CHAPTER 6 – PLAYAS AND SAN BASILIO BASIN SYSTEMS

INTRODUCTION

Emphasis in this chapter is on the relationship between groundwater flow and the hydrogeologic framework of basin-fill aquifers in the Playas and San Basilio Basin systems. Most of the basic concepts and interpretations of how groundwater-flow systems function in the intermontane basins of the transboundary region have already been discussed in considerable detail (Chapters 3 to 5). Discussions here will, therefore, primarily focus on aspects of basin-fill hydrogeology and groundwater flow that distinguish the Playas-San Basilio area from contiguous basins of the region. The chapter concludes with an overview of groundwater quality in the context of hydrogeologic controls on the basin-systems' groundwater-flow regime.

The most important distinguishing feature of the two basin systems described in this chapter is the near coincidence of the International Boundary with the divide for both surface and subsurface drainage that separates the southward flow regime of the San Basilio Basin from the northward flowing geohydrologic system in the Playas Basin. Because there is no significant transboundary groundwater flow between these basin systems, they are treated as distinct geohydrologic units, and coverage of the hydrogeologic framework and related topics will not be as detailed as in Chapters 4 and 5. Additional observations on the San Basilio-La Soda "Playa" flow system will be made throughout this chapter following more detailed discussion of the Playas Basin system.

LOCATION AND PHYSIOGRAPHIC SETTING

Overview

The Playas and San Basilio Basin systems comprise a north-south aligned group of intermontane basins in the Mexican Highland section of the Basin and Range province. The basin systems are continuous in a structural sense and have a total area of about 3,450 km^2 (1,330 mi^2). However, geohydrologic features are only partly connected, and comprise three distinct physiographic units. The most extensive basin landforms are the broad piedmont slopes that extend out from the mountain fronts. These coalescent alluvial-fan surfaces (bajadas) grade to basin-floor areas that range from narrow alluvial flats along axial drainageways to broad bolson plains comprising both alluvial flats and playa-lake depressions.

The main area of concern in this chapter is the Playas Basin system. It is a separate geohydrologic entity that makes a small contribution to transboundary groundwater flow via Hatchet Gap (Chapter 5). Except for two small strips of upland watershed on the Chihuahua side of the border (< 10 km^2, Figure 6-1), the entire Playas Basin system is located in Hidalgo County, New Mexico and has an area of about 2,400 km^2 (925 mi^2). This basin system has two components: (1) an *open* and *drained* "Upper" subbasin (with an area of about 1,440 km^2, 555 mi^2), which discharges partly to the Upper Hachita Subbasin; and (2) a *closed* and (originally) *partly-drained* "Lower" Subbasin (with an area of about 960 km^2, 370 mi^2), which contributes both surface and subsurface flow to the Playas Lake topographic depression. The Upper Playas Subbasin is a major *semibolson* landform with through-going surface and subsurface drainage, while the *closed* Lower Subbasin is a "*classic bolson*" as defined by Tolman (1909, 1937). Playas Lake is a remnant of "pluvial" Lake Playas (Table 3-1), which inundated a basin-floor area of about 65 km^2 (25 mi^2) in latest Quaternary time (Schwennenssen 1918).

The San Basilio Basin, with an area of about 1,050 km^2 (405 mi^2), is located almost entirely in Chihuahua; however, it does include a narrow strip of land (< 50 km^2, 20 mi^2) in New Mexico that extends along the border through the Antelope Wells Port of Entry area. *Note also that the local place name "San Basilio" (historic ranch located near Hwy 2 about 20 km [12 mi] south of Antelope Wells and the Chihuahua community of El Berrendo) is used informally in this report to designate this important geohydrologic basin.*

The San Basilio Basin is here treated as a *closed* and *drained* or *partly drained* geohydrologic unit. Storm-water runoff is captured by a shallow depression occupied by an extensive alkali flat (possible *vadose-phreatic* playa complex), which is informally designated "La Soda Playa" (after a map-feature name at the depression center). Incomplete subsurface (bedrock) closure of the basin is suggested by the most recent topographic map of the area (Carta Topographica, escala 1:50,000, San Francisco cuadrágulo). The "La Soda" depression may therefore discharge groundwater underflow (and also occasionally spill surface water after extreme flooding events) to the northwestern part of the Rio Casas Grandes watershed immediately south of the map area (Figure 3-1, Plate 1). The major *bolson* landform that comprises the San Basilio Basin is therefore considered to have a *partly-drained* groundwater-flow regime, with or without complete topographic closure.

Basin Boundaries

The eastern boundary of the San Basilio Basin is the crest of the Sierra del Perro uplands, which forms the drainage divide with the Rio Casas Grandes Basin to the east. North of the International Boundary, the continuation of this divide forms the border between the Playas and Hachita-Moscos Basin systems. The highlands forming the Hachita-Playas Basin border (Dog, Alamo Hueco, Big Hatchet, and Little Hatchet mountains) have already been described in Chapter 5. The flow connection between the Upper Playas and Hachita subbasins through Hatchet Gap has also been discussed in that chapter.

The western border of the San Basilio and Playas Basin systems is notable because it follows the Continental Divide along a series of high mountain ranges with crest elevations commonly exceeding 2,000 m (6,600 ft). The two major ranges are Sierra San Luis near the Chihuahua-Sonora border, and the Animas Mountains. The latter range extends northward from the low San Luis "Mountains" (and San Luis Pass, Figure 6-1) about 60 km (35 mi) into southern New Mexico. These mountains are the northern extension of the Sierra Madre Occidental of northwestern Mexico, and they are the first major highland area to intercept masses of moist air that seasonally move inland from the Gulf of Mexico and the eastern Pacific Ocean. Most of the large precipitation events are in the late summer and early fall, however, lower magnitude (but very effective) precipitation pulses occur during the winter and early spring in some years (cf. Climate section, Chapter 7).

The southwestern border of the San Basilio Basin (west of La Soda Playa) is Sierra el Medio, with peak elevations of as much as 2,153 m (7,065 ft). To the north, the subbasin boundary steps westward to the crest of Sierra San Luis, which is on the Continental Divide and includes the highest peak in the basin system (2,520 m, 8,270 ft). The northwestern corner of the San Basilio Subbasin is at the International Boundary near Puerto San Luis (elev. 1,970 m, 6,465 ft). As has already been noted, the Upper Playas–San Basilio Basin system border trends east from this point toward Antelope Wells and El Berrendo, while the western margin of the Playas Basin system continues north along the Continental Divide. The Divide is also the common boundary with much of the Animas Basin system to the west (Chapter 7).

Most of the western edge of the Playas Basin system north of the San Luis Mountains is along the crest of the Animas Mountains, with the highest elevation on the Continental Divide reaching about 2,500 m (8,200 ft) near Animas Peak. To the north, the range decreases markedly in width and height, with Gillespie Mountain (2,228 m, 7,310 ft) forming the high point of the central Animas uplift. The eastern slopes of the range north of this area are a part of the Lower Playas Subbasin watershed (Figure 6-1).

