CHAPTER 9 – SAN BERNARDINO BASIN

INTRODUCTION

Emphasis in this chapter is on the relationship between groundwater flow and the hydrogeologic framework of the basin-fill aquifer in the San Bernardino Basin. Basic concepts and interpretations of how groundwater-flow systems function in the intermontane basins of the southwestern New Mexico region have already been described in considerable detail (Chapters 3 to 8). Discussions here will, therefore, primarily focus on aspects of basin-fill hydrogeology and groundwater flow that distinguish the San Bernardino area from other basins of the International Boundary region. The chapter concludes with an overview of groundwater quality in the context of hydrogeologic controls on groundwater flow.

LOCATION AND PHYSIOGRAPHIC SETTING

The United States part of the San Bernardino Basin is located in the extreme southeastern corner of Arizona in Cochise County and the extreme southwestern corner of New Mexico in Hidalgo County. The surface extent encompasses approximately 1,000 km^2 (387 mi^2) in Arizona and about 90 km^2 (35 mi^2) in New Mexico. Even though most of this aquifer system is located in Arizona, it was included because of its significance as a transboundary unit that may have subsurface contributions from the southern Animas Basin system in New Mexico (Chapter 7). The hydrologic basin extends southward and includes as much as 1,040 km^2 (400 mi^2) within the Republic of Mexico (Schwab 1992). For purposes of this report, the southern boundary of the groundwater-flow system is defined as the U.S./Mexico border. A limited amount of published information on hydrogeology and groundwater quality in basin areas to the south is reviewed in this chapter in order to better understand the U.S. part of the area. Data from published maps produced by INGEI have been included in our map products (DGGTN [nd] Agua Prieta [1° x 2°] sheet).

The San Bernardino Basin is an elongated structural basin in the Mexican Section of the Basin and Range province, which is bordered by north-south-trending mountain ranges. The basin is bounded on the east by the southern Peloncillo and Guadalupe mountains, and the Cloverdale Subbasin; on the west by the Perilla and Pedregosa Mountains; and on the north by the San Simon (Valley) Subbasin. The major geomorphic feature in the United States portion of the basin is the extensive Geronimo volcanic field, which is dominated by young basalt flows and vent complexes. The basin is about 47 km (18 miles) wide at the international border and approximately 55 km (21 mi) long from the poorly defined watershed divide at the southern end of the San Simon Valley to the Arizona-Sonora border (Figure 9-1). North-flowing San Simon Creek (Barnes 1991) is tributary to the Gila River Valley near Safford, Arizona. Land-surface altitudes range from 1,132 m (3,715 ft) at the head of the Rio San Bernardino Valley near the International Boundary to 1,993 m (6,539 feet) in the Pedregosa Mountains and 1,966 m (6,450 ft) at Guadalupe Mountain. Rio San Bernardino is tributary to the Batepito-Bavispé-Yaqui fluvial system south of the study area. Rio Yaqui empties into the Gulf of California, west of Ciudad Obragón, Sonora.

San Bernardino Basin is a *semibolson* geomorphic feature. Black Draw, its primary axial drainageway, flows southward into Mexico where it is tributary to the Rio San Bernardino. The draw is ephemeral over its entire length, except for a small cienega reach at the U.S. Fish and Wildlife Refuge and the historic San Bernardino Ranch site (Figure 9-1) where perennial flow is fed by springs and artesian wells. The two major tributaries to Black Draw are Cottonwood Draw and Hay Hollow Wash, both of which head in the Guadalupe Mountains at the east edge of the basin. The western part of the basin is drained by Silver Creek, which heads in the Pedregosa and Perilla mountains and joins the Black Draw-Rio San Bernardino system about 2 km south of the International Boundary. The Guadalupe Canyon drainage basin in extreme southwestern Hidalgo County, New Mexico is also a major contributor to Rio San Bernardino, and the (Rio) Guadalupe-San Bernardino confluence is about 12 km (7.5 mi) south of the border. Rio de Cajon Bonito, the other major tributary with a small New Mexico headwater area at the southwestern edge of the Cloverdale Subbasin, joins the Rio San Bernardino still further downstream at Cuchuverachi (Figure 9-1).

Land and Water Use

The San Bernardino Basin represents a narrow array of land use and landcover categories (Figure 9-1). Forest lands occupy only the higher elevations of the southern Peloncillo and Guadalupe mountains to the east and the Pedregosa Mountains to the northwest, while rangeland covers most of the remaining area. There are no population centers in the United States side of the border. Water use data are not reported for the basin, but the predominate use is for livestock and local wildlife habitat.

Climate

The climate of the San Bernardino Basin is typical of the other semiarid basins in the region. Although there are no climate reporting stations within the basin, there are stations at Douglas (about 16 km, 10 mi west) and Apache (about 10 km, 6 mi north), Arizona. The average daily mean temperature at Douglas for the period 1964-94 was 16.6° C (61.88° F) and the mean total annual precipitation was 37.5 cm (14.77 inches). Most of this annual precipitation is from thunderstorms that occur from July through September. Snow depths at Douglas average only 0.01 cm or 0.004 inches (NCDC 1999). The station at Apache (elevation 1,640 m; 5,380 ft) reported the average daily mean temperature for the period 1965-1980 at 14.3° C (57.7° F) and the mean total annual precipitation at 42.7 cm (16.8 inches) (NCDC 1999). Snow depths at Apache average only 5.3 cm or 2.1 inches (NCDC 1999). Pan evaporation records are not available for either station. *Refer to discussion in Chapter 7 for additional information on climatic conditions in adjacent parts of the southern Peloncillo and Guadalupe mountains in New Mexico.*

HYDROGEOLOGIC FRAMEWORK

Introduction

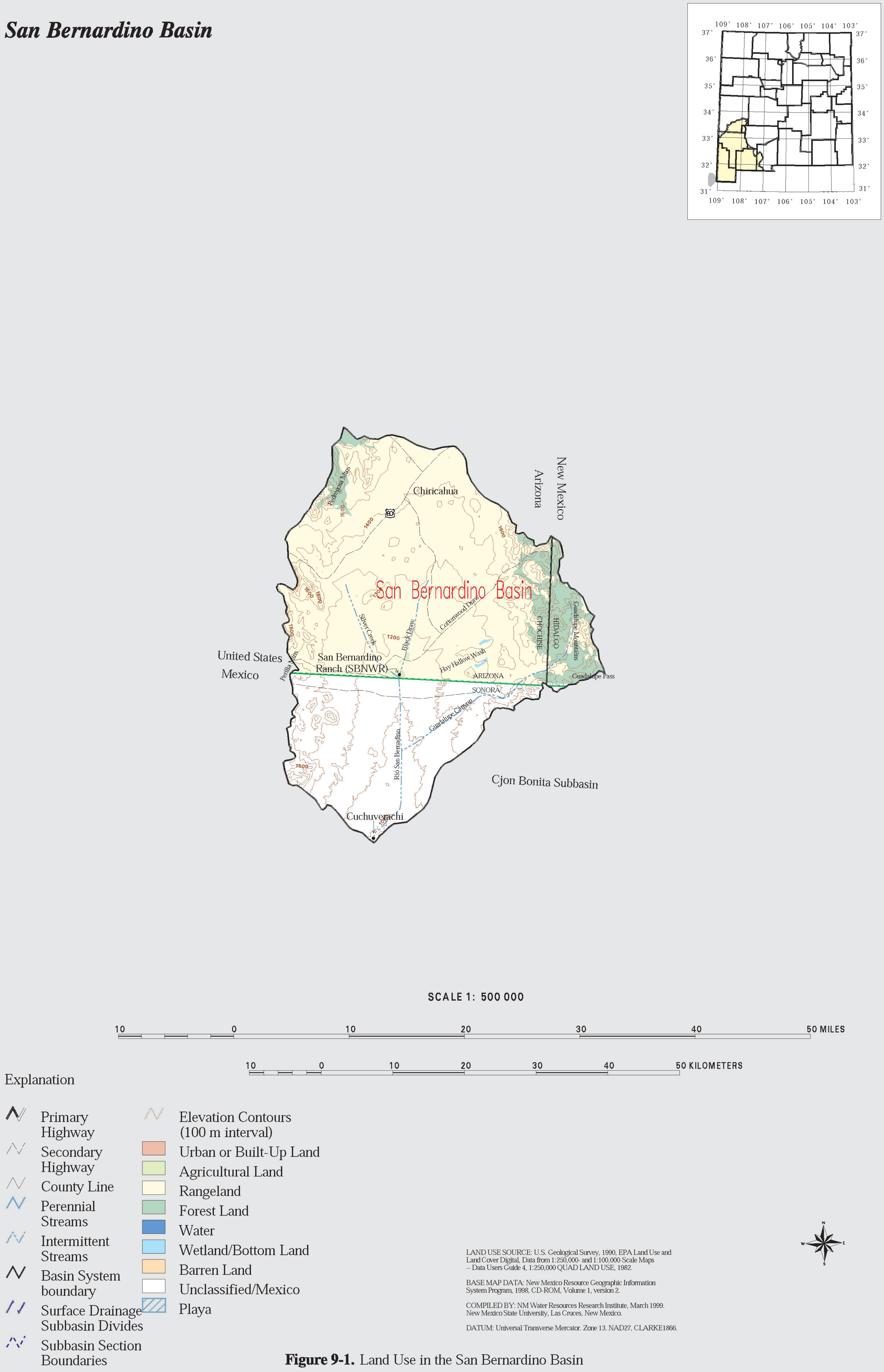
The geologic units in the San Bernardino Basin range in age from Paleozoic to Quaternary (Cooper 1959, Hayes 1982, Kempton and Dungan 1989). The hydrogeologic maps (Figure 9-2 and Plate 1) showing the surficial distribution of bedrock and basin-fill units are a composite of information modified from the reports referenced on Plate 1. Transverse and longitudinal hydrogeologic sections (Plate 1, sections FF', GG' and inset of Figure 9-2) illustrate the effects of complex structural features on basin fill deposits and the aquifer system.

