone extending from the Carrizalillo Hills (on the west) to the West Potrillo uplift (on the east). Section BB' of Hanson and others (1994) shows their interpretation of the hydrogeologic setting. The present study has benefitted greatly from the fact that detailed geologic information on the border zone (primarily from Seager and Clemons 1988, Seager 1989, 1995), which was not available to Hanson and others (1994), has been incorporated into the hydrogeological-framework model presented here (Plate 1, Sections DD' and EE').

Calculations of predevelopment groundwater flow across various sections in the Mimbres Basin are summarized in Table 7 of Hansen and others (1994). The calculations of "total flow in bolson across [the] Mexican border," are in great part based on their conceptual model of the basin's hydrogeologic framework, which reflects preliminary interpretations of (1) isostatic–residual gravity anomalies (cf. Heywood, personal communication 1992) and (2) seismic refraction profiles, recently published by Klein (1995). In addition, their calculations of predevelopment flow assume "mountain-front-recharge" contributions that may be much too large for, at least, the southern part of the basin system (preceding discussion in section on recharge).

Estimates of annual transboundary flow by Hanson and others (1994) in the southern Hermanas Subbasin between the Carrizalillo Hills and the southern Tres Hermanas uplift are about 2.8 x 10^6 m^3 (2,300 ac-ft), based on a horizontal hydraulic conductivity value of about 2 m/d (6 ft/d), a hydraulic gradient of 0.0003, and a cross sectional area of about 14 km^2 (1.5 x 10^8 ft^2). The latter dimension approximates a saturated section that is about 16 km wide and 0.8 km deep. This cross-sectional area and the slope appear to be reasonable values. The estimate of hydraulic conductivity, however, may be at least one order of magnitude too high, because all of the basin fill in part of the Middle and Lower Gila Group (HSU-MLG) has estimated horizontal hydraulic conductivities in the "very low" range (facies *7-9*, Table 3-8). Groundwater-flow lines in this area, moreover, appear to parallel the International Boundary (Figure 4-3), and underflow from the Hermanas Subbasin may in fact contribute to the aquifer in the Columbus and Palomas area.

With reference to the southern Hermanas Subbasin, it is also important to note that shallow groundwater levels in the reach of the Rio Casas Grandes immediately east of Boca Grande (and southwest of the Palomas volcanic field) appear to be slightly higher than water levels in the playa-lake depression of Laguna Polvaredones. However, intensive pumping of groundwater for crop irrigation immediately north of the playa on the New Mexico side of the border (in T.29S, R.9 and 10W, just east of the Carrizalillo Hills) has greatly complicated the interpretation of both modern and predevelopment flow directions.

The area of major concern, in terms of transboundary flow, extends from the Tres Hermanas uplift across the Columbus and southern Florida *(Mesquite Lake)* subbasins to the West Potrillo uplift. This major structural high (Seager 1989) is bounded on the west by the Camel Mountain fault zone, and it appears to block effectively groundwater outflow to the east (into the southern Mesilla Basin). Test borings and geophysical data indicate that the *Mesquite Lake* section is the deepest part of the entire Mimbres Basin system (Seager 1995, Klein 1995). Estimate of pre-development transboundary flow by Hanson and others (1994) across the Florida Subbasin segment of the New Mexico-Chihuahua boundary is about 5 x 10^6 m^3/yr (4,100 ac-ft/yr), based on a horizontal hydraulic gradient of 0.0003 and estimated cross-section area of about 25 km^2 (2.7 x 10^8 ft^2). The cross-section dimensions approximate a saturated section that is about 20 km wide and at least 1.2 km thick. Unlike the case of the Hermanas Subbasin, except for the hydraulic gradient value, estimates of average basin-fill thickness and hydraulic conductivity appear to be too high by several orders of magnitude, particularly in the case of the hydraulic conductivity value. Here, the bulk of the saturated basin fill appears to be either fine-grained (playa and lacustrine) deposits of the Middle to Upper Gila Groups (facies *9* and *3* of HSU's MG2 and UG2) or conglomeratic mudstones and sandstones of the Lower to Middle Gila Hydrostratigraphic Units (MLG: facies *7-10*). Again, intensive aquifer development in the Columbus-Palomas area, which now intercepts most transboundary flow, greatly complicates interpretations of the modern and predevelopment groundwater-flow systems.

Special hydrologic conditions in the Columbus Subbasin area, documented by Blandford and Wilson (1987), also need to be further investigated. This is one of the few areas of the entire basin system where large volumes of groundwater have been produced from basaltic and andesitic volcanics (units Tba and Tub, Plate 1) that underlie and are interbedded with a wide variety of Gila Group Hydrostratigraphic Units (UG2/MLG: primarily facies *1, 3, 4, 5, 7, 9*).

It appears to be a valid assumption that groundwater in the southern Mimbres Basin system that is not consumed by pumping in the southern Hermanas-Columbus (Palomas)-Florida Subbasin areas, or by other significant evapotranspiration losses, ultimately drains as underflow into the "El Barreal" and Salinas de la Union system of *vadose* and *phreatic* playas. As already noted, these *closed-basin* areas occupy much of the floor of the *undrained* Bolson de los Muertos.

Salinas de la Union, located just beyond the south-eastern part of the study area (Plate 1, Figure 3-1) appears to be the ultimate *sink* for the regional groundwater-flow system. This premise is supported by the observation that the Salinas area has thermal springs and flowing wells (tapping aquifers that supply water of widely varying quality and temperature), as well as commercial deposits of sodium sulfate in thick playa-lake evaporite sequences (Brand 1937, Córdoba et al. 1969, p. 31, and Reeves 1969).

The elevation of the potentiometric surface in the Salinas de la Union area is about 1,170 m (3,835 ft), which is at least 50 m (160 ft) above the channel of the Rio Grande near the Ciudad Juárez–El Paso metropolitan area about 90 km (55 mi) to the northeast. Therefore, at an average hydraulic gradient of about 0.0006, some regional component of underflow could (very slowly) move in that direction, but intervening basin-boundary structures and water-quality considerations suggest that this scenario is unlikely.

GROUNDWATER QUALITY

General Hydrochemistry

General water quality in the Mimbres Basin aquifer system is shown in the regional stiff map (Figure 4-5). Groundwater in the northern half of the Mimbres Basin is usually less than 500 mg/L TDS. Groundwater is especially dilute (<250 mg/L TDS) along the Mimbres River. Near and extending across the U.S./Mexico border, groundwater is usually greater than 500 mg/L TDS, reaching concentrations greater than 1,000 mg/L in the southernmost part of the Mimbres Basin system.

The stiff map indicates that hydrochemical facies change from mostly Ca-HCO_3 type waters north of Deming, to Ca-Na-Mg-HCO_3 and Na-HCO_3 waters near Deming, to Na-HCO_3 and Na-SO_4-Cl-HCO_3 facies between Columbus and Laguna de Guzman. At the southernmost part of the Mimbres Basin, groundwaters are mostly a Na-SO_4 type facies (Figure 4-5).

North-to-south hydrochemical trends shown in the stiff map are also illustrated in the hydrochemical Piper plots (Figure 4-6). Seven north-to-south zones are subdivided for illustration of Piper plots. Piper plots indicate that groundwater evolves from mostly Ca-HCO_3 type waters in zone 1, to Ca-Na-Mg-HCO_3 type waters in zones 2 and 3, to Na-SO_4-Cl-HCO_3 and Na-SO_4-Cl type waters in zones 4, 5, 6, and 7 (Figure 4-7). Sulfate is an especially dominant constituent in groundwaters in Mexico.

The chloride and sulfate maps are color coded by constituent ranges (Figures 4-8 and 4-9). These maps show areas that exceed recommended drinking water standards for sulfate and chloride. Most groundwaters in the United States have acceptable concentrations of chloride, except near Columbus where a few groundwaters exceed the recommended drinking water limit of 250 mg/L. Groundwaters are often less than 10 mg/L Cl near Silver City and Deming. Several groundwaters in Mexico, especially along the basin's eastern margin, exceed 250 mg/L Cl. With few exceptions, sulfate patterns mimic patterns shown in the chloride map (Figures 4-8 and 4-9). Some sulfate concentrations northwest and southeast of Laguna de Guzman exceed 250 mg/L.

Saturation Indices

Saturation indices were computed for 41 groundwater analyses in the U.S. portion of the Mimbres Basin. These analyses include temperature and pH measurements, which are required for computation of saturation indices using PHREEQC (Parkhurst 1995). The absence of temperature measurements in Mexico preclude the use of Mexican groundwater data for computation of saturation indices.

PHREEQC analyses indicate that groundwater is typically at equilibrium with respect to calcite and dolomite, although there is a much wider range of values for the latter (Figure 4-10). Despite the high sulfate content of many samples near Columbus, none of the samples appears to be consistently within the range of values indicating equilibrium with respect to gypsum. In all cases, waters are undersaturated with respect to halite.