At its north end, the Animas range is abruptly terminated by a broad topographic and structural saddle (crossed by NM Hwy 9 and the former SPRR route) that separates the northern Animas from the southern Pyramid mountains (Figure 6-1). The low point on this unnamed pass between the Lower Playas and Lower Animas subbasins (here informally named the Animas-Pyramid Gap) has an elevation of 1,376 m (4,515 ft). At South Pyramid Peak (1,800 m; 5,910 ft), the Continental Divide turns abruptly to the east and crosses another topographic and structural saddle between the southern Pyramid uplift and the Brockman Hills. This Divide segment separates the northern (Lower) Playas Basin system from the Lordsburg Subbasin of the Animas Basin system. This saddle is here informally named the Brockman-Pyramid Gap, and its lowest elevation is about 1,347 m (4,419 ft).

The northeastern boundary of the Playas Basin system is formed by another short segment of the Continental Divide that follows the crest of the Coyote Hills. About 13 km (8 mi) northwest of Hachita, the basin boundary crosses the saddle between the northern Little Hatchet Mountains and the Coyote Hills. The Hachita-Playas section of NM-Hwy 9 and former the SPRR route (Vista Siding) also pass through this topographic "gap." The Playas-Hachita basin border to the south follows the crest of the Hachita uplift.

The "Animas-Pyramid" and "Brockman-Pyramid" Gaps at the north end of the Playas Basin system are important physiographic as well as geohydrologic features in that they (1) mark the lowest points on the Continental Divide between southern Mexico and western Canada, and (2) may coincide with buried bedrock saddles (and/or fracture zones) that allowed (predevelopment) underflow to

Playas and San Basilio Basin System

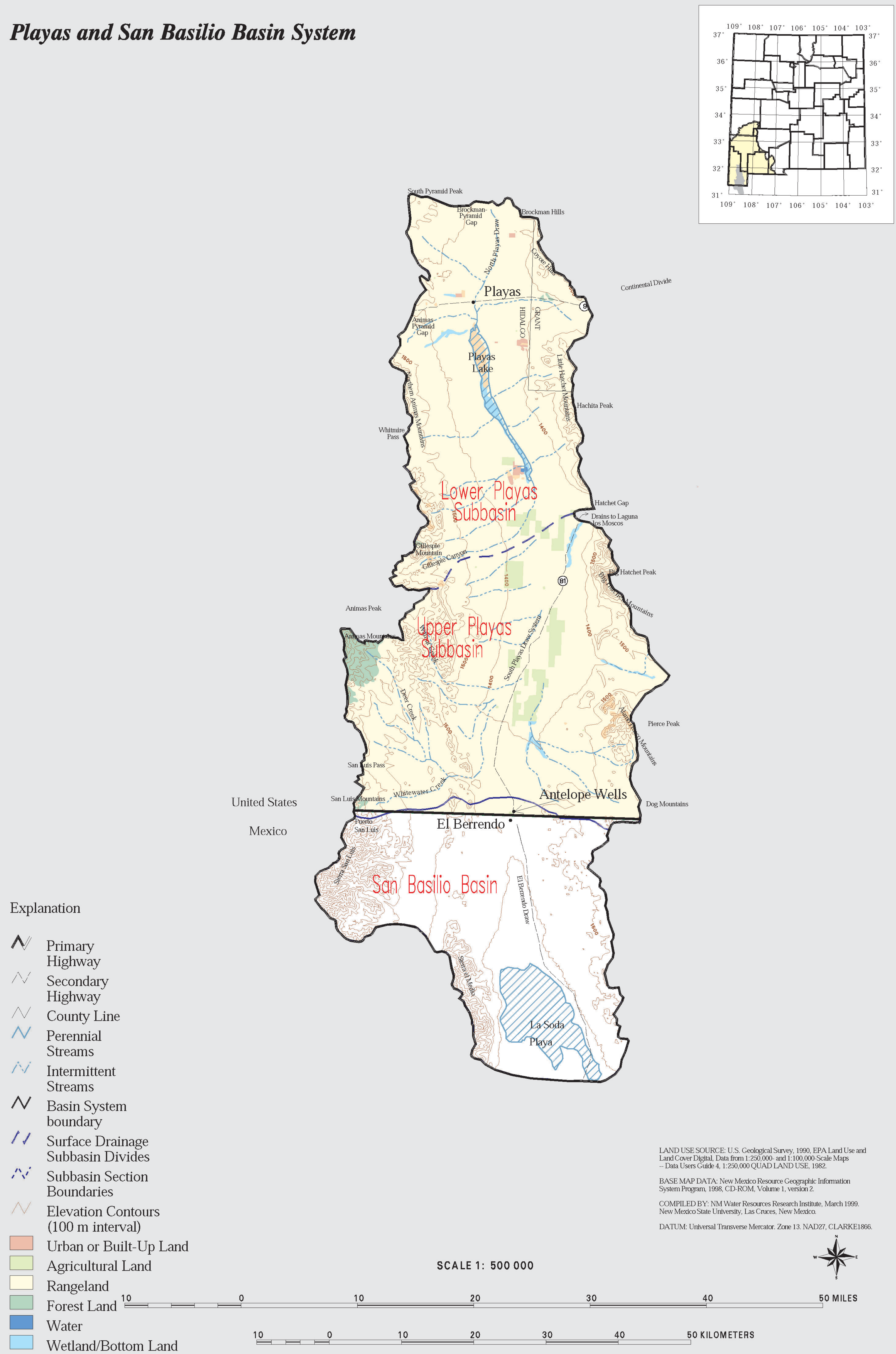


Figure 6-1. Land use in the Playas and San Basilio Basin system

move northwestward from the Lower Playas Subbasin to the groundwater-flow system in the Lower Animas Subbasin, which ultimately discharges to the Gila River Basin.

Drainageways

There are no perennial streams in either the San Basilio or Playas Basin systems with the exception of short headwater reaches of upper canyon tributaries in highest parts of the Sierra San Luis and the southern Animas Mountains. Most of these streams contribute runoff and aquifer recharge in the northwestern San Basilio Basin and the southwestern Upper Playas Subbasin (Figure 6-1). The Deer-Whitewater Creek and Walnut Creek watersheds are the largest highland drainage basins in the latter area.

Major axial systems of draws occupy the floors of (1) the northern San Basilio Basin; (2) the Upper Playas Subbasin; and (3) the northern part of the Lower Playas Subbasins. The axial draw of the San Basilio Basin is here informally named El Berrendo Draw after the nearby Mexican border community south of Antelope Wells. As indicated on Figure 6-2 and Plate 1, the upper reach of this draw may occasionally receive flood runoff from of the alluvial-fan system that heads on the western slope of the Dog Mountains just north of the major drainage divide between the San Basilio Basin and Upper Playas Subbasin. Flood discharge down through El Berrendo Draw ultimately reaches La Soda Playa.