The San Bernardino Basin was formed during a period of extensional tectonics and Basin and Range faulting starting at least 15 million years ago and continuing to the present (Sawyer and Pallister 1989, Schwab 1992). Movement along high-angle normal faults along the basin margins produced the overall north-south trending basin structure and the paralleling mountain uplifts. Several meters of vertical offset of basin-fill deposits occured along the Pitayachi Fault during the "Great Earthquake of 1887." This fault is located at the eastern edge of the basin in Sonora, just south of the study area boundary. (Aguillera 1888, Sumner 1977, Herd and McMasters 1982, Bull and Pearthree 1988).

The mountains surrounding the San Bernardino Basin are composed primarily of Cretaceous and Tertiary intermediate and silicic volcanics (Cooper 1959, Hayes 1982). Outcrops of Cretaceous and Paleozoic sedimentary rocks occur in the Perilla Mountains, the southern end of the Chiricahua Mountains, the Pedregosa Mountains, and the southeastern corner of the valley floor in Arizona (Drewes 1980, Hayes 1982). The extensive cover of Pliocene and Pleistocene basalt flows and associated volcanic vent units of the Geronimo volcanic field obscures most of the basin's internal structural features. However, unpublished geophysical and geological investigations of potential geothermal resources (Stone and Witcher 1982) show that the basin includes at least two major structural subdivisions and buried fault zones in addition to the fault zones bounding the western (Pedregosa-Perilla) and eastern (Peloncillo-Guadalupe) range blocks. The interpretation of basin structure presented in this report (Plate 1, sections FF' and GG' Figure 9-2), indicates that only the western half of the San Bernardino Basin floor is underlain by a deep structural depression with thick Neogene basin fill. This feature is interpreted as a east-tilted half graben that is flanked by a shallowly buried bedrock bench (strongly east-tilted) that occupies much of the eastern part of the topographic basin. The half graben structure appears to die out northward across an eastward-stepping *accommodation zone* at the south end of the San Simon Subbasin (Plate 1, section EE').

Over half of the basin floor is covered by basalt flows of Late Miocene to Middle Pleistocene age in the Geronimo volcanic field (Kempton et al. 1987). Radiometric ages of basalts range from 5 to 9 million years old (ma) in flows on the western and eastern flanks of the basin, to 0.26 to 3.6 ma for flows on the basin floor (Lynch 1978, Kempton et al. 1987, Kempton and Dungan 1989). The log from a 247 m (809 ft) well in sec. 13, T.22S., R.30E., revealed the presence of at least four basalt flows separated by basin-fill

San Bernardino Basin



LAND USE SOURCE: U.S. Geological Survey, 1990, EPA Land Use and Land Cover Digital, Data from 1:250,000- and 1:100,000-Scale Maps -- Data Users Guide 4, 1:250,000 QUAD LAND USE, 1982.

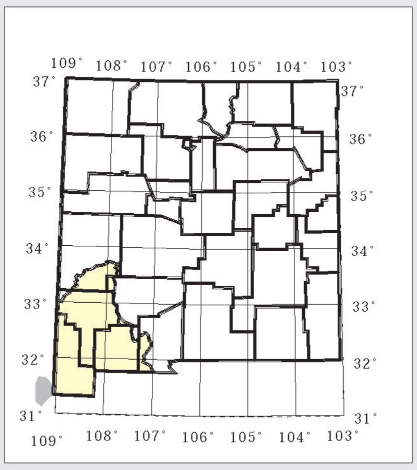
BASE MAP DATA: New Mexico Resource Geographic Information System Program, 1998, CD-ROM, Volume 1, version 2.

COMPILED BY: NM Water Resources Research Institute, March 1999. New Mexico State University, Las Cruces, New Mexico.

DATUM: Universal Transverse Mercator. Zone 13. NAD27, CLARKE1866.

Figure 9-1. Land Use in the San Bernardino Basin

San Bernardino Basin



GEOLOGY SOURCE:

Geologic data for the United States were transcribed from:

Seager, 1995; Seager, et al, 1982; Clemons, 1976; Clemons, 1977; Clemons, 1979; Clemons, 1981; Clemons and Seager, 1973; Elston, 1967; Hedlund, 1977; Drewes, et al, 1985; Broomfield and Wrucke, 1961; Zeller, 1971.

Geologic, hydrogeologic, and topographic data for Mexico were transcribed from the following published maps:

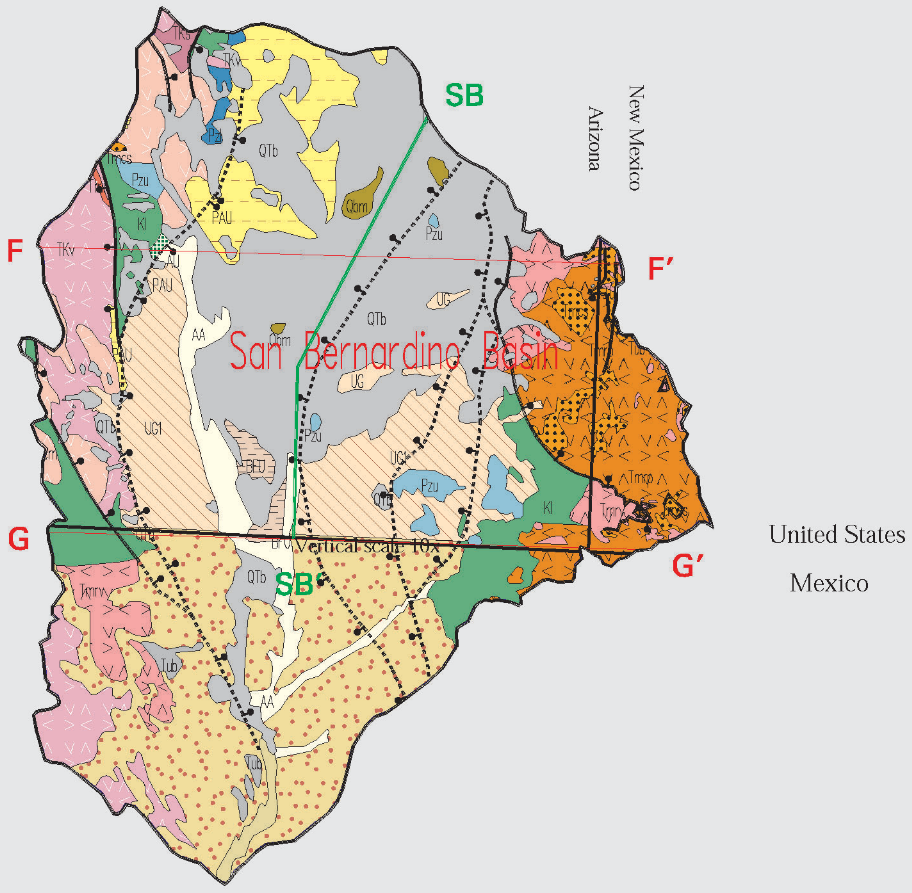
Carta Topografica, Carta Geologica, Carta Hidrologica de Auguas Superficiales, Carta Hidrologica de Auguas Subterraneas.
- Cuidad Juarez H13-1 1:250K
- Agua Prieta H13-4 1:250K

NOTE: Published Mexico data was used in order to improve interpertation of Trans-boundary Aquifers of the United States.

BASE MAP DATA: New Mexico Resource Geographic Information System Program, 1998, CD-ROM, Volume 1, version 2.

COMPILED BY: NM Water Resources Research Institute, March 1999.
New Mexico State University, Las Cruces, New Mexico.

DATUM: Universal Transverse Mercator. Zone 13. NAD27, CLARKE1866.