Origin of Solutes

The data in each Piper plot (Figure 4-6) are averaged arithmetically to denote mean hydrochemical concentrations (Figure 4-7). These data indicate evolutionary hydrochemical trends along a north to south transect. Calcium and magnesium are the dominant cations in zone 1. Sodium becomes the more dominant cation to the south. Bicarbonate in zone 1 becomes less abundant proportionally to sulfate and chloride in groundwaters to the south (zones 2 through 7).

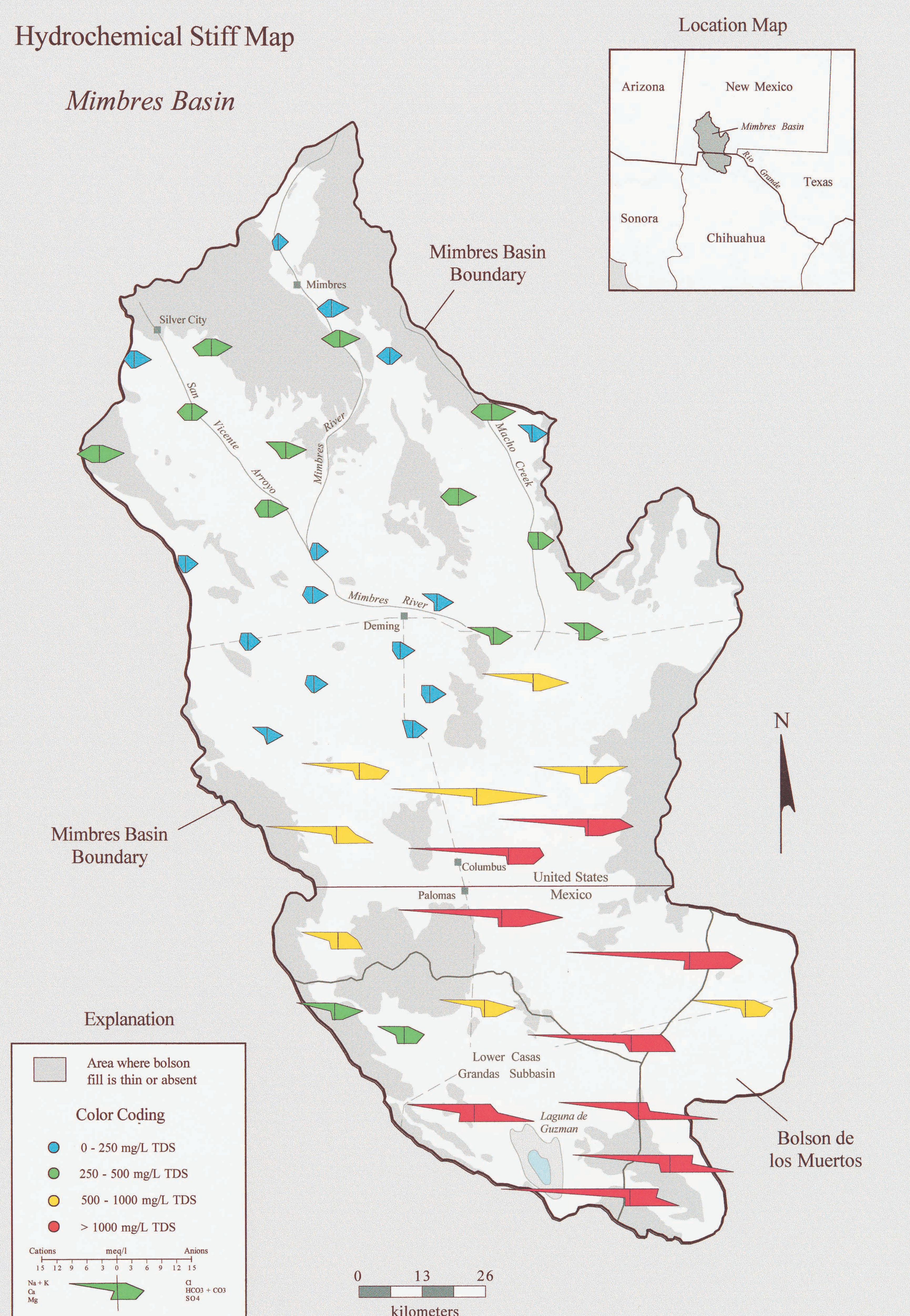


Figure 4-5. Hydrochemical stiff map for the Mimbres Basin, and associated basins, showing stiff diagrams color coded by TDS ranges (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

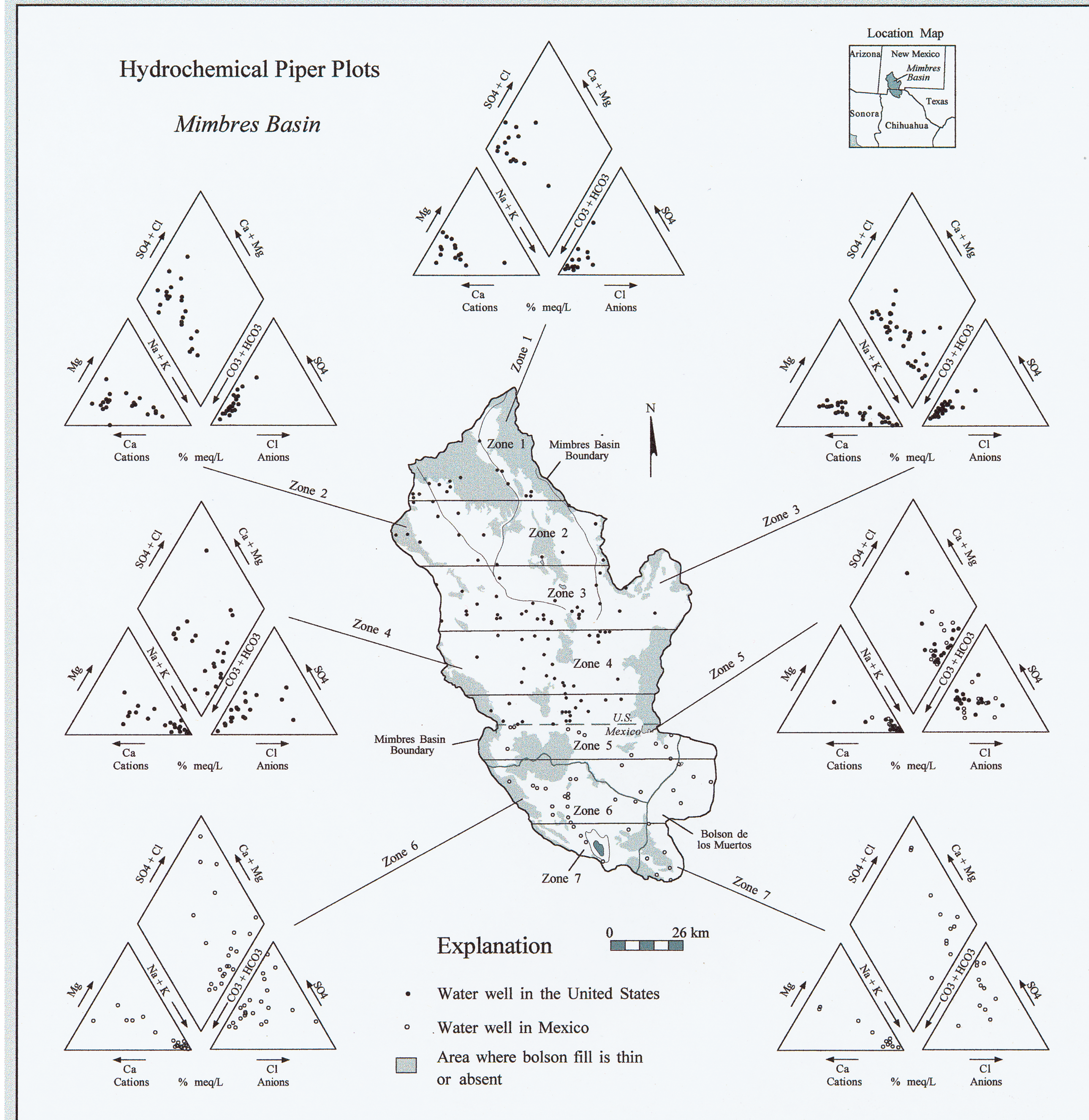


Figure 4-6. Piper plots for 7 north-south zones in the Mimbres Basin, and associated basins. These indicate hydrochemical facies that vary from calcium-bicarbonate type waters in zone 1 to sodium-sulfate-chloride type waters in zone 7 (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