The complex of axial drainageways on the floor of the Upper Playas Subbasin also has no formal name and it is here simply referred to as the South Playas Draw "system or complex." Major contributors of storm runoff are the Deer-Whitewater Creek and Walnut Creek watersheds in the southern Animas Mountains, and several drainage basins in the Alamo Hueco and western Big Hatchet mountains. As already noted, some storm runoff flowing down the axial South Playas drainageway ultimately "spills" through Hatchet Gap into the Upper Hachita Subbasin. A component of this flow, however, appears to be diverted occasionally to a series of shallow drainageways that contribute storm runoff to the extensive alluvial flats that mark a broad zone of transition between the Upper and Lower Playas subbasins in the bolson plain area west of Hatchet Gap. The main upland watershed contributing storm runoff to this particular area is the Gillespie Creek basin that heads in the central Animas Mountains south of Gillespie Mountain (Figure 6-2).

The axial draw at the north end of Lower Playas Subbasin heads near "Brockman-Pyramid Gap" and it terminates in a small fan-delta at the north end of Playas Lake. This drainage is here informally designated North Playas Draw. Its major watershed for flood runoff comprises the southern slopes of the Southern Pyramid and Coyote Hills uplifts south of the Continental Divide.

Land Use

Both the Playas and San Basilio Basin systems represent a moderate array of land use and landcover components, including small forest areas in the Animas Mountains and Sierra San Luis along the western border, and extensive rangeland on the lower-elevation mountain and piedmont slopes, and on central-basin floors. Large barren, ephemeral-lake plains with alkali flats are also present on basin floors in the southern San Basilio Basin and the Upper Playas Subbasin (Figure 6-1). The border community of Antelope Wells-El Berrendo, and the industrial town of Playas (Phelps Dodge Corporation) are the only urban centers. Completion of (Mexican) Federal Highway 2 across the San Basilio Basin, which will link the Casas Grandes Valley (Ascensión-Janos) and Douglas (AZ) -Agua Prieta (Sonora) areas, should have a significant impact on basin system development in the near furture. Most cropland areas that had been developed in the Upper Playas Subbasin (and shown on Figure 6-1) are not currently cultivated. Many irrigation water rights have been acquired for mineral processing uses following the construction of the Playas Smelter at the south end of Playas Lake. As indicated in Table 1-3, the annual water use for mineral processing increased from about 4.89 x 10^6 m^3 (3,961 ac-ft) in 1990 to about 6.06 x 10^6 m^3 (4,913 ac-ft) in 1995. However, the current decline in copper production throughout the region suggests that groundwater production for mine/mill uses (including urban use at Playas) will be curtailed for an unknown period of time.

Climate

No climate reporting stations are located in the Playas and San Basilio Basin systems. The stations at Hachita (east) and Animas (west) in adjacent basins are expected to be typical of the general area. Except for the highest parts of the Animas, Big Hatchet and San Luis ranges, climate is arid to semiarid with mostly clear skies and limited rainfall and humidity. Average annual precipitation was reported at 25.2 cm (9.93 in) per year at Hachita and 27.8 cm (10.96 in) per year at Animas. Most annual precipitation is from thunderstorms that occur from July through September. Snow depths average 11.5 cm or 4.54 inches at Hachita and 15.1 cm or 5.96 inches at Animas (NCDC 1999).

HYDROGEOLOGIC FRAMEWORK

Overview

As in the two proceeding chapters, emphasis here is on the hydrogeologic framework of individual structural basins in this part of the Basin and Range tectonic province. The first part of this section deals with bedrock- and structural-geologic controls on basin-fill aquifer composition groundwater-flow system behavior. The major published sources of information on the geologic setting of the Playas and San Basilio Basin systems are maps and reports by Zeller (1958, 1959, 1962, 1970, 1975), Zeller and Alper (1965), Erb (1979), Drewes and others (1985), and Bryan (1995). Supplemental geophysical and geologic interpretations of deep-subsurface conditions by DeAngelo and Keller (1988), Klein (1995), Corbitt (1988), and Thompson (1982) were used in preparation of the hydrogeologic cross sections (Figure 6-1, PP'; and Plate 1, DD' to GG'). Geologic and geohydrologic information on the San Basilio Basin was compiled from the DGGTN (nd) mapping of the Agua Prieta (2°) sheet. In addition, the reconnaissance work on basin-fill deposits in the Playas "Valley" area by Schwennesen (1918) and Doty (1960) has provided an excellent base for development of the conceptual models of the basin-fill hydrogeologic framework and groundwater-flow systems presented here. As in the basin systems previously described (Chapters 4 and 5), most synthesis and interpretation of information on the Late Cenozoic history and hydrogeologic setting has been done specifically for this study by J. W. Hawley.

Basin Boundary and Intra-Basin Structural Elements

The major geologic features of the Playas and San Basilio Basin systems are first considered in terms of basin-boundary conditions and partitioning effects in intra-basin areas. The combination of (1) transverse and longitudinal (dominant flow directions) hydrogeologic cross sections (Plate 1, DD' - GG'; Figure 6-2, PP'), and (2) the surface distribution patterns of bedrock units, basin-fill classes, and faults (Plate 1) allows placement of reasonable limits on estimates of aquifer properties and groundwater-flow behavior.

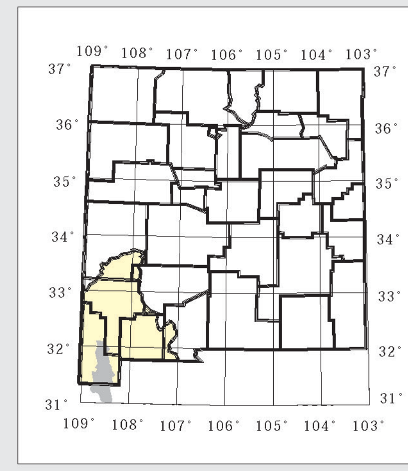
As already noted, there are three major subbasins in the area under discussion (San Basilio Basin, Upper Playas, and Lower Playas) that are linked along a south to north structural trend. This series of downfaulted basin blocks appears to be formed by two half-graben elements with opposing sense of tilt. The bold eastern escarpment of Sierra el Medio, rising almost 900 m (3,000 ft) above the floor of La Soda Playa, supports the premise that most of the San Basilio Basin is a west-tilted half graben. This structure ascends to the east and merges with the Sierra del Perro uplift; but to the north, the San Basilio tilt domain appears to abruptly terminate just south of El Berrendo. A buried bedrock high in the latter area marks a zone of transition in deformational style that "accommodates" a shift from the dominant west tilt of basin-range blocks of the La Soda-Sierra el Medio area to the east-tilted, half-graben and horst structures that characterize most of the Playas Basin system (Plate 1, sections DD'- GG'). This class of tectonic features, which is associated with overlapping fault terminations and relatively abrupt shifts in extensional style along basin trends without appreciable strike-slip faulting, is recognized throughout the Basin and Range province (Stewart 1998). Faulds and Varga (1998, p. 1) recommend that these features be classed as *accommodation zones*:

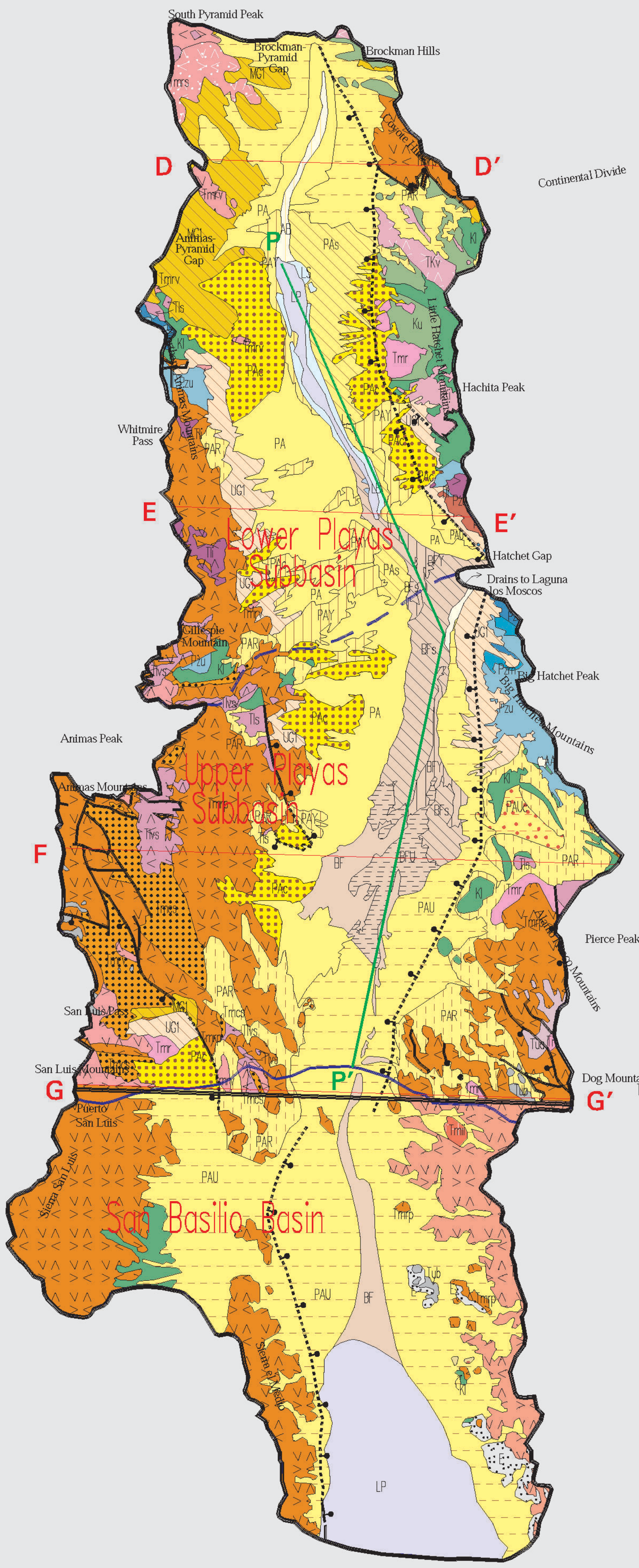
"All normal-fault systems must terminate both along and orthogonal to strike. As many as four terminations may be associated with a single culmination. Most normal-fault systems terminate in either transfer zones or *accommodation zones* [emphasis added]. In the non-genetic classification proposed here, transfer zones are defined as discrete zones of strike-slip and oblique-slip faulting that generally trend parallel to the extension direction and typically facilitate a transfer of strain between extended domains arranged in an en echelon pattern. *Accommodation zones* are belts of overlapping fault terminations and can separate either systems of uniformly dipping normal faults or adjacent domains of oppositely dipping normal faults. They can trend parallel, perpendicular, or oblique to the extension direction. A review of variously extended continental provinces and passive continental margins reveals that the style of deformation within transfer and *accommodation zones* is independent of the magnitude of extension."

Bedrock Components

In addition to this structural complexity of major fault-block uplifts and individual basins, exposed bedrock terranes also comprise a wide variety of stratigraphic and lithologic units that range in age from Precambrian to Early Pliocene (Plate 1, Figure 6-2). Since the dominant lithologic and structural components of the Hatchet and Alamo Hueco, Dog Mountain uplifts on the east side of the Playas Basin system have already been described (Chapter 5), attention here is focused on the other ranges forming the basin-system perimeter.

Playas and San Basilio Basin System





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

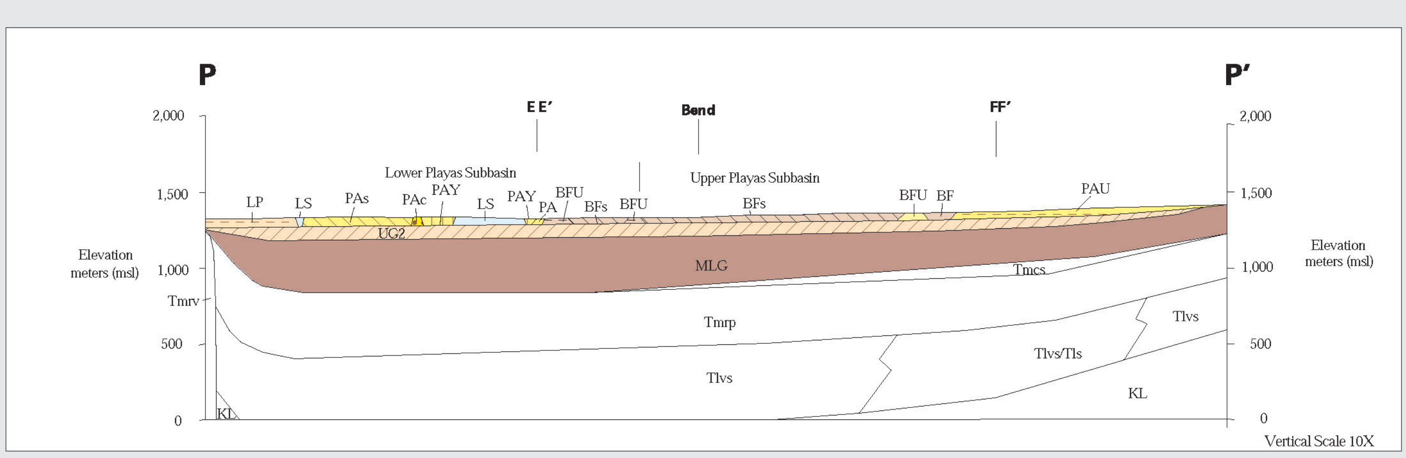
UGL
UG
UG1
UG1c
UG2
UG2r
UG2s
MG
MG2
MG
LG

Upper Santa Fe Group

USL
US1
US1c
US2
US2r
MSF
LSF

Bedrock Units are listed on Plate 1

Profile



UG2 - Upper Gila HSUs, undifferentiated fine to medium grained basin-floor deposits; including those of ancestral Mimbres and Rio Santa Barbara systems; mostly facies !fnt93714;3

MLG - Middle and Lower Gila undivided HSUs, only on cross-sections

SCALE 1: 500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

Figure 6- 2. Hydrogeologic map and profile for the Playas and San Basilio Basin System.