Explanation

Post Gila and Santa Fe Group deposits

Alluvial deposits

AA
AB
AR
AP
AU
VAO
VAY
VA

Eolian deposits

E

Fluvial deposits

RG
RCG
RCG
RCGd
RSB
RMr
RM
RMF
RMFc
RMFf
RA
RAc
RAf
CA
TA

Basin Floor deposits

BF
BFs
BFP
BFY
BFO
LB
LS
LP
LPs
LL
BFU

Piedmont Slope deposits

PA
PAs
PAc
PAY
PAR
PAO
PAU
PAUc

Gila and Santa Fe Group Hydrostratigraphic Units

Upper Gila Group

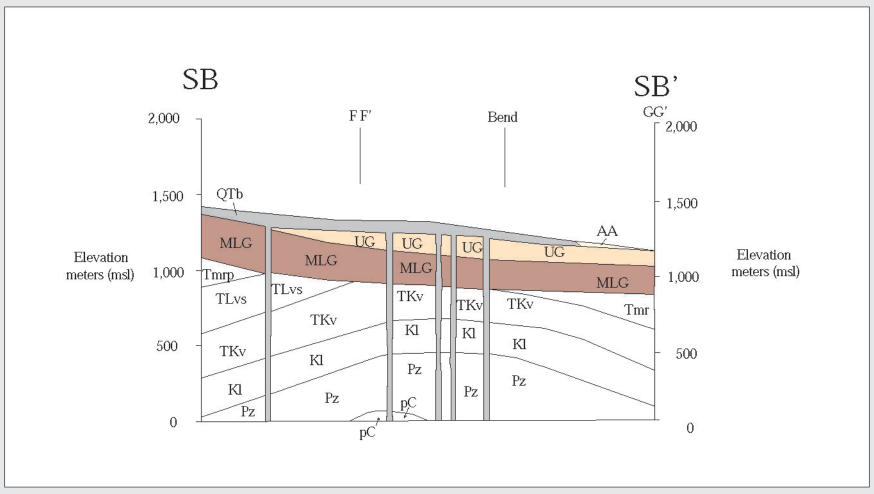
UGL
UG
UG1
UG1c
UG2
UG2r
UG2s
MG
MG2
MG
LG

Upper Santa Fe Group

USL
US1
US1c
US2
US2r
MSF
LSF

Bedrock Units are listed on Plate 1

Profile



QTb - Pliocene-Pleistocene: Basalt flows, dikes and plugs
UG - Early Pleistocene to late Miocene, Upper Gila HSUs, undivided basin-floor to medial piedmont slope deposits (includes Mimbres Formation); includes facies ***1, 2, 3 and 5*** ; upper part in vadose zone
MLG - Middle and Lower Gila undivided HSUs, only on cross-sections

SCALE 1: 500 000

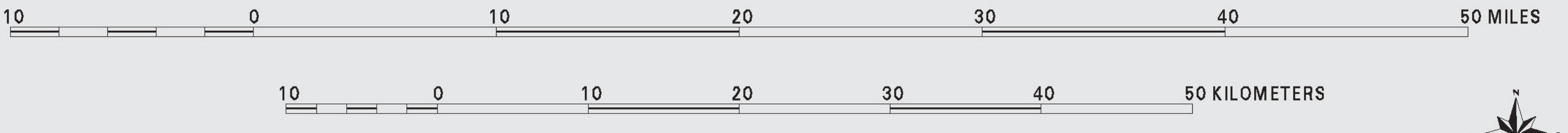


Figure 9-2. Hydrogeology map and profile of the San Bernardino Basin.

sediments of sand and clay. Total thickness of the basalt flows decreases to the south. Well-log data shows a 2.4 m (8 ft) interval of basalt in a 30 m (100 ft) well in sec. 16, T.24S., R.30E., but basalt was not present in a 177 m (580 ft) well about 3.2 km (2 mi) east, in sec. 14. Another well, in sec. 2, T.24S., R.31E., did not encounter basalt, but it penetrated 1,731 m (5,679 ft) of Paleozoic strata, starting in Permian limestone and bottoming in Cambrian quartzite. Data from well-construction logs are insufficient to compare lithological characteristics such as particle size, percentage, and degree of consolidation of the basin-fill sediments. A thin layer of alluvium covers the basalt flows around the southern and western margins of the basin (Lynch 1973, p. 13).

Basin-Fill Aquifer System

Major Hydrostratigraphic Subdivisions

As already noted, a major distinguishing feature of the San Bernardino Basin aquifer system is the occurrence of interlayered basalt flows and a variety of associated volcanic vent units in the Upper Gila Group basin-fill sequence. Lithostratigraphic units within the structural basin area range in age from Paleozoic to Quaternary in age (Plate 1, Figure 9-2), however, the basin fill forms the only important aquifer component. Neogene and Quaternary deposits are here subdivided into major hydrostratigraphic-unit classes as defined in Chapter 3 (Figure 3-5, Tables 3-2, 3-3). Previous workers have lumped much of this material into an undivided "basin-fill" unit (Schwab 1992). Preliminary interpretations of geophysical data in transects across the basin (Stone and Witcher 1982) suggest that maximum basin fill thickness may be about 300 m (1,000 ft) (sections FF' and GG' Plate 1). It should be noted here, however, that most of this fill comprises Middle and Lower Gila Hydrostratigraphic Units (discussed below) that are partly indurated, commonly medium to coarse-grained, and (at least locally) structurally deformed. Probably only the upper 100 m (300 ft) of saturated basin fill correlates with the upper part of the Gila Group, and these deposits commonly are interbedded with basaltic units of the Geronimo volcanic field.

As has been previously emphasized, the hydrostratigraphic-unit (HSU) classification introduced in this report (including HSUs: LG, MLG, MG, UG) provides a logical mechanism for subdividing the basin fill into mappable units that are primarily defined in terms of stratigraphic position, depositional environment, and lithologic properties (cf. lithofaces assemblages) that directly relate to aquifer behavior. The deepest part of the San Bernardino Basin in Arizona appears to be a half-graben structure that contained a southward flowing axial stream system (semibolson landform) throughout much of its evolution. Composition of dominant hydrostratigraphic units, therefore, should reflect both piedmont-slope and basin-floor alluvial and fluvial environments of deposition (e.g., HSUs: UG1, UG2 and MG1, MG2).

The second important class of hydrostratigraphic units in the basin system comprises (1) surficial alluvium in major drainageways (draws, arroyos, canyon floors) and (2) finer grained sediments on basin and valley floors characterized by restricted surface-flow regimes (alluvial-flat, cienega deposits). Where saturated, these deposits are important components of the geohydrologic system in terms of groundwater recharge, movement and discharge. Hydrostratigraphic units AA and BFU represent these valley-fill categories in the San Bernardino Basin.

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 (HSUs) that form the framework of the basin-fill aquifer system. The explanation of Plate 1 provides a key to the lithofacies composition of the major hydrostratigraphic units that are schematically depicted on hydrogeologic maps and sections in this report (Plate 1 and Figure 9-2, sections FF' - GG'). For example, the dominant lithofacies assemblages (*7* and *8*) of the Middle and Lower Gila HSU: MLG (and undivided Tug in Mexico) are conglomeratic sandstones and mudstones (older piedmont facies). Considering the probability that the San Bernardino Basin has had axial drainage for much of Neogene time, there should also be a significant amount of gravelly sand to conglomeratic sandstone (facies *2* and *4*) and interbedded (partly indurated) sand and silt-clay (facies *3*) in hydrostratigraphic units UG2 and MLG. Where present, these deposits would have been associated with former channels and floodplains of the ancestral Rio San Bernardino system. Overlying Upper Gila piedmont deposits (HSUs: UGl, UGlc; primarily facies *5* and *6*) are a very minor component of the aquifer system because they are usually above the water table.

Hydraulic Properties of Major Aquifer System Components

General observations made in Chapters 4 to 7 on basin-fill hydraulic properties also pertain to the San Bernardino Basin. Schwab (1992) reports that the lava flows that are interbedded within the basin fill have the potential for acting locally either as aquifers or confining layers. These hydraulic properties depend on the extent of fracturing, and individual basalt flow dimensions. Groundwater also occurs in the surrounding mountains within zones of fractured or weathered volcanics, in isolated blocks of sedimentary rocks, and in thin layers of valley-fill alluvium overlying the bedrock (Schwab 1992). Much of the basin fill comprises conglomeratic sandstones and mudstones of the Lower and Middle Gila Hydrostratigraphic Units (undivided MLG). Upper Gila Hydrostratigraphic Units are present, but here they are mostly in the vadose zone except in the structurally deepest, west-central part of the basin, that underlies much of the Silver Creek drainage system (Figure 9-1).

MAJOR COMPONENTS OF THE GROUND-WATER FLOW SYSTEM

Surface-Water Components

Surface flow in the San Bernardino Basin has three components that directly interface with groundwater flow: (1) ephemeral streams in arroyos and draws, (2) widely scattered springs and seeps in higher uplands, and (3) one large cienega area with springs and flowing wells. The three major stream valleys crossing the basin are Black Draw along the basin axis, and the valleys of Silver Creek and Cottonwood Draw, respectively, near the western and eastern basin margins. Except in their mountain reaches and near the International Boundary, these streams are clearly ephemeral because reported depths to groundwater in the immediate vicinity of axial drainageways commonly range from 15 to 19 m (50 to 300 ft) (Schwab 1992).