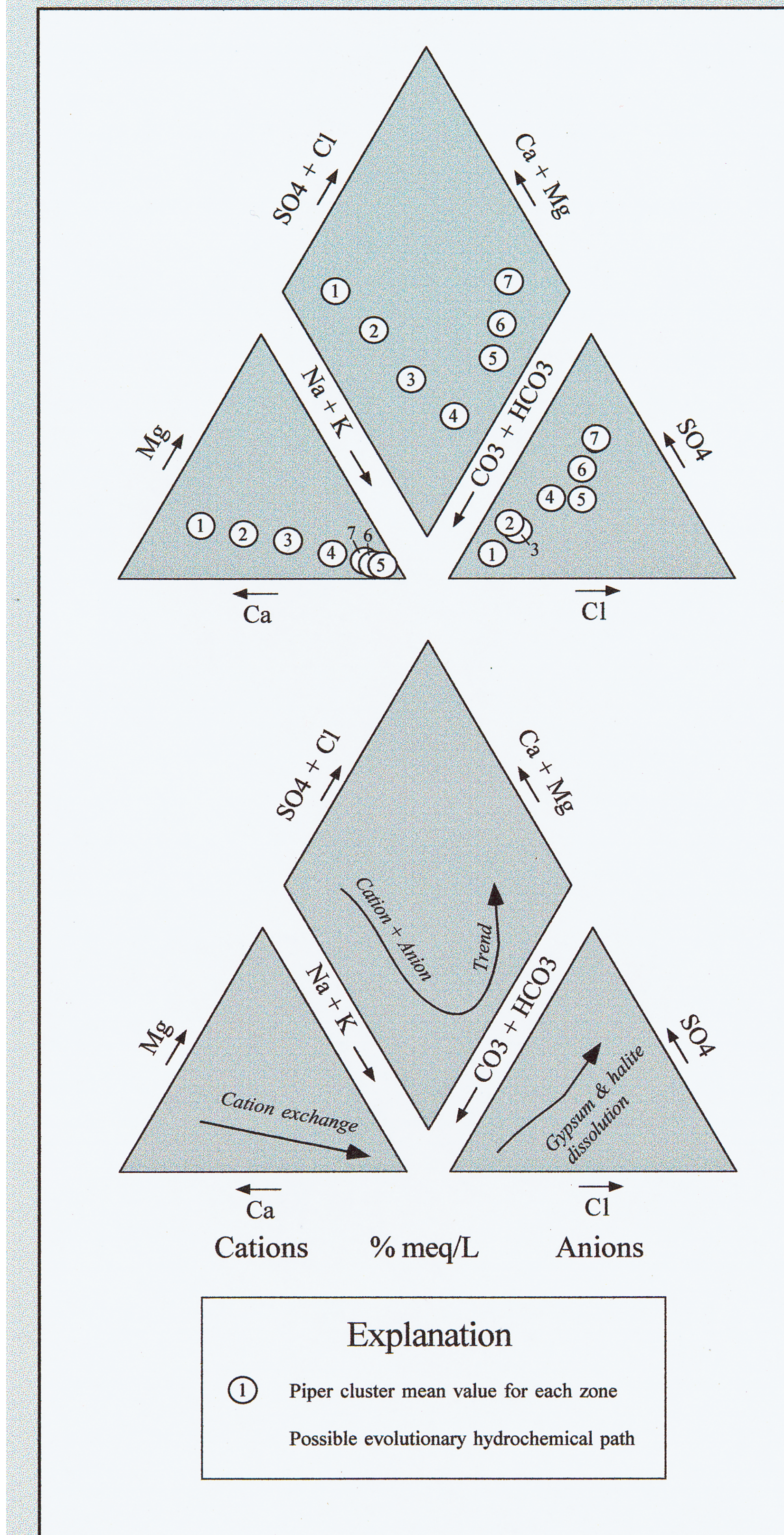


Figure 4-7. Hydrochemical Piper plot that summarizes mean Piper cluster concentrations for seven zones from Figure 4-6. Lower figure shows possible evolutionary hydrochemical trends for these data.

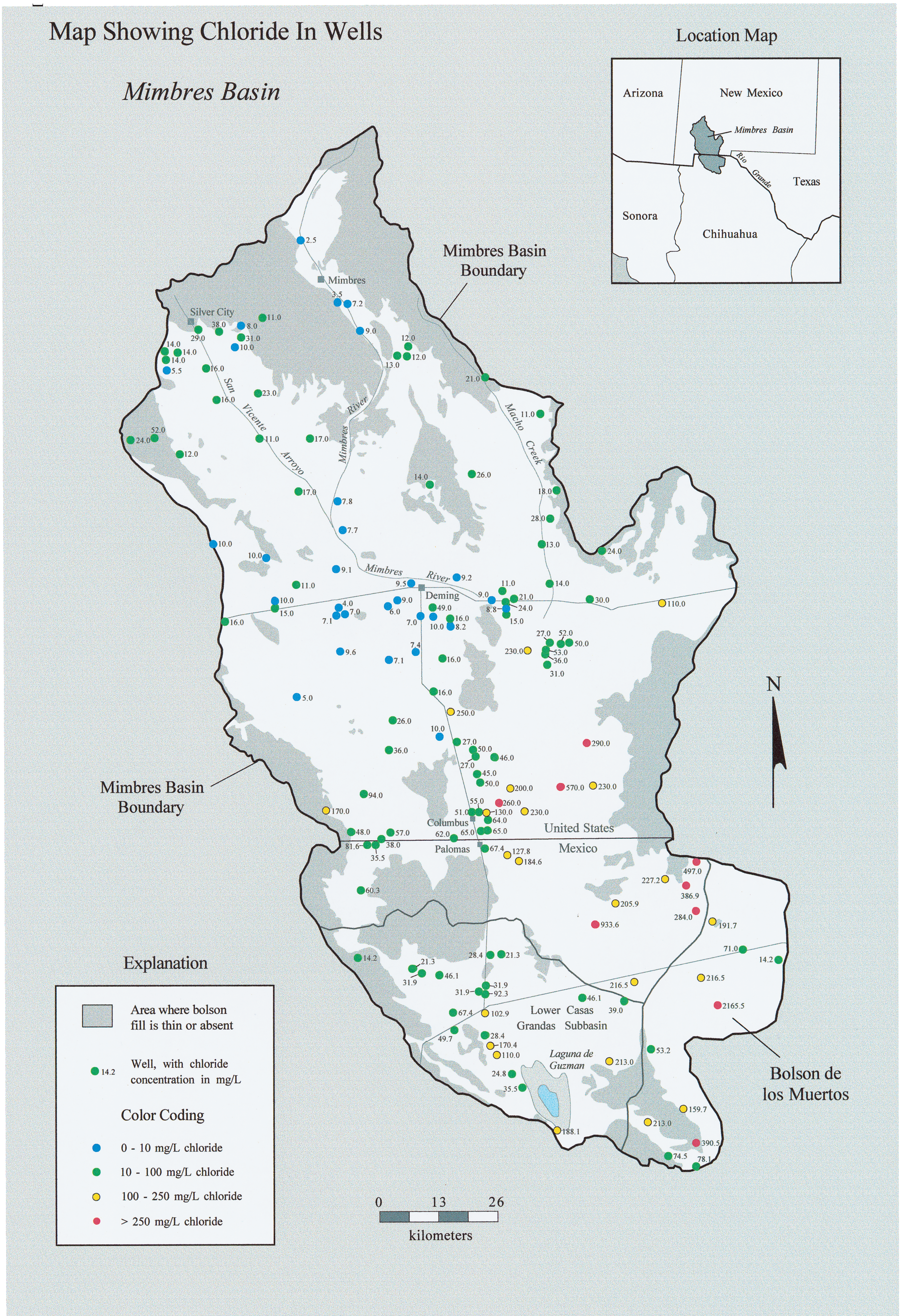


Figure 4-8. Map for the Mimbres Basin, and associated basins, showing chloride concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