Bedrock units exposed in the Sierra del Perro area east of the San Basilio Basin are primarily mapped as intermediate to basaltic volcanics of Middle to Late Tertiary age (DGGTN nd, Agua Prieta Sheet a), while Sierra el Medio and Sierra San Luis to the west primarily consist of Middle Tertiary silicic pyroclastic units and lavas. Cretaceous sedimentary rocks (limestone, conglomerate, sandstone, and mudstone) are also exposed in a few upland areas flanking the San Basilio Basin.

Except for its extreme northern end, where a variety of Paleozoic rocks overlie Precambrian crystalline basement units, most of the Animas uplift comprises a complex suite of Middle and Lower Tertiary silicic volcanic rocks, including pyroclastic and flow units. Intermediate plutonic rocks of Oligocene age, and numerous small basalt flows of Miocene-Pliocene age are also exposed, respectively, in the central and southern part of the range. An Upper Oligocene conglomerate and sandstone unit (The OK Bar Conglomerate of Zeller and Alper 1965) crops out in a large area of the upper Deer Creek watershed southeast of Animas Peak (map unit Tmcs-Plate 1). The eastward dip of this unit coincides with the general tilt of the Animas Mountain block which merges with the upper Playas half graben further to the east (Plate 1, FF').

As schematically shown on section FF', the conglomerate and sandstone map unit-Tmcs (OK Bar correlative) directly underlies the Lower Gila Hydrostratigraphic Unit (LG), which is also a conglomeratic sandstone, in the central part of the Lower Playas Subbasin. Map units Tmcs and LG would only be distinguishable in borehole samples if interbedded silicic volcanic rocks (mainly tuffs) are present – a characteristic of the OK Bar Conglomerate. This illustrates a common problem of how to correctly define the base of the (Gila Group) basin-fill aquifer system throughout the "Southwestern Alluvial Basins Region." Since the unit Tmcs (OK Bar conglomerate) occurs on high mountain summits, both in the Animas Mountains and the Peloncillo-Guadalupe range to the west, and also in low lying basin-fault blocks, it clearly predates Basin and Range tectonism. Therefore, map unit Tmcs must be excluded from Gila Group basin-fill, even though its lithologic composition may be essentially identical.

The other important structural and lithologic component of the basin system perimeter is at the northern end of the Lower Playas Subbasin. This area includes the Animas-Pyramid and Brockman-Pyramid "Gaps" (crossed by the Continental Divide), which may be sites of groundwater discharge to the Lower Animas and Lordsburg subbasins, respectively (Figures 3-1 and 6-1). These broad topographic saddles contain locally thick, older Gila Group units which overlie a very irregular buried bedrock surface that is primarily formed on silicic volcanic rocks (both flows and pyroclastic units, Plate 1). Andesitic volcanics are also exposed at South Pyramid Peak at the northwestern corner of the Lower Playas Subbasin, and lower Cretaceous clastic rocks (mostly shales and sandy siltstones) form the Brockman Hills to the east. The Coyote Hills at the northeastern edge of the basin system are primarily composed of silicic pyroclastic units and interbedded tuffaceous mudstones and sandstones.

As will be emphasized in the sections of this Chapter on groundwater flow, observations on the predevelopment shape of the potentiometric surface (water table of Schwennesen 1918, and Doty 1960) indicate that a small component of regional groundwater discharge exited the Upper Playas Subbasin through either, or both the Animas-Pyramid and Brockman-Pyramid gaps. It is here suggested that the predevelopment underflow model is indeed reasonable solely on the basis of interpretations of bedrock (lithologic and buried topographic) and structural conditions made during the present study.

Basin-Fill Aquifer System

Major Hydrostratigraphic Subdivisions

Neogene (Miocene and Pliocene) basin fill forms the only important aquifer system in the Playas and San Basilio Basin systems. Neogene and Quaternary basin and valley fills are here subdivided into the major hydrostratigraphic-unit classes defined in Chapter 3 (Figures 3-5, Tables 3-2, 3-3). Previous workers in the study area have lumped much of this material into "valley fill" and/or "older alluvium" units, or Gila "conglomerate." Schwennesen (1918, p. 32) was the first to make specific correlation of older stream-deposited "valley fill" in the Grant-Hidalgo County area with the Gila conglomerate of Gilbert (1875).

As already stated, all intermontane-basin fills of early Miocene to Middle Pleistocene age west of the Rio Grande rift structural province are included in the Gila Group lithostratigraphic unit. Unlike workers in parts of the Mimbres Basin, Schwennesen (1918) and Doty (1960) did not specifically recognize "upper" and "lower" Gila-type basin fill subdivisions, but they did note that drillers encountered partly indurated "valley-fill" in some areas at depths below 100 m (330 ft). However, in the deepest (eastern) parts of the Upper Playas Subbasin half graben, Doty (1960) also observed that irrigation (test and production) wells encountered as much as 300 m (1,000 ft) of poorly consolidated basin fill. All of this material, which is mostly saturated, appears to be in the Middle to Upper Gila Hydrostratigraphic Unit sequence described below.

Preliminary interpretations of geophysical data in transects across the transboundary (Klein 1995) suggest that maximum basin-fill thickness may range from 400 to 600 m (1,300-2,000 ft) (Plate 1, Sections DD' - GG'). As observed elsewhere (Chapters 4 and 5), however, most of the deposits exclusive of the upper 100-300 m (300-1,000 ft) beneath the central bolson plains are probably in the Middle and Lower Gila Hydrostratigraphic Units.

The hydrostratigraphic-unit (HSU) classification introduced in this report is also used provisionally in the Playas Basin system to subdivide Early Quaternary and older basin-fill deposits into (informal) Upper (UG), Middle (MG), and Lower Gila (LG) Hydrostratigraphic Units, which that are (1) mappable on both regional and local scales, and (2) primarily defined in terms of stratigraphic position depositional environment, and lithofaces components that directly relate to aquifer behavior. Units AA, AB, BF, and LP are post-Gila stream, playa, and lake deposits that are important valley- and basin-fill hydrostratigraphic components that locally play an important role in the recharge and discharge mechanisms of the groundwater-flow regime in the Playas and San Basilio Basin systems. *Note that Gila Group basin-fill is undivided south of the International Boundary (map unit Tug).*

Major Lithofacies Assemblages

Since the Playas and San Basilio structural basins are half-graben tectonic features, with both *open* and *closed* surface-flow-system elements, a wide variety of depositional environments and (bolson and semibolson) lithofacies assemblages are present. In a *semibolson* setting coarse fan-piedmont facies will grade to coarse to fine fluvial deposits of axial drainageways, while in a *bolson* setting piedmont-slope facies will grade to fine-grained playa and lake deposits (with or without evaporites). In addition, sandy to silty eolian sediments will typically be deposited on basin floors and piedmont slopes downwind from ephemeral-lake plain surfaces.