Topographic maps and other historical documents covering parts of the San Bernardino Basin show a number of springs (seeps?) in mountain valleys and canyons. However, these surface-water features have not been described in terms of detailed flow or water-quality measurements. The following comment by Hanson and others (1994, p. 20) related to the Mimbres Basin system also applies to this area: "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 . . ." In the context of basin-fill groundwater-flow, nearly all springs and seeps in the upland parts of the basin system are here considered to be components of "mountain-front-recharge" because at least some of their discharge ultimately contributes to the basin-fill groundwater reservoir (cf. Figure 3-3). The only springs that act as drains to this reservoir are restricted to the lowest parts of the groundwater flow system near the San Bernardino Ranch historic site and the U.S. Fish and Wildlife Refuge (Schwab 1992).

Recharge

As is the case for all basin-fill aquifers in this semiarid region, only a small percentage of basinwide precipitation and surface runoff contributes to groundwater recharge. Considering the absence of extensive mountain areas above 1,800 m (6,000 ft) in the San Bernardino Basin, and the widespread cover of semiarid grassland and desert scrub, most of the average annual precipitation of about 40 cm (16 in) is lost to evapotranspiration. It is here assumed that:

1. Higher parts of the basin system that drain to the upper valley of Rio San Bernardino (primarily a discharge area near the International Boundary) have a surface area of about 1,000 km^2 (385 mi^2).
2. This area receives 4 x 10^8 m^3 (324,000 ac-ft) of unevenly distributed annual precipitation of about 40 cm (16 in).
3. Two percent of this precipitation, about 8 x 10^6 m^3 (6,480 ac-ft), contributes to groundwater recharge.

This is clearly a rough minimum estimate, but the values are supported by geohydrologic investigations in all the other basins of the study area (cf. Chapters 4 to 7).

The mountain-front-recharge component would, of course, vary considerably from place to place. It should be a significant contributor to the groundwater reservoir in this area, however, because the San Bernardino Basin is bordered by the southern Peloncillo-Guadalupe range to the east and the Pedregosa Mountains to the northeast. Both of these ranges have forest cover indicating much higher effective precipitation than in the highlands bordering the more arid basin systems to the northeast (cf. Chapters 4 to 7 Climate discussions).

The other significant source of recharge in the San Bernardino Basin is water percolating through thinner parts of the vadose zone beneath the emphemeral-stream channels of the system's three major drainageways: Silver Creek, Black Draw, and Cottonwood Draw. This component is termed "tributary recharge" by Kernodle (1992a) in distinction from "mountain-front-recharge." Since Silver Creek and Cottonwood Draw receive floodwater runoff and upland spring discharge from the highest mountain areas of the basin perimeter, they may contain significant recharge reaches.

Most piedmont slopes and basalt-capped basin-floor surfaces are not considered to be important recharge areas. The water table in these places is commonly very deep, locally exceeding 90 m (300 ft), and the component basin-fill deposits, which are interbedded with or capped by basaltic volcanics in many places, are commonly poorly sorted and partly indurated (mostly carbonate cements). The vegetative cover of semiarid-zone grasses and desert scrub, moreover, is very effective in capturing most of the annual precipitation.

Movement and Discharge

Since there has never been any significant effort to develop groundwater resources in the Arizona-New Mexico part of the San Bernardino Basin, groundwater movement and discharge have remained essentially at a "predevelopment" state. However, the local history of attempts to locate water supplies for a livestock and domestic uses suggest that substantial supplies of economically recoverable groundwater are not present.

Groundwater flow direction in the San Bernardino Basin has been described by Stone and Witcher (1982), Longsworth (1991), and Schwab (1992). The amount of groundwater flow is at best an estimate due to the uncertainties in the hydraulic gradient, aquifer thickness, and hydraulic conductivity. The general shape of the potentiometric surface shows that groundwater first moves toward the basin center from the bordering mountain ranges and a poorly defined flow divide at the south edge of the San Simon Valley Subbasin (Barnes 1991). It then moves southward to the regional *sink* formed by the Rio San Bernardino Valley in Mexico (Schwab 1992) (Figure 9-3). Most groundwater in the New Mexico portion of the San Bernardino Basin generally moves southwestward into Arizona and Mexico following the Guadalupe Canyon drainage basin topography.

CONCEPTUAL MODEL OF GROUNDWATER FLOW

The conceptual model of groundwater flow in the San Bernardino Basin aquifer system is here examined in the context 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 relevant information presented in this section are graphically illustrated or tabulated on Plate 1, Figures 9-2 and 9-3, and Tables 3-2 to 3-6. Kernodle's (1992a) basic guidelines for development of "U.S. Geological Survey Ground-Water-Flow Models of Basin-Fill Aquifers in the Southwestern Alluvial Basin Region . . . " provide a template for the conceptual model of groundwater flow described in this section and have been discussed at length in Chapter 4.

As is the case of the *open* and *drained* Gila River Basin system (Chapter 8), which ultimately discharges to the Gulf of California, the San Bernardino Basin is a *semibolson* that is part of a *drained* groundwater and *open* surface-water system. This system ultimately flows to the Rio Yaqui and the Gulf of California. Basin-fill hydrostratigraphic units in the saturated (phreatic) zone include (1) older fan alluvium on piedmont slopes of upper basin areas, (2) fluvial deposits of through flowing ancestral streams that occupied parts of the basin floor as it aggraded, and (3) widespread basin-floor deposits in the north-central basin area, which include basalt flows and vent units of the Geronimo volcanic field. These volcanics cap and are interbedded with Upper Gila Hydrostratigraphic Units (UG1-2) that are only partly saturated. The dominant aquifer system comprises Middle to Lower Gila Group Hydrostratigraphic Units (MG1-2, MLG) and undivided Gila Group basin fill (unit Tug) in Mexico. As already noted, the few specific reports on aquifer properties indicate that most basin-fill units have limited capacity for groundwater production, and estimates of the available water of good quality are speculative at best.

Even though saturated thickness of the basin-fill aquifer system is as much as 300 m (1,000 ft) in a few areas (based on geophysical-survey interpretations by Stone and Witcher 1982), the thickness of productive aquifer zones are probably less than 200 m (660 ft) in most places. Much of the basin-fill is partly indurated and well consolidated. This material has low porosity and permeability and comprises Neogene subdivisions of the Middle to Lower Gila Group (HSU: MLG). A "liberal" estimate of available ground-water stored in the upper part of the basin-fill sequence that should form the most productive (unconfined) portion of the aquifer system is about 5 x 10^9 m^3 (5 km^3; 4 x 10^6 ac-ft.). This estimate assumes an aquifer surface area of about 5 x 10^8 m^2 (500 km^2; 1.24 x 10^5 acres), an average saturated thickness of 100 m (330 ft), and a specific yield of 0.1. Since semiconfined to confined conditions are well documented in the lower part of the basin (Schwab 1992), use of the specific yield term in this type of calculation may not be appropriate in that area.

Even though site-specific information is lacking on subsurface geologic and hydrologic conditions in most of the San Bernardino Basin, a reasonable conceptual model of groundwater flow in the basin-fill aquifer system can be constructed on the basis of (1) hydrogeologic maps and cross sections, and groundwater-flow direction and gradient (Plate 1, Figures 9-2, 9-3); and (2) supporting interpretations of hydrostratigraphic units and lithofacies assemblages in terms of their geohydrologic behavior (Plate 1 explanation, Tables 3-4 to 3-6). The basic hydrogeologic framework of the area is shown on Plate 1 and Figure 9-2. *Note that east-west sections FF' and GG' are roughly normal to the basin's structural axes and principle drainage lines.*

Longitudinal section SB-SB' (Figure 9-2) closely follows the course of Black Draw from the San Bernardino Basin divide to the International Boundary, and it approximates the principal line of groundwater flow in the northern San Bernardino Basin. Since this section parallels the dominant (N-S) structural grain of the half graben that is tilted toward the "eastern basin" (footwall) uplift, no major faults are crossed (Plate 1, section FF'). Total thickness of Gila Group Hydrostratigraphic Units (UG and MLG), including basalt flows along the line of section SB-SB', ranges from 200 to 300 m (660-1,000 ft), with no more than 200 m (660 ft) of Upper Gila Hydrostratigraphic Units (UG1 and UG2) being present. The unsaturated valley fill alluvium of Middle (?) to Late Quaternary age that caps the Gila Group along Black Draw (HSUs: BFU and AA, facies *a* and *b*) is probably no more than 20 m (65 ft) thick.

In the general area that is crossed by the east-west segment of the International Boundary (Plate 1, section GG'), the potentiometric surface is at or slightly above the land surface (Figure 9-3). This area is near the upper end of the Rio San Bernardino Valley, and includes the distal parts of the Cottonwood Draw and Silver Creek drainage basins. Several flowing wells and springs are also reported on both sides of the border at the San Bernardino Ranch historic site (Schwab 1992). Characteristics of basin boundaries and aquifer (geohydrologic) components along hydrogeologic section GG' (between the Perilla and Guadalupe uplifts) place the following limits on a very preliminary calculation of transboundary-groundwater discharge from the Arizona part of the San Bernardino Basin. This flow estimate is based on the following assumptions:

1. Cross-section area of saturated basin fill is about 1.25 x 10^6 m^2 (1.35 x 10^7 ft^2), assuming a width of 9 km (29,500 ft) and a wedge thickness ranging from 0 to 300 m (0 to 1,000 ft).
2. The hydraulic gradient is 0.01 (from Schwab 1992).
3. Horizontal hydraulic conductivity of combined hydro-stratigraphic units UG (100 m thick), and MLG (200 m thick) is about 1.5 m/day (5 ft/day).