Map Showing Sulfate In Wells

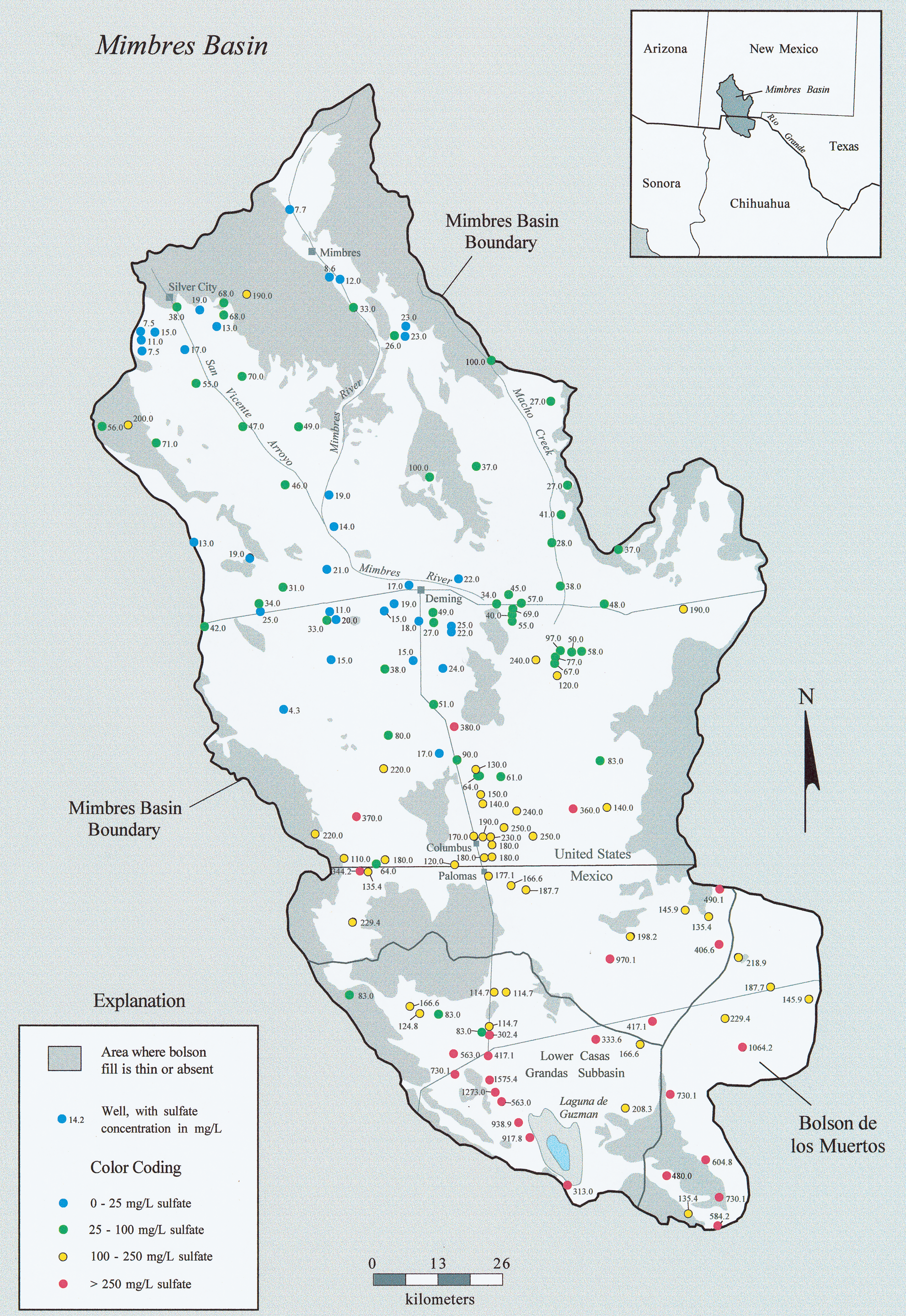


Figure 4-9. Map for the Mimbres Basin, and associated basins, showing sulfate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

The most likely sources of Ca and Mg in groundwaters in the Mimbres Basin include dissolution of the relatively soluble minerals calcite, dolomite, and gypsum:

$CaCO_3 + H_2O + CO_2 = Ca + 2HCO_3$ (4.1)
$CaMg(CO_3)_2 + 2CO_2 + 2H_2O = Ca + Mg + 4HCO_3$ (4.2)
$CaSO_4 \bullet 2H_2O = Ca + SO_4 + 2H_2O$ (4.3)

The minerals pyroxene and amphibole are less soluble and produce smaller amounts of Ca and Mg by dissolution:

$CaMg(Si_2O_6) + 4CO_2 + 6H_2O = Ca + Mg + 4HCO_3 + 2Si(OH)_4$ (4.4)
$Ca_2Mg_5Si_8O_{22}(OH)_2 + 14CO_2 + 22H_2O = 2Ca + 5Mg + 14HCO_3 + 8Si(OH)_4$ (4.5)

If Mg and Ca originated solely from the dissolution of carbonates and carbonate cement, and from the weathering of accessory pyroxene and amphibole minerals, the ratio of (Ca+Mg) to HCO_3 would be 0.5 (Sami 1992). Plotting the quantity (Ca + Mg) against HCO_3 and drawing a line with a slope of 1:2 gives the amount of calcium and magnesium derived from dissolution of calcite (1 mole Ca to 2 moles HCO_3), dolomite (2 moles of [Ca+Mg] to 4 moles of HCO_3), pyroxene (2 moles of [Ca+Mg] to 4 moles of HCO_3) and amphibole (2 moles of Ca, 5 moles of Mg, and 14 moles of HCO_3) (Figure 4-11). Several of the points plot near the 1:2 line (Figure 4-11), but many of the points plot well below the line. Other points plot above the 1:2 line, indicating an additional source of Ca and Mg (Figure 4-11). To account for remaining Ca due to dissolution of gypsum (eqn 4.3), the quantity ($Ca + Mg - SO_4$) is plotted against HCO_3 (Figure 4-12). Nearly all of the points plot well below the 1:2 line, indicating that another process is removing Ca and Mg from solution.

Cation exchange is a process that removes Ca and Mg from groundwaters by substitution for bound Na on clays (Drever 1982):

$Na_2\text{-clay} + Ca^{+2} = Ca\text{-clay} + 2Na^+$ (4.6)
$Na_2\text{-clay} + Mg^{+2} = Mg\text{-clay} + 2Na^+$ (4.7)

The forward reaction may account for deficient Ca and Mg in groundwaters (Figure 4-12). To test the influence of cation exchange on the hydrochemical signature of groundwaters in the basin, the molar quantities (Na - Cl) are plotted against ($Ca + Mg - SO_4 - 0.5HCO_3$) (Figure 4-13). The quantity (Na - Cl) represents excess Na coming from sources other than halite dissolution. The quantity ($Ca + Mg - SO_4 - 0.5HCO_3$) represents the Ca and Mg derived from sources other than dissolution of calcite, dolomite, pyroxene, amphibole, and gypsum. Together, these quantities represent the amount of monovalent and divalent cations available for cation exchange. A 2:1 exchange line shows how much Na is contributed from cation exchange (positive [Na - Cl] values). Most of the points plot very close to the 2:1 exchange line and nearly all points have positive (Na-Cl) values (Figure 4-13). These values reflect excess Na caused by the cation exchange process.

Gypsum dissolves as groundwater flows toward and across the International Border (Hanson et al. 1994). Most groundwater samples have (Ca/SO_4) molar ratios greater than 1.0 for salinities less than 0.75 mmols/L Cl (Figure 4-14). Most molar (Ca/SO_4) values are less than 1.0 for salinities greater than 0.75 mmols/L Cl. These trends indicate that gypsum dissolves at higher salinities, which produces an equal molar contribution of Ca and SO_4, and simultaneous removal of Ca by cation exchange. Saturation indices suggest that calcite may also precipitate in some areas, which would remove Ca from solution.

Further evidence for cation exchange is provided by a plot of molar (Na/Cl) vs Cl (Figure 4-15). This plot suggests the influence of halite dissolution on groundwater at salinities greater than 2 mmols/L Cl:

$NaCl = Na + Cl$ (4.8)

Points trend toward a 1:1 (Na/Cl) molar ratio, but nearly all of the points plot slightly above the 1:1 ratio line for chlorinities (chloride concentrations) greater than 2 mmols/L Cl (Figure 4-15). This implies an excess source of Na from cation exchange, as implied by several other lines of evidence.

The previous analysis indicates that the water chemistry of the Mimbres Basin aquifer is controlled by several simple reactions and processes:

- Dissolution of dolomite, calcite, and calcite cement in dilute groundwaters, possible dissolution of accessory pyroxene, amphibole, and other minerals.
- Dissolution of gypsum, especially near Columbus and extending into Mexico, where groundwaters are more saline.
- Dissolution of halite in all except very dilute groundwaters.
- Cation exchange favoring exchange of Ca for bound Na.

Dissolution of specific minerals is a function of their spatial locations in the basin (Figure 4-16). Halite occurs in rainwater, and precipitates in soils when rainwater evaporates (Hem 1985, Sami 1992). The halite can be dissolved by runoff and carried into groundwater along arroyos and other recharge areas. Evaporation of groundwater by natural discharge and by irrigation recycling further concentrates salts in soils and groundwater. Gypsum and halite are present along the basin floor in the southern half of the basin, having precipitated in various phreatic playas. Gypsum and halite dissolve when meteoric groundwaters come into contact with these evaporite minerals. Carbonates are present in the mountains and precipitate as caliche along mountain fronts and at interior locations in the basin. Other rocks, such as volcanic and intrusive igneous rocks, probably contribute smaller amounts of dissolved minerals to groundwaters in the basin (Figure 4-16).