Lithofacies assemblages, as emphasized in Chapter 3 (Figure 3-6, Tables 3-4 to 3-6), are the basic building blocks of the individual hydrostratigraphic units that, in aggregate, form the basin-fill aquifer system. The explanation of Plate 1 provides a key to the lithofacies composition of the major hydrostratigraphic units (HSUs) that are schematically depicted on hydrogeologic maps and sections in this report (Plate 1 and Figure 6-2, sections DD' - GG', PP'). For example, the dominant lithofacies assemblages of Upper Gila HSUs (UG1, UG1c) throughout the Playas-San Basilio area are poorly consolidated piedmont-slope facies units *5* and *6*, while underlying Middle and Lower Gila HSUs (MG1, MG1c, MLG, LG) piedmont facies units *7* and *8*. It should be noted, however, that most of piedmont facies units *5* and *6* are in Upper Gila Group deposits (UG1 and UG1c) that are in the vadose zone. Facies assemblages *7* and *8* comprise partly indurated to well indurated conglomeratic sandstones and mudstones deposited during earlier stages of Basin and Range extension and half-graben formation. As has already been discussed, basal Gila HSUs rest on Oligocene conglomerates and sandstones (map unit Tmcs) such as the OK Bar conglomerate (Zeller and Alper 1965) that would be nearly impossible to distinguish in subsurface unless interbedded volcanics rocks (e.g., Tmr, Tmrp) are present.

Considering the probability that the northern San Basilio and Upper Playas subbasins have had axial drainage for much of Neogene and Quaternary time, basin floors should be underlain by a significant amount of conglomerate sandstone (coarse-grain subfacies of assemblage *4*), sand and gravel (facies *1* and *2*), and interbedded sand and silt-clay (facies *3*). These facies assemblages are the major components of HSUs: MG2 and UG2, which represent deposits of axial streams that were active in many *semibolsons* during earlier climatic regimes (such as Pleistocene "pluvials") that had much more effective runoff than during the Holocene.

Basin-floor and distal piedmont-slope facies assemblages (*1-4, 5, 7, 9, 10, c*) are major basin-fill components in the Playas Lake-North Playas Draw and La Soda Playa-southern Berrenda Draw areas of the central Lower Playas and San Basilio basins, respectively. These facies are major components of Upper Gila and post-Gila HSUs: UG2, UG1, AA, AB, BF, and LP. Fine grained basin-floor facies (*3, 8, 9*) may form most of the entire Gila Group basin fill sequence (HSUs: MG2, MLG, LG) directly beneath Playas Lake and La Soda Playa. *Note that prior to filling the Playas Basin system to the level of the Hatchet Gap "sill," basin-floor lacustrine (ephemeral and perennial) conditions may have prevailed in a much larger area of the Lower Playas Subbasin relative to the present Playas Lake floor. The proportion of fine grained facies (9 and 10) should therefore be expected to increase with depth in that area. The high sodium sulfate values in groundwater north of the present playa noted in the concluding section of this chapter may also reflect the presence of buried evaporites.*

Hydraulic Properties of Major Aquifer System Components

Doty (1960) provides a good overview of information collected on general well performance and hydraulic properties of the basin-fill aquifer in the South Playas Draw "complex" of the Upper Playas Subbasin. This basin-floor area extends southward about 35 km (22 mi) from Hatchet Gap to near the place where drainage from the Deer-Whitewater and Walnut Creek watersheds join the axial draw "complex." Maximum depth of wells in the area is about 300 m (1,000 ft) and the zone of saturation is close to the surface (within 15 to 30 m, 50 to 100 ft). Shallow wells at Las Cienegas Ranch in the northern part of the South Playa Draw system historically flowed (Schwennesen 1918), but later observations by Doty (1960) indicate that (1) high artesian pressure is a very localized phenomenon (at Las Cienegas and at Playas Lake) and (2) most of the groundwater-flow system that he described is unconfined.

Much of the water pumped for irrigation during the 1948-1958 period of Doty's (1960) studies was produced from the upper 500 ft of basin fill. These deposits are here included in Upper Gila Hydrostratigraphic Units UG2 and UG1. Underlying fill (to the observed depth of 300 m, 1,000 ft) is either the basal UG-HSU or the upper MG-HSU, or it includes parts of both of the hydrostragraphic units. Information from short-term pumping tests compiled by Doty (1960) showed a range in specific capacities of irrigation wells from 107 to 734 m^3/d/m (6 to 41 gpd/ft) of drawdown, with an average specific capacity computed from 1948-1956 data of about 411 m^3/d/m (23 gpd/ft). He (p. 16) also stated that "average discharge of irrigation wells is about 800 gpm (4,350 m^3/d), the yields ranging from about 200 to 1,700 gpd (1,090 - 9,265 m^3/d)."

Doty's (1960, p. 19) transmissivity (T) estimate of about 50,000 gpd/ft (620 m^2/d, 6,650 ft^2/d) is based on (1) his interpretation of the short-term pumping tests of irrigation wells in the Upper Playas Subbasin, and (2) his extrapolation from specific capacity measurements (T values ranging from 70,000 - 80,000 gpd/ft to 20,000 - 33,000 gpd/ft, respectively). Assuming an effective producing-zone thickness of about 100 m (330 ft) in the irrigation-well field, reasonable hydraulic conductivity values should be about 6 m/d (20 ft/d) for parts of Upper Gila Hydrostratigraphic Units UG2-1.

Recalling the discussion of hydraulic properties of the upper basin-fill aquifer component in the Mimbres Basin system (Figure 4-3; from Hanson et al. 1994, Figure 9), the above estimate of well-specific-capacity and aquifer-performance (T) ranges appear to be a reasonable characterizaton of groundwater production potential (at least for the short-term in the local area). Emphasis here should also be put on the potential for land subsidence and earth-fissure formation in the central Playas Basin area if too much pumping stress is put on the aquifer system.

MAJOR COMPONENTS OF THE GROUND-WATER FLOW SYSTEM

Surface-Water Components

Surface flow in the Playas and San Basilio Basin systems has three components that directly interface with groundwater flow: (1) ephemeral streams in arroyos and draws, (2) widely scattered springs, seeps, and associated reaches of intermittent-streams at higher elevations, and (3) springs, seeps, and wetland (cienega) areas along the western edge of Playas Lake.