The estimated annual transboundary discharge based on these assumptions is about 6.8 x 10^6 m^3 (5,545 ac-ft). Recalling that total estimated annual recharge for the U.S. portion of the San Bernardino Basin groundwater system is about 8 x 10^6 m^3 (6,480 ac-ft), both values appear reasonable approximations of a real-world geohydrologic system.

GROUNDWATER QUALITY

General Hydrochemistry

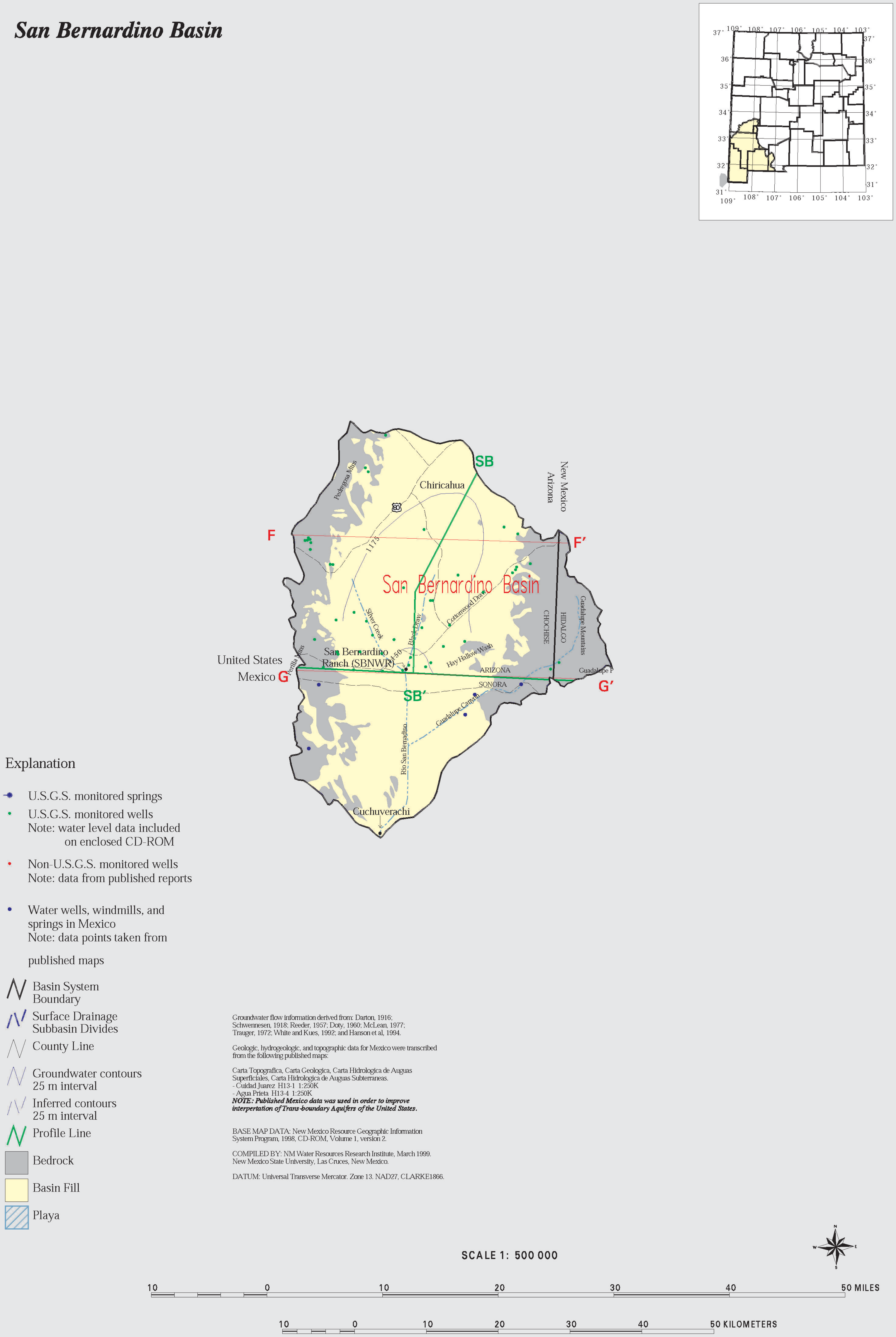
Water quality data in the San Bernardino Basin, shown in the regional stiff map and Piper diagram (Figures 9-4 and 9-5), are limited. The sparse data constrain interpretation of origin of solutes and limit the extent to which comments can be provided on the spatial distribution of hydrochemical facies and salinity (Longsworth 1991). Times series data are not available to assess historical change, and absence of field index parameters do not allow calculation of saturation indices.

The available data show that specific groundwater samples in the basin are less than 1000 mg/L TDS (Figure 9-4). Variable concentrations of salinity are shown in the U.S. part of the San Bernardino Basin. A few samples, shown in the yellow stiff patterns, are clustered near the U.S./Mexico border. These vary from 500 to 1000 mg/L TDS. Another cluster of samples at the international border, near the axis of the basin, is less than 250 mg/L TDS. Other samples in the U.S. part of the basin have variable TDS and no particular salinity trends are evident. The data in Mexico are too limited to evaluate salinity relationships to spatial locations in the basin.

The stiff map (Figure 9-4) and Piper diagrams (Figure 9-5) indicate that the hydrochemical facies are mostly Ca-Mg-Na-HCO_3 type waters in the U.S. part of the San Bernardino Basin. There is a progression toward Na-dominated waters in the United States (Figure 9-5). This seems to suggest that monovalent-divalent cation exchange is an important process north of the border. Groundwaters in Mexico are also Ca-Mg-Na-HCO_3 dominated waters, with wide scatter shown in the relative concentrations of cations (Figure 9-5). A single analysis in Mexico, located on the eastern margin of the basin, is a Na-SO_4 dominated water. The determination of origin of solutes and the analysis of evolutionary hydrochemical trends is not possible with the available data. The anion maps show concentrations of chloride and sulfate in groundwaters in the San Bernardino Basin (Figures 9-6 and 9-7). All of the chloride analyses are less than 25 mg/L Cl (Figure 9-6). Overall, this basin contains the most dilute chloride concentrations of any of the basins in the study area.

The sulfate map indicates that sulfate exceeds the recommended USEPA drinking water standard of 250 mg/L in only one analysis in the San Bernardino Basin (Figure 9-7). This sample, with a sulfate concentration of 270 mg/L SO_4, is located in the western bedrock highlands (Figure 9-7). Many groundwater samples have sulfate concentrations

San Bernardino Basin



Groundwater flow information derived from: Darton, 1916; Schwennesen, 1918; Reeder, 1957; Doty, 1960; McLean, 1977; Trauger, 1972; White and Kues, 1992; and Hanson et al, 1994.

Geologic, hydrogeologic, and topographic data for Mexico were transcribed from the following published maps:

Carta Topografica, Carta Geologica, Carta Hidrologica de Auguas Superficiales, Carta Hidrologica de Auguas Subterraneas.
- Cuidad Juarez H13-1 1:250K
- Agua Prieta H13-4 1:250K

NOTE: Published Mexico data was used in order to improve interpertation of Trans-boundary Aquifers of the United States.

BASE MAP DATA: New Mexico Resource Geographic Information System Program, 1998, CD-ROM, Volume 1, version 2.

COMPILED BY: NM Water Resources Research Institute, March 1999. New Mexico State University, Las Cruces, New Mexico.

DATUM: Universal Transverse Mercator. Zone 13. NAD27, CLARKE1866.

Figure 9-3. San Bernardino groundwater contours, flow directions, and aquifer- stream relationships.