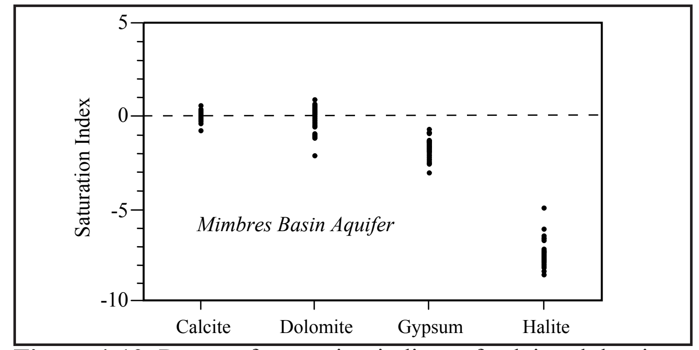


Figure 4-10. Range of saturation indices of calcite, dolomite, gypsum, and halite for the Mimbres Basin Aquifer

Irrigation Water Quality

Groundwater has low alkali hazard and medium salinity hazard in most groundwater samples collected in zones 1, 2, and 3 (Figure 4-17). Salinity risk increases from medium hazard to high hazard in zones 4 through 7. Alkali hazard is low to very high in zones 4 through 7. Plants with low salt tolerance should not be cultivated in zones 4 through 7.

Nitrate in Groundwater

The nitrate map suggests that nitrate is not a serious threat to the health of the residents in the Mimbres Basin (Figure 4-18). Nearly all of the analyses are well below 5 mg/L NO_3-N. Two reported analyses exceed the recommended drinking limit of 10 mg/L NO_3-N. These are likely a result of point-source contamination due to septic tanks or barnyards. None of the reported analyses in Mexico exceed 2 mg/L NO_3-N.

SUMMARY

The Mimbres Basin system has a major important trans-international boundary aquifer component. The system is an interconnected group of intermontane subbasins that covers an area of about 13,300 km^2 (5,140 mi^2), and includes parts of the United States and the Republic of Mexico. Approximately 11,400 km^2 (4,410 mi^2) of the basin system is in southwestern New Mexico, including parts of Grant, Luna, Doña Ana and Sierra counties. Most of the area lies within the Mexican Highland section of the Basin and Range physiographic province. The northernmost part of the basin system is dominated by high volcanic plateaus and north to northwest-trending mountain ranges of the Datil-Mogollon section of the Transition Zone province. The only major perennial stream in the Mimbres Basin system is the upper reach of the Mimbres River, which is located in the eastern Datil-Mogollon section. South of the Grant-Luna county line, all reaches of the river and its tributary arroyo systems are emphemeral.

Much of the western and all of the northern boundary of the Mimbres Basin system is formed by the Continental Divide, and most of the eastern border is the surface-water divide with watersheds of the Mesilla and Palomas Basin systems adjacent to the Rio Grande Valley. Major boundary highlands include the Black and Pinos Altos ranges in the Datil-Mogollon section, and the Goodsight, Big Burro, Cedar Mountain and Sierra Alta ranges of the Mexican Highland section. The three major mountain areas of the basin system's interior are, from north to south, the Cooke's Range, Florida Mountains, and Tres Hermanas Mountains.

The entire southern boundary of the basin system is poorly defined in terms of both surface-and subsurface-flow regimes. Subbasins east and southeast of the Columbus-Palomas area merge southward with the extensive ephemeral-lake plains (*vadose* and *phreatic playas*) of the northwestern Bolson de los Muertos, and the fan-delta complex of the terminal Rio Casas Grandes that presently flows into the *closed* and *undrained* basin of Laguna Guzman. The Bolson de los Muertos is the regional sink for the *open* and *partly-drained* Mimbres Basin system and was the site of "pluvial Lake Palomas" in Late Pleistocene time.

A wide variety of land use/landcover categories are present in the Mimbres Basin system. Forest areas are prevalent in the higher elevations in the north and rangeland is the major category in the transition zone to drier, lower-elevation areas to the south. Lowlands contain a mix of irrigated

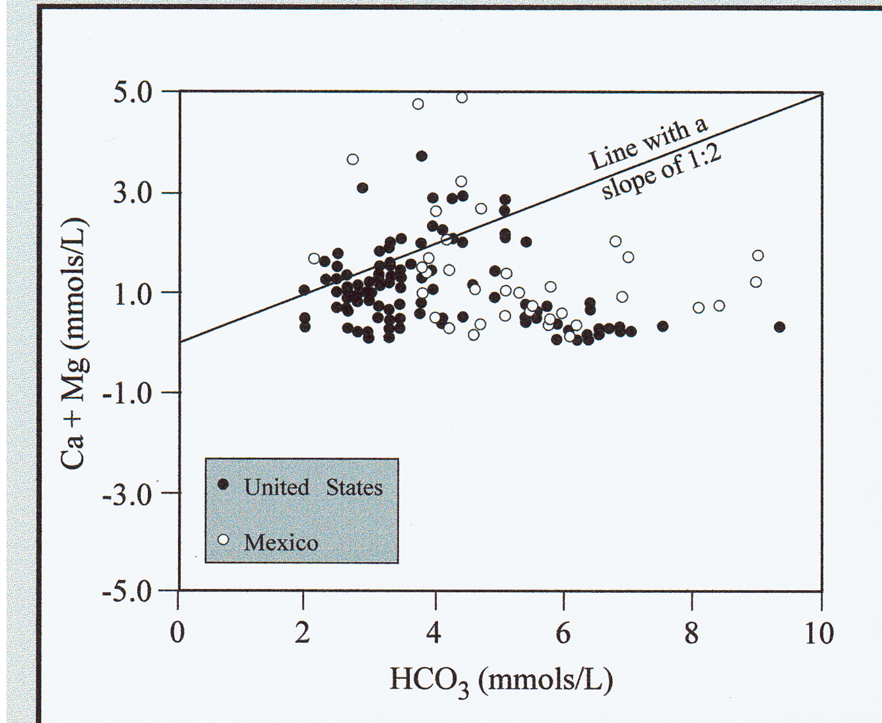


Figure 4-11. (Ca + Mg) vs HCO_3 plot, Mimbres Basin aquifer (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

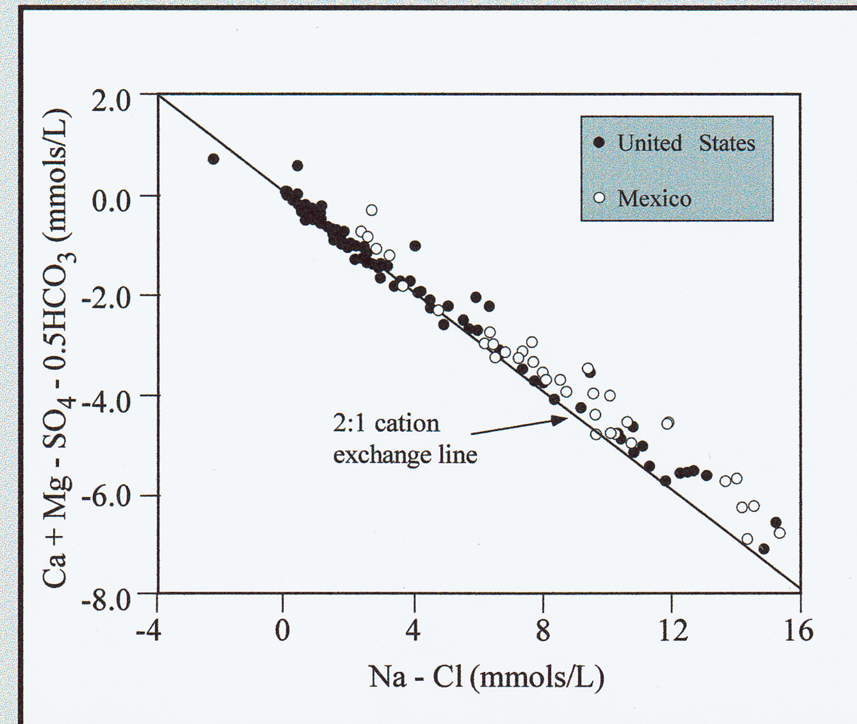


Figure 4-13. (Ca + Mg - SO_4 -0.5HCO_3) vs (Na - Cl) plot, Mimbres Basin aquifer (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