The major areas of locally intermittent mountain streams (southern Animas and San Luis ranges), and larger draws and arroyos were briefly described in the physiographic setting section. The only large axial drainageways in the basin system are three informally named draws: (1) El Berrendo that carries storm runoff southward to La Soda Playa, (2) North Playas Draw that flows southward to Playas Lake, and (3) the South Playas Draw "complex or system" that discharges flood flows through Hatchet Gap to the Upper Hachita Subbasin, and is also a storm runoff contributor to the southern Playas Lake depression. Doty (1960) also noted flood waters commonly move as "sheetflows" down the larger drainageways of the Upper Playas Subbasin toward Playas Lake. All these draws are clearly ephemeral with underlying vadose-zone thickness ranging from about 10 m to more than 30 m (30 ft to 100 ft).

Topographic maps and parts of Schwennesen's (1918) report covering the Playas Basin system show a few springs and seeps in higher mountain valleys and uppermost piedmont areas that probably support very short reaches of intermittent stream flow in down-valley areas. However, none of these surface-water features have been described in terms of detailed flow or water-quality measurements. As discussed in the next section and previously noted (Chapters 4 and 5), most springs and seeps in the upland parts of the basin system are considered to be components of "mountain-front-recharge," because at least some of their discharge percolates downward and laterally through bedrock fractures and ultimately contributes to the basin-fill groundwater reservoir (Figure 3-3).

The larger springs specifically noted in the basin system by Schwennesen (1918) and Doty (1960) are in lowland areas and comprise discharge points of the regional and/or local groundwater-flow system. Springs, seeps, and associated cienega wetlands are primarily located at the southwestern edge of Lake Playas in the Lower Playas Subbasin. Additional information on springs of the study area can be found in White and Kues (1992). Occurrence of springs in the San Basilio Basin area is not covered in this report.

Recharge

The following discussion on recharge is also restricted to the Playas Basin system. As is the case for all basin-fill aquifers in this arid to 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) along the eastern, northern, and northwestern borders of the basin system, and the widespread cover of desert scrub and semiarid grassland (McCraw 1985, Van Devender 1990), most of the average annual precipitation of about 25-30 cm (10-12 in) is lost to evapotranspiration. In the southwestern part of the Upper Playas Subbasin, however, higher watersheds in the southern Animas and San Luis Mountains range from 2,000 to 2,500 m (6,550 - 8,200 ft) in elevation. Forest vegetation in these places indicates that mean annual precipitation may locally be as high as 50 cm (20 in).

It is here assumed that (1) the Upper Playas watershed that drains to the Lower Playas bolson plain between Hatchet Gap and Playas Lake (primarily a discharge area) has an area of about 2,000 km^2 (770 mi^2); (2) this area receives 7×10^8 m^3 (567,000 ac-ft) of unevenly distributed annual precipitation of about 35 cm (14 in); and (3) one percent of this precipitation (7×10^6 m^3; 5,670 ac-ft) contributes to groundwater recharge. This is clearly an "estimate" but the value is close to Doty's (1960) "maximum" recharge estimate of about 6.2×10^6 m^3 (5,000 ac-ft) for the entire "Playas Valley" area, and it generally agrees with recharge value ranges reported for other basins of the study area (cf. Chapters 4, 5, 7-9).

The mountain-front-recharge component would, of course, vary considerably from place to place. However, it should be a significant contributor to the groundwater reservoir in basins adjacent to the major fault-block uplifts with substantial watershed areas above 1,800 m (6,000 ft). These areas include parts of the Big and Little Hatchet range, the Alamo Hueco Mountains, and most notably, the southern and central Animas Mountains. The controls of various rock types on effectiveness of mountain-front-recharge discussed in Chapter 5 also pertains to the Playas Basin system.

The other significant source of recharge in the basin system would be water percolating through thinner parts of the vadose zone beneath the stream channels and alluvial flats of the system's only major axial drainageway, the South Playas Draw "complex." This component is termed "tributary recharge" by Kernodle (1992a) in distinction from "mountain-front-recharge." However, since the lower reach of the South Playas Draw contributes both floodwater runoff and underflow to the Upper Hachita Subbasin through Hatchet Gap (Chapter 5), that area clearly plays a more complex recharge-discharge role in the groundwater-flow system (see following discussion).

The broad piedmont slopes separating range fronts from axial drainageways and alluvial flats are not considered to be significant places for recharge (Trauger and Herrick 1962). As previously noted (1) the water table in these areas is commonly very deep, locally exceeding 90 m (300 ft); (2) the component coalescent alluvial-fan deposits (Gila Group: UGl/MGl/MLG; facies assemblages *5-9*) are very poorly sorted and partly indurated (including carbonate and zeolite cements); and (3) the vegetative cover of desert scrub and semiarid-zone grasses is very effective in capturing most of the annual precipitation. However, major flood runoff events from the Deer-Whitewater, Walnut, and Gillespie canyon watersheds in the southern and central Animas Mountains could occasionally contribute substantial flood runoff to the South Playas Draw "system."

Previous investigations discussed in Chapter 5 (Schwennesen 1918, Doty 1960, Trauger and Herrick 1962) have documented the presence of a narrow topographic saddle and shallowly buried bedrock "sill" at Hatchet Gap that allows small amounts of surface flow and groundwater underflow from the Upper Playas Basin system to "spill" or "leak" into the Upper Hachita Subbasin (Schwennesen 1918, Figure 17). Calculations described in Chapter 5, however, suggest that no more than 8,500 m^3/yr (7 ac-ft/yr) of underflow escapes from the Upper Playas Subbasin aquifer system. Moreover, there is no published documentation of flood flow discharge through Hatchet Gap, but it is here also considered to be low.

Movement and Discharge

The direction and amount of groundwater flow is at best an estimate due to the uncertainties in the hydraulic gradient, aquifer thickness, and hydraulic conductivity. The general groundwater-flow system in the Playas Basin was originally described by Schwennesen (1918). Groundwater in the basin system generally flows northward in the Upper Playas Subbasin from near the Mexico border toward the Hatchet

Gap where flow lines divide. Except for the small underflow component through the Gap, most movement appears to be northwestward through the Lower Playas aquifer system toward the Playas Lake depression (Figure 6-3). South of the combined groundwater and surface-water divide, along the International Boundary zone near Antelope Wells, groundwater-flow is toward La Soda Playa in the Lower San Basilio Basin.