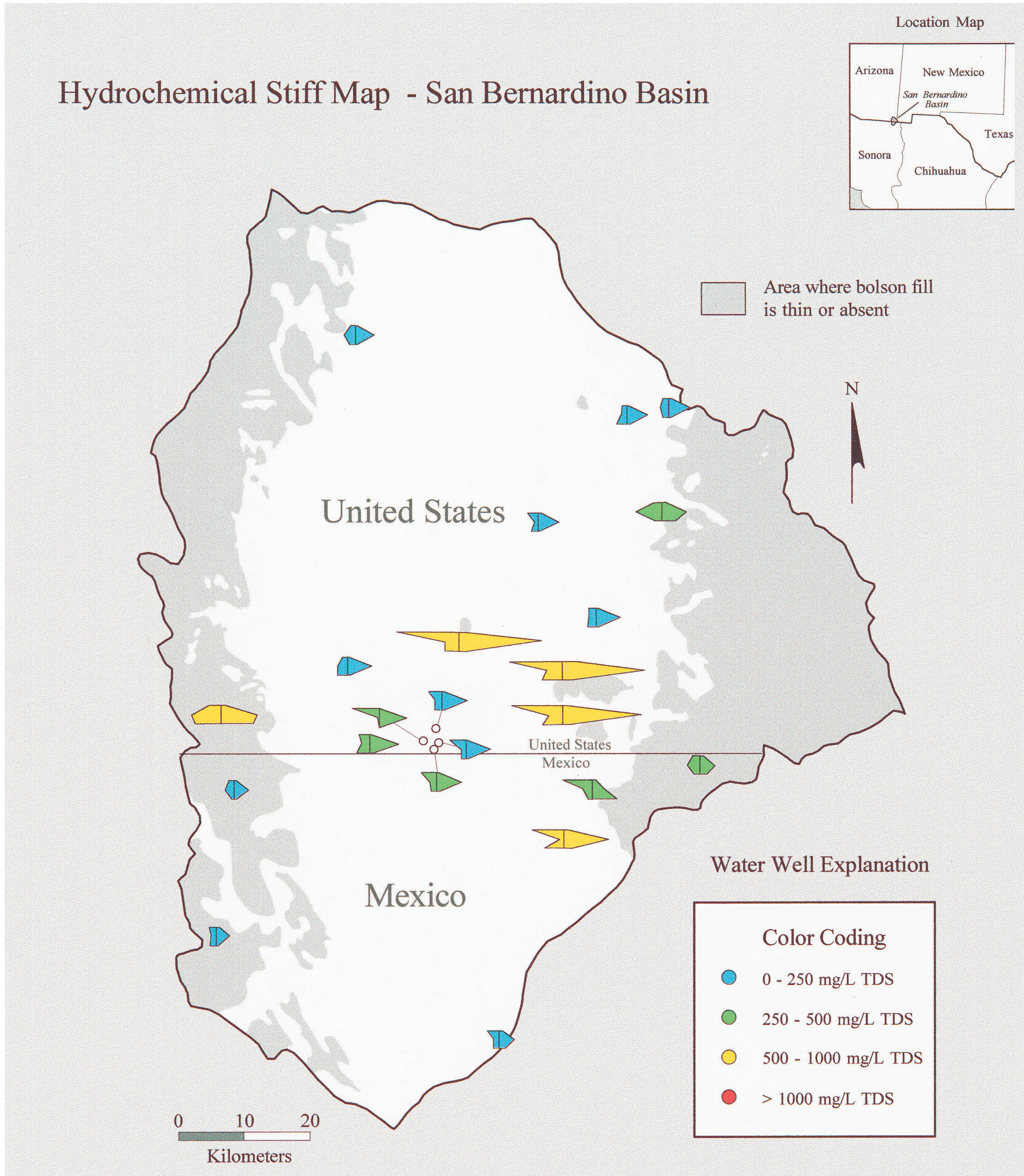


Figure 9-4. Hydrochemical stiff map for the San Bernardino Basin, color coded by TDS ranges (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica

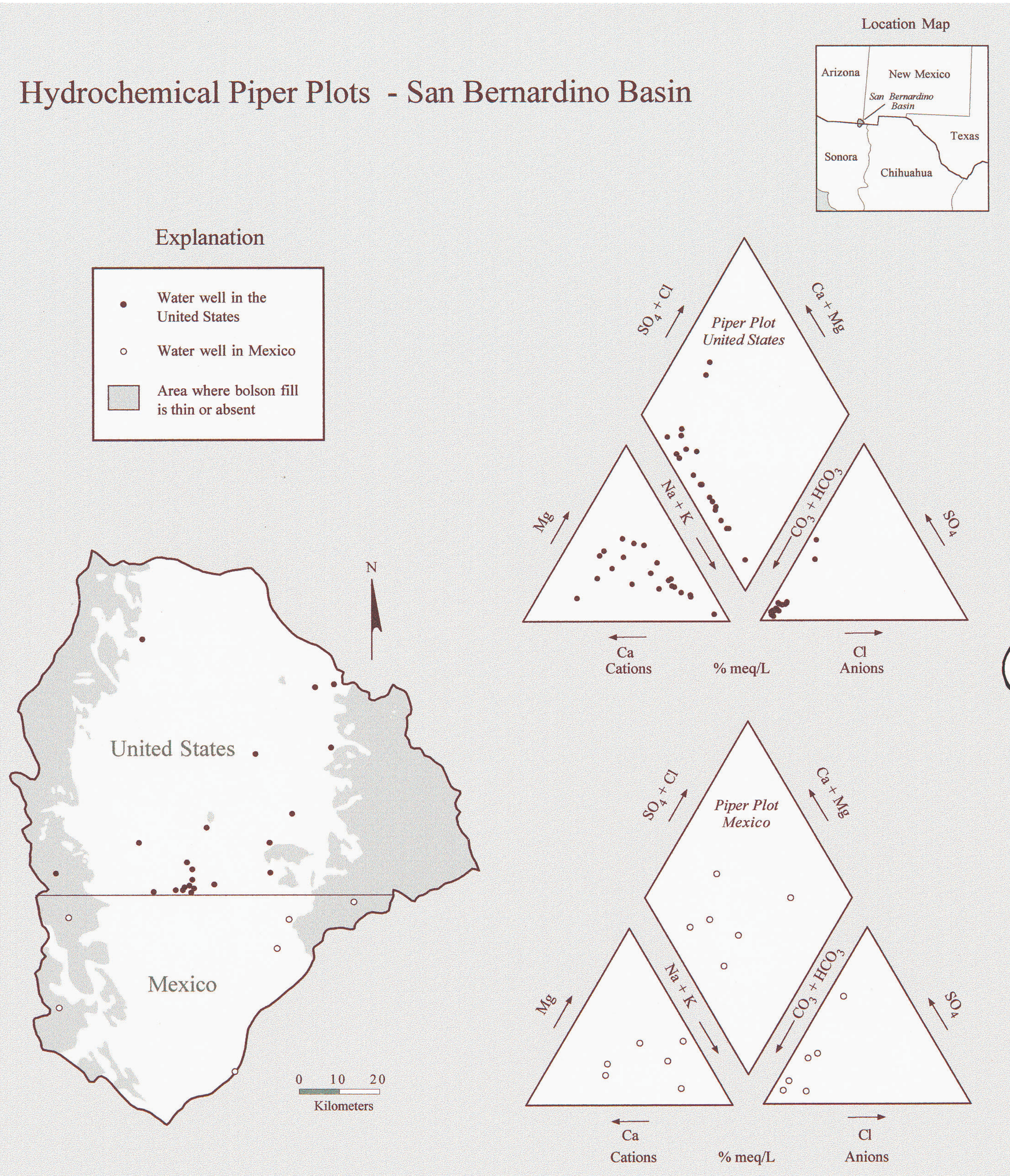


Figure 9-5. Hydrochemical Piper plots for groundwater in the San Bernardino Basin, U.S. and Mexico (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

Figure 9-6. Map for the San Bernardino Basin, showing chloride concentrations in water wells (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatic

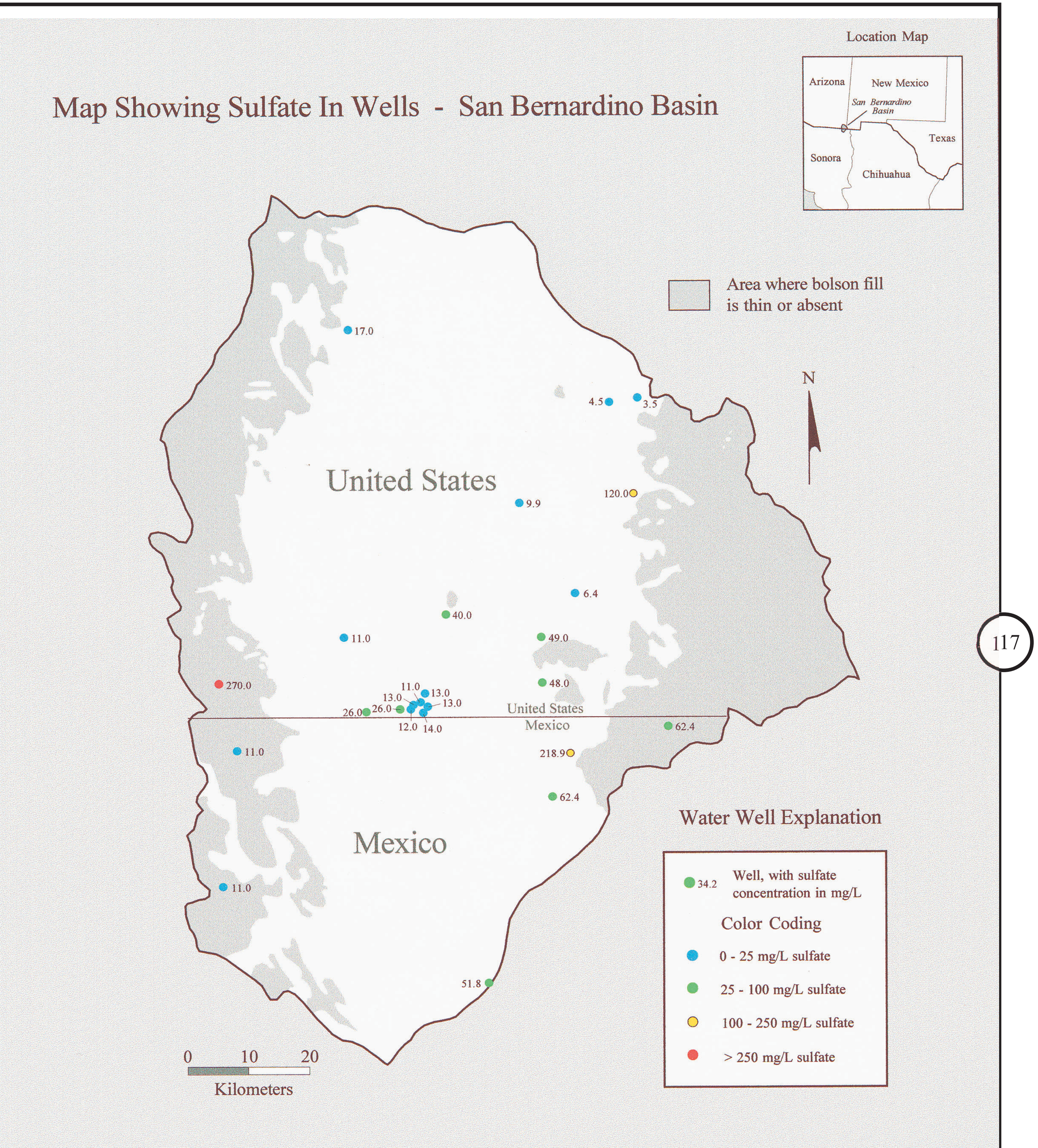


Figure 9-7. Map for the San Bernardino Basin, showing sulfate concentrations in water wells (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

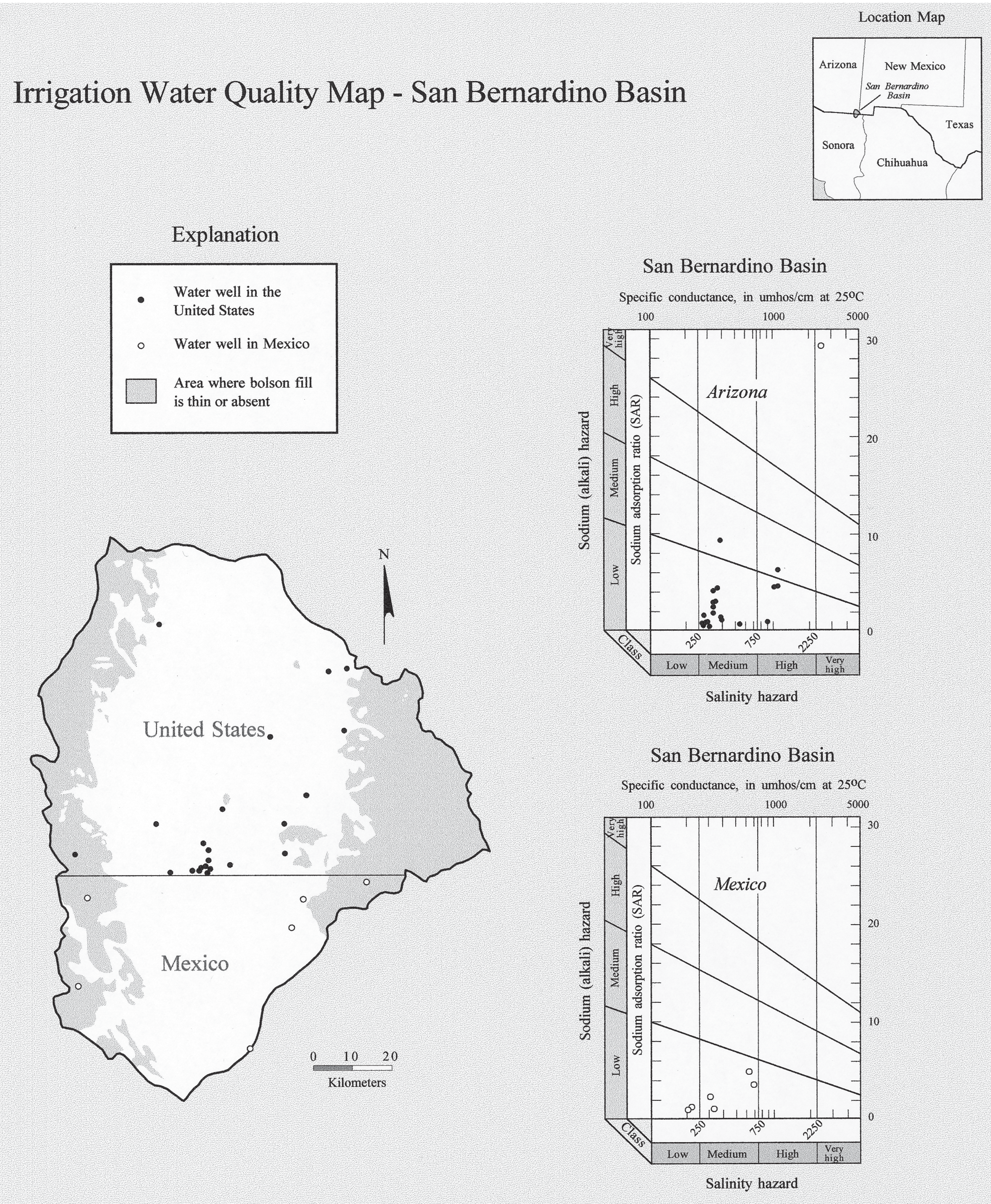


Figure 9-8. Irrigation water quality map for the San Bernardino Basin, U.S. and Mexico (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

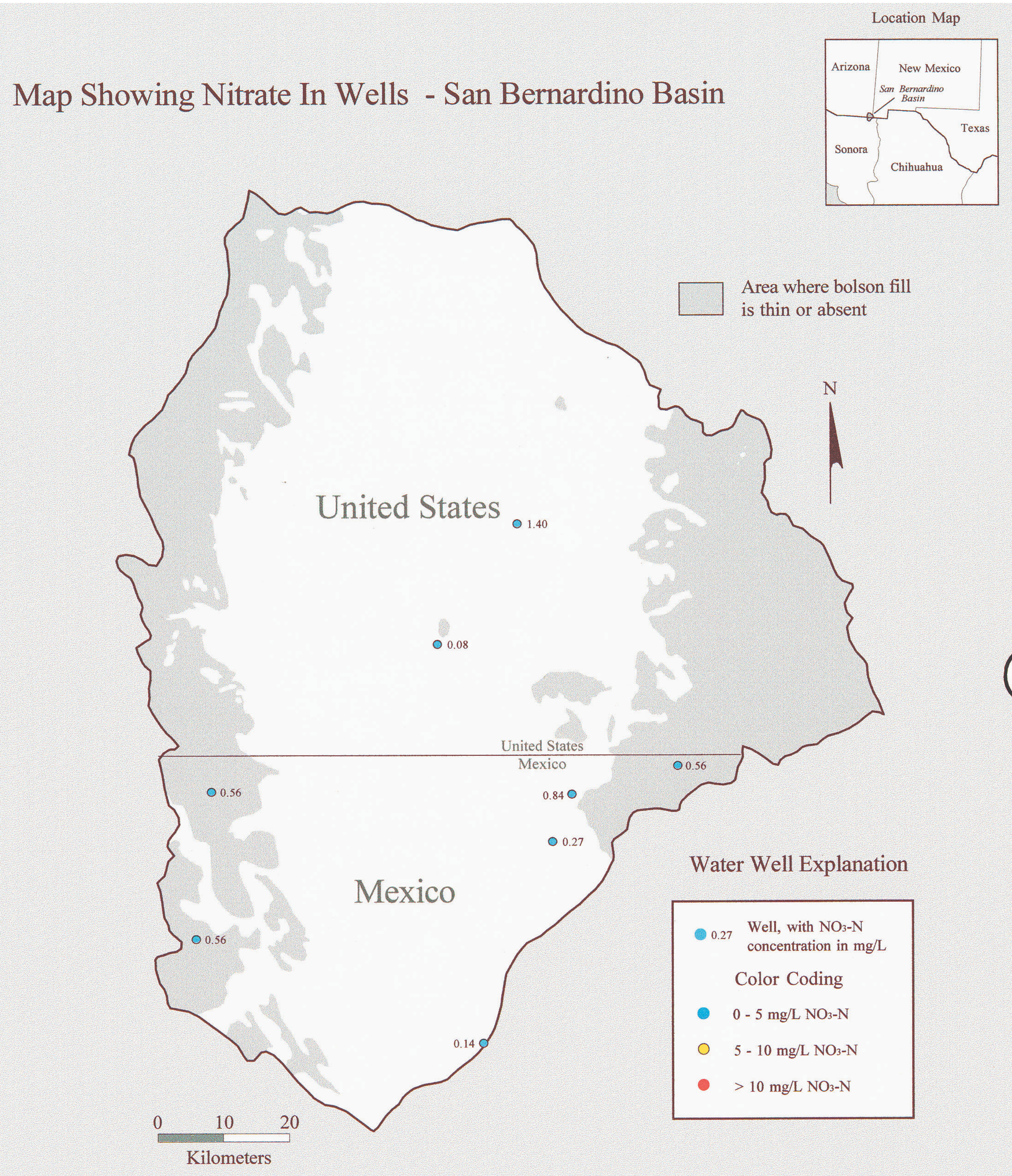


Figure 9-9. Map for the San Bernardino Basin, showing nitrate concentrations in water wells (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

that are less than 25 mg/L SO_4. Groundwaters have relatively higher sulfate concentrations on the eastern side of the basin, usually varying from 25 to 250 mg/L SO_4.