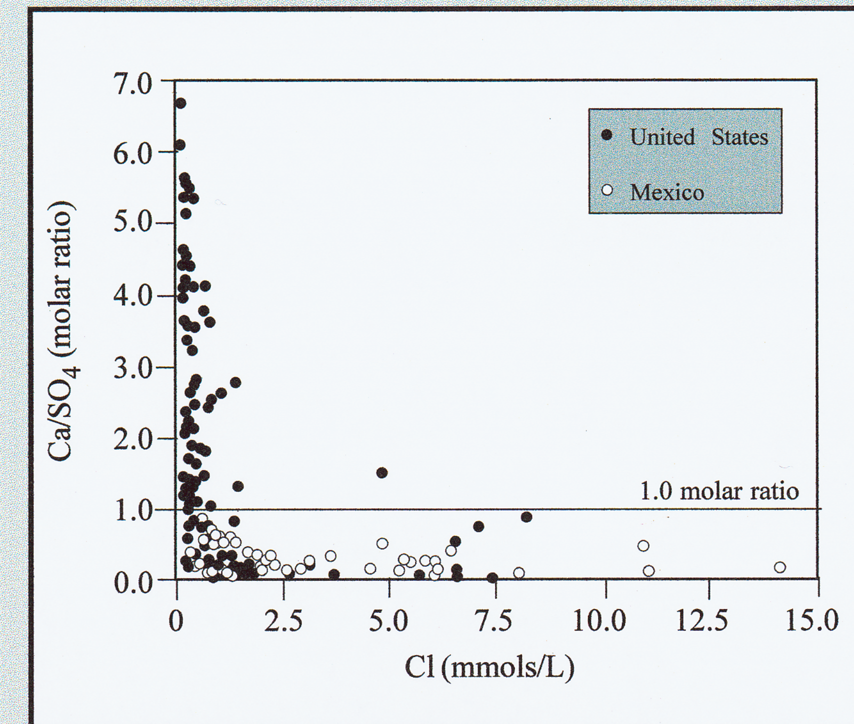


Figure 4-14. (Ca/SO_4) vs Cl plot, Mimbres Basin aquifer (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

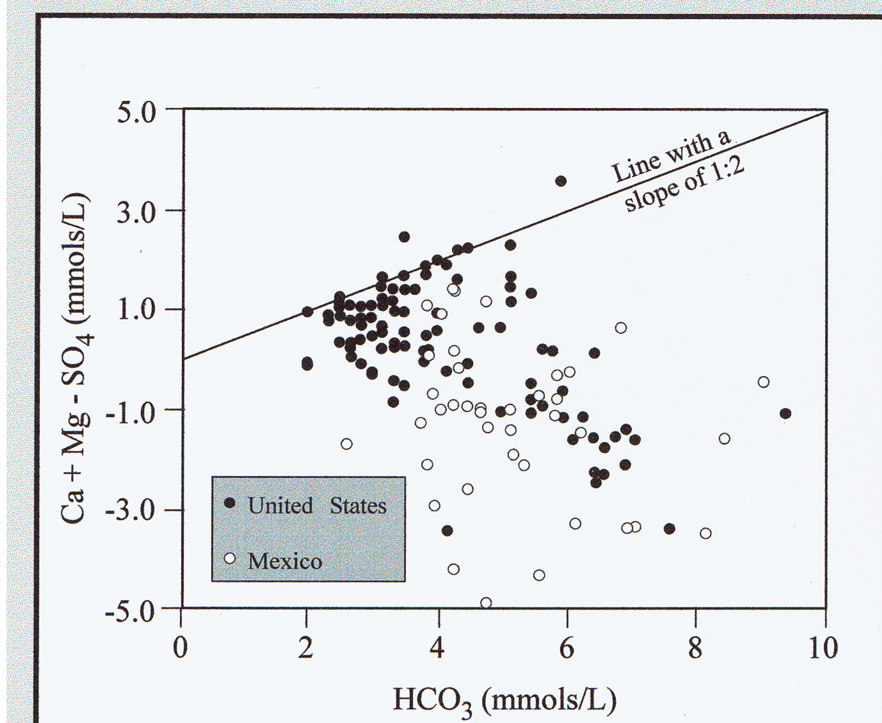


Figure 4-12. (Ca + Mg - SO_4) vs HCO_3 plot for groundwaters in the Mimbres Basin (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

Figures 4-11 through 4-15 show a series of cation/anion scatter plots for groundwaters in the Mimbres Basin aquifer, southwestern New Mexico and northern Chihuahua, Mexico. These data suggest that dissolution of calcite, dolomite, halite, and sulfate, along with cation exchange processes, are the most dominant processes that control groundwater chemistry in the Mimbres Basin.

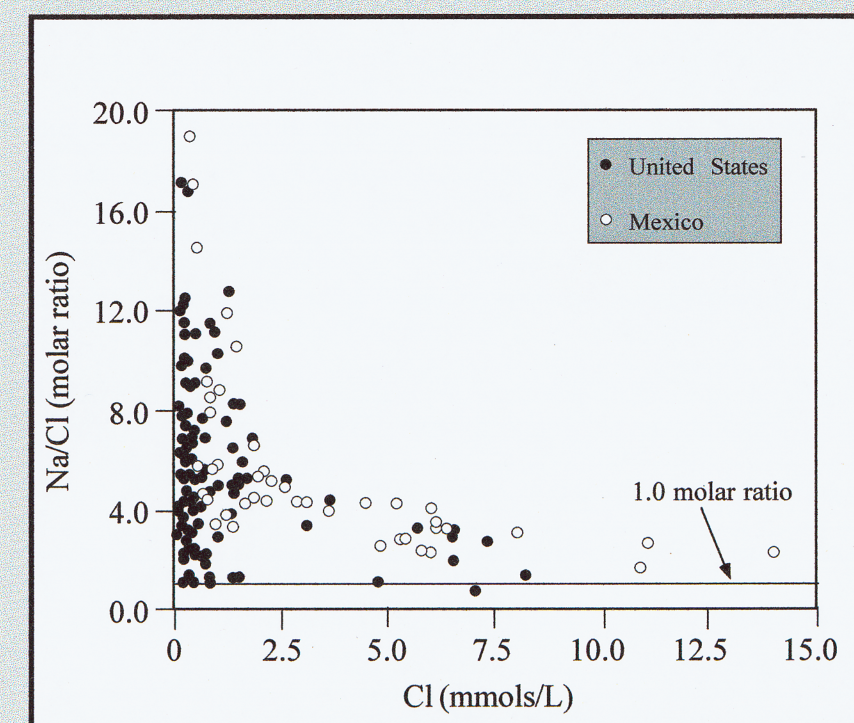


Figure 4-15. (Na/Cl) vs Cl plot, Mimbres Basin aquifer (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

farmland, rangeland and alkali-flats. The use of groundwater includes agriculture, municipal, mineral processing, general industrial, and public drinking water supply.

The climate is typical of the arid southwest, with mostly clear skies and limited rainfall and humidity. Average annual precipitation varies from less than 25.4 cm (10 inches) per year in low lying portions of the basin to as much as 76.2 cm (30 in) per year at higher elevations. Mean annual temperatures of basin-floor areas are in the 14.9 to 16.8E C (58.9 to 62.3E F) range, and annual pan evaporation recorded at a typical site is 261 cm (103 in).

The hydrogeologic framework of the Mimbres system is characterized by a mosaic of very deep structural subbasins, where fill thickness locally exceeds 1,000 m (3,300 ft), and intervening bedrock highs. The latter form not only "insular" mountain ranges and hilly uplands but also buried "sills" where saturated basin fill is relatively thin and groundwater flow is restricted. The primary aquifer system is formed by unconsolidated to partly indurated sediments of the basin fill, which here includes surficial deposits of the ancestral Mimbres River (RM, RMF), and Upper and Middle Hydrostratigraphic Units (HSUs) of the Gila Group (UG, MG). The aquifer system has unconfined, semiconfined and confined components. It is laterally extensive, but its thickness is quite variable. Basaltic volcanics interbedded with the middle and lower parts of the basin-fill sequence also form important local aquifer zones, particularly in the Columbus-Palomas area and parts of the San Vicente and Upper Mimbres subbasins.

Specific capacities of wells in the main area of groundwater production near Deming decrease with depth. Highest average specific-capacities (232 - 304 m^3/d/m; 13 - 17 gpm/ft) are reported in wells completed in the upper 100 m (330 ft) of saturated basin-fill, with values of 143 - 214 m^3/d/m, (8 - 12 gpm/ft) reported for wells completed at depths between 100 and 200 m (330 and 660 ft), and 125 to 161 m^3/d/m, (7 to 9 gpm/ft) in wells penetrating 200 and 300 m (660 and 1,000 ft) of saturated fill. Below 300 m to 450 m (1,500 ft) average values were less than 107 m^3/d/m (6 gpm/ft). Published estimates of aquifer transmissivity vary from 5 to 4,600 m^2/d (54 to 50,000 gpm/ft). Coarse-grained, unconsolidated Upper Gila and post-Gila fluvial deposits of the ancestral Mimbres River (HSUs: UG2 and RM-RMF) are the main aquifer units in the upper 100 m (330 ft) of the saturated zone near Deming, while the major components of the 100 to 200 m (336-660 ft) interval are Upper to Middle Gila HSUs. Basin-fill deposits penetrated between 200-300 m (660-1,000 ft) and below 300 m, respectively, are here correlated with conglomeratic sandstone and mudstone basin-floor facies of Middle and Lower Gila Hydrostratigraphic Units.