Irrigation Water Quality

Groundwater has low alkali hazard and low-to-medium salinity hazard in the Mexican portion of the San Bernardino Basin (Figure 9-8). Most groundwater samples in the United States part of the San Bernardino Basin have low alkali hazard and medium salinity hazard (Figure 9-8). A smaller subset of groundwater samples in the United States has a high salinity hazard. Only two samples have a medium alkali hazard. These data suggest that irrigation water quality is good for most varieties of crops (Schwab 1992).

Nitrate in Groundwater

Nitrate data are very limited in the San Bernardino Basin (Figure 9-9). It is impossible to determine the extent to which nitrate may present a threat to the health of the residents in the basin with these data. The very limited data indicate that all samples contain less than 2.0 mg/L NO_3-N, both in the United States and Mexico. More data are needed, especially in the United States, to determine risks due to nitrates.

SUMMARY

The San Bernardino Basin contains an important trans-international boundary aquifer component, and includes the southeastern, southwestern and northeastern corners of the states of Arizona, New Mexico and Sonora, respectively. Most of the basin is in Cochise County, Arizona (1,000 km^2; 387 mi^2) and Mexico (1,040 km^2; 400 mi^2), and only about 90 km^2 (35 mi^2) of the watershed is in Hidalgo County, New Mexico. The entire area is in the Mexican Highland section of the Basin and Range physiographic province.

The part of the San Bernardino Basin described in this chapter is flanked on the west by the Pedregosa and Perilla Mountains and on the east by the southern Peloncillo and Guadalupe Mountains, the southwestern Cloverdale (San Luis) Subbasin, and the northern Sierra San Luis. The basin is a *semibolson* geomorphic feature, and its axial drainageway is designated Black Draw (ephemeral to intermittent) in Arizona, and Rio San Bernardino (intermittent to perennial) in Sonora. The dominant landforms in the Arizona part of the basin-floor are widespread basalt flows and numerous associated vents of the Geronimo volcanic field. Elevations in the United States part of the basin range from 1,993m (6,539 ft) in the Pedregosa Mountains and 1,966m (6,450 ft) at Guadalupe Mountain to 1,132m (3,715 ft) near the lower end of Black Draw.

The San Bernardino Basin extends at least 40 km (25 mi) into Mexico as a distinct basin-range structure. Several meters of movement on the east-basin boundary fault occurred during the "1887 Earthquake" in northeastern Sonora. The nature of the basin's structural linkage with the San Simon Basin (Valley) to the north, however, is uncertain because of the young volcanic cover in the drainage divide area between these two distinct geohydrologic systems. The *open* and *drained* system to the north is linked to the Safford Valley reach of the Gila River via San Simon Creek (Draw). The Black Draw-Rio San Bernardino drainage basin, also an *open* and *drained* system, is linked to the Yaqui River and the Gulf of California by the valleys of Rio Batepito and Rio Bavispe in central Sonora.

The major eastern tributaries to Black Draw and Rio San Bernardino are (1) Cottonwood Creek and Draw, which heads the western slope of the southern Peloncillo and Guadalupe mountains along the NM-AZ border, (2) Guadalupe Canyon-Rio Guadalupe, with headwaters in the southern Guadalupe Mountains and along the western rim of the Cloverdale Subbasin; and (3) Rio (de) Cajon Bonito, which heads on the northwestern slopes of Sierra San Luis (including a short Continental Divide segment) and along the southwestern Cloverdale Subbasin run. These streams are primarily ephemeral, but they do have short, spring-fed intermittent to perennial reaches in mountain areas. Cottonwood Draw is tributary to an intermittent to perennial reach of (lower) Black Draw at the north edge of the San Bernardino National Wildlife Refuge (and historic ranch site) about 3.5 km (2 mi) north of the International Boundary. The Refuge is also the site of several flowing wells and wet-meadow bottomlands (cienegas). The Rio Guadalupe and Rio (de) Cajon Bonito confluences with the Rio (de) San Bernardino are, respectively, about 12 km (7.5 mi) and 24 km (15 mi) south of the Arizona-Sonora border. The only large western (mostly ephemeral) tributary to the axial drainage system in the study area is Silver Creek. It heads in the Perillo-southern Pedregosa range and joins Rio (de) San Bernardino about 2 km (1.25 mi) south of the International Boundary.

Land use/landcover categories in the San Bernardino Basin system are predominantly rangeland, with forest areas in highest parts of the Peloncillo-Guadalupe and Pedregosa mountains. There are no population centers of any type on the United States side of the border. Water use data are not available for this part of the basin. Climate ranges from semiarid on the basin floor to subhumid in higher parts of the Pedregosa, Peloncillo, Guadalupe, and Sierra San Luis ranges. Mean annual precipitation and average daily mean temperature recorded at Apache (AZ), about 10 km (6 mi) north of the basin at an elevation of 1,640 m (5,380 ft), are 42.7 cm (16.8 in) and 14.3^o C (57.7^o F).

Geophysical surveys, local test drilling for oil and gas resources, and surficial geologic mapping in the Arizona part of the study area indicate than only the western half of San Bernardino Basin floor is underlain by a deep structural depression with moderately thick (about 300 m, 1,000 ft) Gila Group deposits. This east-tilted half-graben structure is flanked by a shallowly buried bedrock bench that occupies much of the eastern part of topographic basin. The deep western basin block continues southward into Mexico, but it appears to shallow northward into a structurally high *accommodation zone* marking a northeastward-stepping transition to a west-tilted half-graben in the southern San Simon Basin. The extensive cover of basalt flows (Late Miocene to Middle Pleistocene) in the Geronimo volcanic field obscure structural relationships in most of this area.

Most of the basin fill comprises undivided, Middle and Lower Gila Hydrostratigraphic Units (HSU: MLG) that are partly indurated and structurally deformed. Probably only the upper 100m (330 ft) of saturated basin fill correlates with the upper part of the Gila Group. These deposits (hydrostratigraphic units UG1, UG2) are interbedded with all but the oldest basalts of the Geronimo volcanic field in the north-central part of the basin. Lava-flows in the upper basin-fill sequence have the potential for acting either as aquifers or confining layers. These hydraulic properties depend on the extent of fracturing and individual flow dimensions. Thick saturated parts of the Upper Gila Group basin fill (HSUs: UG1-UG2) appear to be restricted to the deep (western) structural depression that underlies much of the Silver Creek drainage system. A very liberal estimate of available groundwater of good quality that is stored in the San Bernardino Basin aquifer system of southeastern Arizona is about 5 x $10^9 m^3$ (4 x 10^6 ac-ft).

The San Bernardino Basin, in addition to the Cloverdale and Upper Animas subbasins of the Animas Basin system, is the least arid part of the area immediately adjacent to the International Boundary. A larger proportion of annual precipitation and effective recharge occurs in late fall to early spring (Chapter 7) than in all other parts of the study area except the Datil-Mogollon section (Chapter 8). A provisional minimum estimate of annual recharge in the United States part of the basin is about 8 x $10^6 m^3$ (6,480 ac-ft). Since semiconfined to confined hydraulic conditions are well documented in the lower part of the basin, estimates of storage coefficient values (in the "specific yield" range) in calculation of available water in storage are probably much too high.

The first major point of surface discharge for the Arizona-New Mexico part of the groundwater-flow system is the lower reach of Black Draw in the historic San Bernardino Ranch and cienega area that extends about 4 km (2.5 mi) across the International Boundary from the upper end of Rio (de) San Bernardino. A very preliminary estimate of transboundary groundwater flow from the Arizona part of the basin is 6.8 x $10^6 m^3$ (5,545 ac-ft) per year.

Limited available data on groundwater quality in the San Bernardino Basin show that specific samples all have TDS values of less than 1,000 mg/L, with a cluster of samples near the basin axis along the International Boundary that have less than 250 mg/L TDS. Hydrochemical facies are mostly Ca-Mg-Na-HCO_3 type waters in the Arizona and New Mexico part of the basin, with this facies also being dominant in samples from the Sonora area. A single analysis in Mexico, on the eastern basin margin, is a Na-SO_4 dominated water. All chloride analyses are less than 25 mg/L Cl. Overall, the San Bernardino Basin contains the most dilute chloride concentrations of any of the basins in the study area.

Groundwater has low alkali hazard and low-to-medium salinity in the Mexican portion of the basin. Most samples in the United States part of the basin have low alkali and medium salinity hazards, with medium alkali to high salinity hazards noted in a few samples. The very limited information on nitrate in groundwater shows values of less than 2.0 mg/L NO_3-N.