A very liberal estimate of available water of good quality in storage is no more than 3.78 x 10^{10} m^3 (37.8 km^3, 3.06 x 10^7 ac-ft). This assumes an average saturated thickness of basin-fill of about 100 m (330 ft) and specific yield value of 0.1. At many localities much of the upper basin fill is either fine grained or partly indurated, however, and semiconfined to confined conditions appear to better characterize the aquifer system.

The Mimbres Basin system is typical of most arid to semiarid regions with only a very small percentage of basinwide precipitation and surface runoff contributing to groundwater recharge. Data indicate that this contribution is less than 2% of the average annual precipitation or about 7.8 x 10^7 m^3 (63,145 ac-ft) with the mountain-front component being about 6.62 x 10^7m^3 (55,300 ac-ft).

Groundwater in the Mimbres Basin system generally moves from the northern highlands to the interior basins and southward toward the U.S./Mexico border. Much of this flow has been intercepted by irrigation wells in the Deming and Columbus-Palomas area during the past century. The ultimate *sink* for groundwater moving across the International Boundary is discharge by evapotranspiration in ephemeral lakes and *phreatic playas* of the Bolson de los Muertos (terminating at Salinas de la Union). Isolated interior mountains also locally modify the regional flow pattern by adding minor amounts of recharge and altering the width and depth of the basin-fill aquifer.

The predevelopment groundwater flow was from the United States into Mexico and was estimated at about 8 x 10^6 m^3 (6,500 ac-ft) annually. Extensive groundwater development has altered the direction of groundwater-flow across the U.S./Mexico border to a south to north direction. Most of this flow is now intercepted by intensive aquifer development in the Columbus-Palomas area. Moreover, published estimates of basin-fill aquifer thickness, hydraulic-conductivity values, and possibly mountain-front recharge, in groundwater-flow models appear to be much too large. Models should therefore be developed that more adequately characterize flow in the basin-fill aquifer system from a three-dimensional perspective.

The groundwater in the northern half of the Mimbres Basin is usually less than 500 mg/L TDS and is especially dilute (<250 mg/L TDS) along the Mimbres River. Near and extending across the border, groundwater is usually greater than 500 mg/L TDS, reaching concentrations greater than 1,000 mg/L in the southernmost part of the Basin. Hydrochemical facies change from mostly Ca-HCO_3 type waters north of Deming to Ca-Na-Mg-HCO_3 and Na-HCO_3 waters near Deming. Na-HCO_3 and Na-SO_4-Cl-HCO_3 hydrochemical facies are dominant between Columbus and Laguna de Guzman, with groundwaters in the south-easternmost Mimbres Basin system being mostly Na-SO_4 type facies. The alkali hazard is low and salinity hazard is medium in most groundwater samples collected. The salinity risk increases from medium to high hazard toward the border, and the alkali hazard also becomes higher. Nitrate is not a serious threat to the health of the residents in the basin with nearly all of the analyses well below 5 mg/L NO_3-N. Only two reported analyses exceed the recommended drinking limit of 10 mg/L NO_3-N.

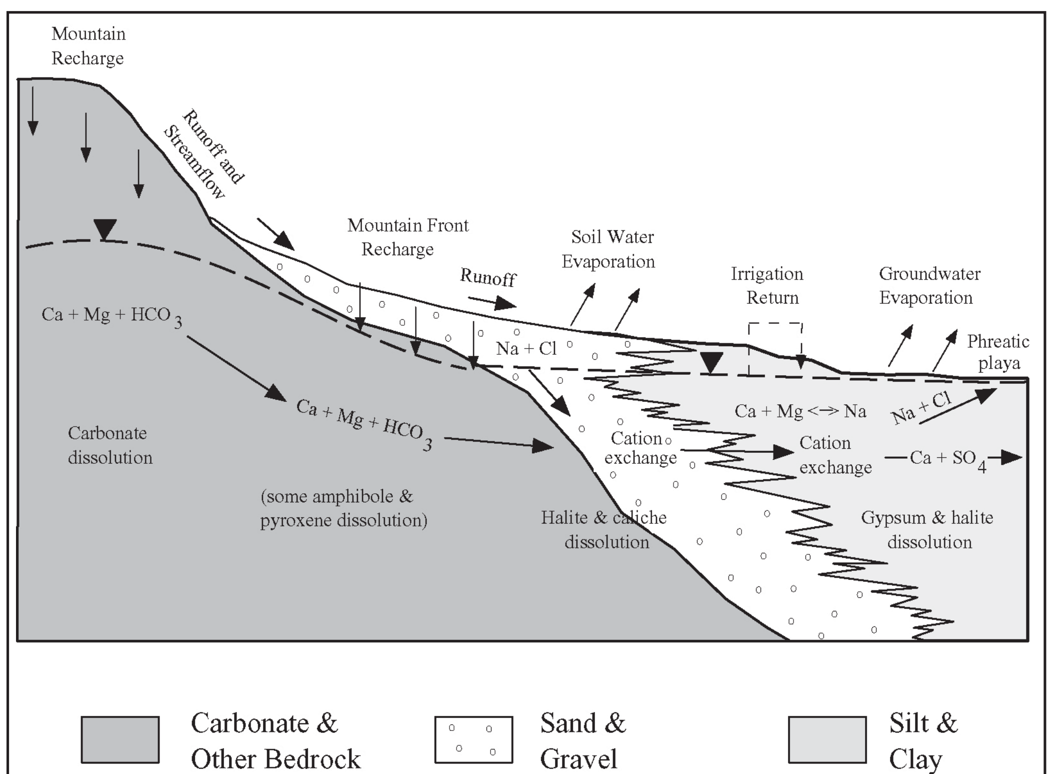
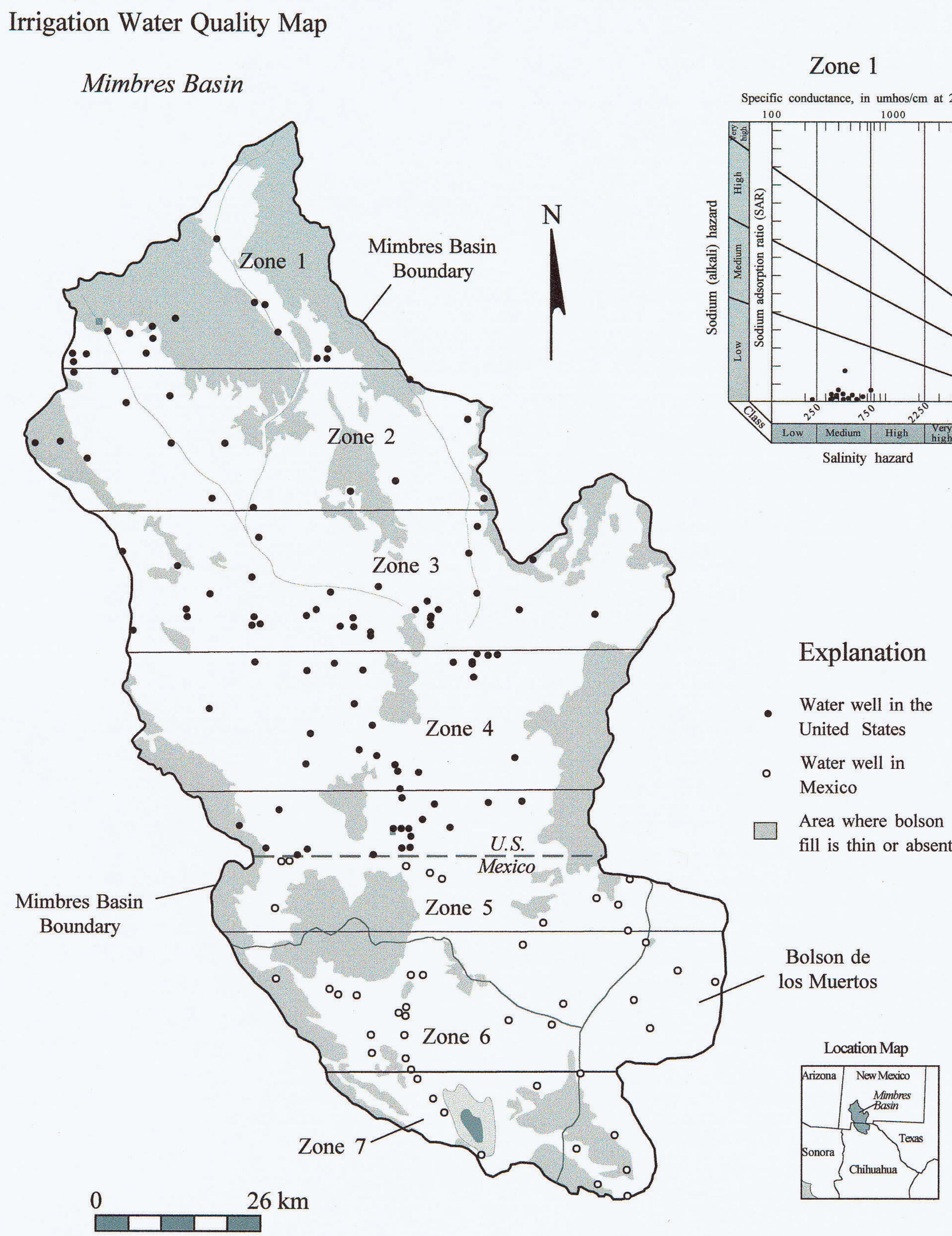


Figure 4-16. Conceptual hydrochemical evolution cross-section illustrating chemical reactions and processes that influence the hydrochemistry in the Mimbres Basin aquifer.



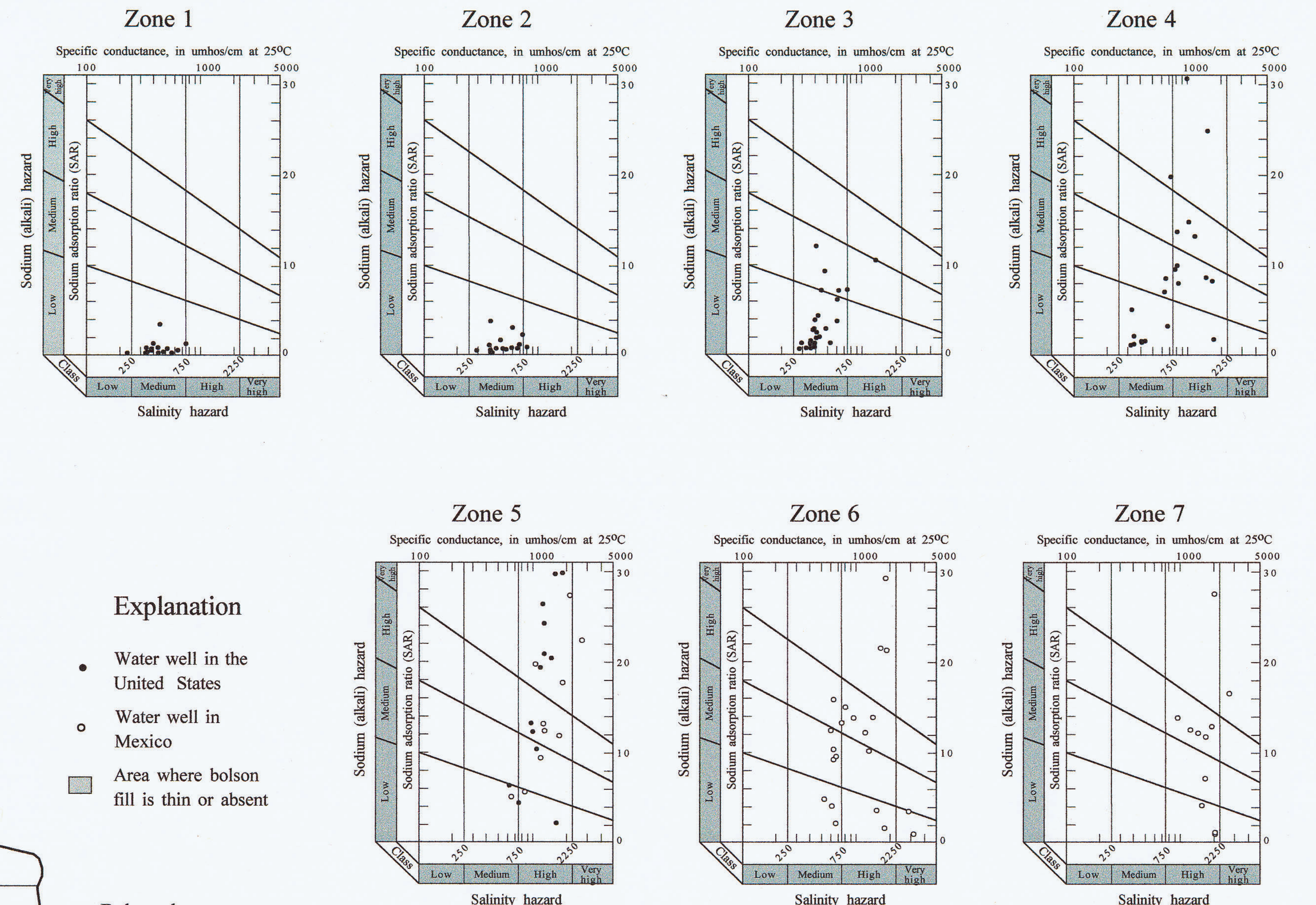


Figure 4-17. Irrigation water quality map for 7 north-south zones in the Mimbres Basin, and associated basins. These data indicate that the salinity and sodium (alkali) hazards increase along the north-south trend, making groundwater less suitable for sensitive crops. (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

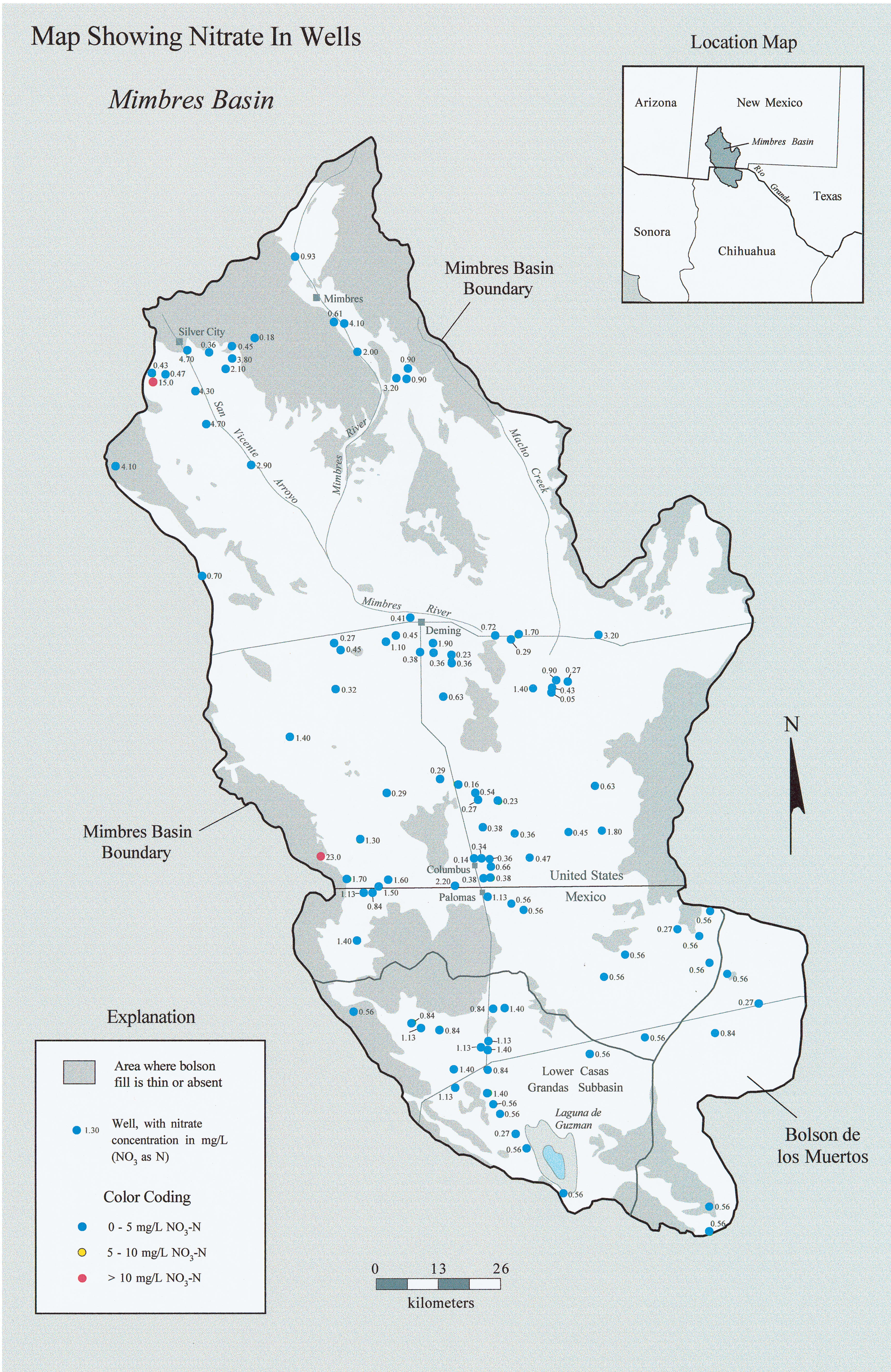


Figure 4-18. Map for the Mimbres Basin, and associated basins, showing nitrate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).