Groundwater movement in the Playas Valley generally mimics the direction that surface water flows across the topography. The eastern axial component of groundwater-flow in the Upper Playas Subbasin is toward Hatchet Gap, while a western component appears to contribute underflow to the *closed* Lower Playas Subbasin (Figure 6-3). Brady and others (1984) have mapped Lake Playas as a phreatic playa. However, flow in the northern Playas Lake area continues northward beyond the playa-lake plain (Schwennesen 1918, Doty 1960). The relatively flat water table in the northern portion of the Playas Basin system and the presence of springs along the southwestern margin of Lake Playas indicate that *undrained* groundwater-basin conditions locally exist (Doty 1960). However, Schwennesen (1918) documented that the water table was at least 15 meters (50 feet) below the Lake Playas floor near its northern end, and he suggested that some groundwater from the Lower Playas Subbasin may contribute to regional underflow into the Lower Animas Basin and Gila River aquifer systems to the northwest. Doty (1960, p. 15) further observed that there was no salt crust on the playa surface also indicating net downward movement of subsurface water. Doty (1960) and Reeder (1957) both recognized the potential for a small amount of underflow discharge to the Animas area through basin-fill and bedrock units at Animas-Pyramid Gap in the predevelopment period. Schwennesen (1918, p. 112) suggested that the Brockman-Pyramid Gap was a more probable discharge zone, with underflow there contributing to groundwater flow of the Upper Lordsburg Subbasin (Animas Basin system-Chapter 7).

Groundwater pumpage is not reported for the basin separately, however, most of the mining (and mineral processing) uses reported in Table 1-3 for Hidalgo County pertain to the Lower Playas Subbasin. Doty (1960) earlier noted that irrigation agriculture during the ten-year period covered by his study used substantially more groundwater than could be supplied by his estimated annual recharge of about 6.2 x 10^6 m^3 (5,000 ac-ft).

CONCEPTUAL MODEL OF GROUND-WATER FLOW

The conceptual model of groundwater flow in the Playas 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, Figure 6-2 and 6-3, 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 described at length in Chapter 4.

As is the case in all of the basin systems described in this report, with the exception of the two completely *open* systems (Upper Gila and San Bernardino) that ultimately drain to the Gulf of California, the Playas Basin is here classed as a *closed* and *partly drained* groundwater-flow system (Figure 3-2). Basin-fill hydrostratigraphic units in the saturated (phreatic) zone include (1) older fan alluvium beneath piedmont slopes throughout the basin system, (2) fluvial deposits of through-flowing ancestral streams that occupied the floors of the Upper Playas and northernmost Lower Playas Subbasins, (3) widespread basin-floor deposits in the Lower Playas Subbasin immediately south and north of the floor of Playas Lake, and (4) sediments of the playa-lake plain itself. Units 3 and 4 comprise a complex of alluvial-flat, fan-delta, lake, playa, and eolian sediments.

Even though saturated thickness of the basin-fill aquifer is as much as 600 m (2,000 ft) in a few areas, the thickness of productive aquifer zones rarely exceeds 200 m (660 ft). Much of the older basin fill is partly indurated and well consolidated. This material has low porosity and permeability and comprises Neogene (Miocene and Pliocene) subdivisions of the Middle and Lower Gila lithostratigraphic groups. Upper Gila Hydrostratigraphic Units (UG1-2) are the dominant aquifer system beneath the bolson-floor area extending north from the east central Upper Playas Subbasin (South Playas Draw "complex") to the lower reach of North Playas Draw (near NM-9). Underlying Middle to Lower Gila Group Hydrostratigraphic Units (MG1-2, MLG) form the primary water-bearing units elsewhere in the basin.

Site-specific information is lacking on subsurface geologic and hydrologic conditions in most of the Playas Basin system, however, 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 (Plate 1, Figure 6-2), 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). East-west sections DD' to GG' are roughly normal to the axis of the Playas Basin system. Sections DD' and FF' cross the major axial drainageways (North Playas Draw and the South Playas Draw "complex") of the Lower Playas and Upper Playas subbasins. All of these schematic cross sections illustrate the half-graben structural framework of this group of *semibolson* and *bolson* landforms, with both *open* and *drained*, and *closed* and *partly drained* components.

Longitudinal section PP'(Figure 6-2) closely follows the zone of axial surface drainage from the San Basilio-Playas watershed divide (near Antelope Wells) to the northern end of Playas Lake, and it approximates the principle line of south to north groundwater flow in the Playas Basin system. No large faults are crossed by section PP' since it parallels the dominant structural grain of the Playas half graben. The hanging-wall block of the latter feature is tilted away from the Animas range and eastward toward the Hatchet uplift (footwall block). Total thickness of Gila Group Hydrostratigraphic Units (UG, MG, LG or UG, and MLG) along the line of section PP' ranges from less than 100 to at least 500 m (300-1,650 ft) in the Upper Playas Subbasin, with no more than 200 m (660 ft) of Upper Gila Hydrostratigraphic Units (UG1 and UG2) being present. In the Lower Playas Subbasin, unsaturated drainageway fill and lacustrine sediments of mostly Late Quaternary age cap the Gila Group in much of the basin-floor area (HSUs: AA, AB, BF, LP facies *b* and *c*). These units are probably no more than 30 m (100 ft) thick. Lake and playa sediments (LP-facies *c*) are only saturated in the local *phreatic playa* and spring-discharge zone at the southwestern edge of Playas Lake. Most of the "Lake" floor should be classed as a *vadose playa*.

Maximum basin-fill thickness, probably exceeding 500 m (1,650 ft), is inferred to be near the western frontal-fault zone of the (Big and Little) Hatchet uplift. This major Basin and Range structure separates the east-tilted (hanging wall) Upper and Lower Playas Subbasin blocks from the (footwall) Big and Little Hatchet horst blocks (Plate 1, Sections EE' - FF'). Sections EE' and FF' also illustrate the geologic and structural framework of the Animas range to the west. Cross section GG' shows the half-graben structural style along the International Boundary, with the east-tilted Dog Mountain uplift forming the southeastern basin boundary. As already noted, much of the San Basilio Basin is a west-tilted half graben, with La Soda Playa being located over the deepest part of the hanging-wall block that is in turn down faulted against the high standing, Sierra el Medio-footwall block.

The single area with demonstrable potential for at least some additional groundwater production (irrigation and/or small urban-industrial uses) is located in the northern and central parts of the Upper Playas Subbasin and includes the broad drainageway complex of South Playas Draw. This area was investigated by Doty (1960), who utilized drillers logs, well-performance (specific-capacity) data, and limited aquifer-test information collected between 1948 and 1955 when irrigation operations were in an early stage of active development. He further supplemented his own observations on the geohydrologic behavior of the basin-fill aquifer system with interpretations on regional hydrogeology by Schwennesen (1918), Darton (1933) and other co-workers (e.g., Reeder 1957, Trauger and Herrick 1962, Trauger and Doty 1965). The hydrogeologic framework of this part of the Upper Playas Subbasin is illustrated by cross section FF' (Plate 1) where it intersects with longitudinal section PP' (Figure 6-2). The aquifer zone appears to have a maximum thickness of about 300 m (1,000 ft), however, most of the groundwater production comes from poorly consolidated basin-fill deposits, here correlated with the Middle to Upper Gila Group Hydrostratigraphic Units (HSUs: UG2-1, MG2-1 [facies assemblages *1-5*] that are no more than 150 m (500 ft) thick.

Pumping-test and well-production data interpreted by Doty (1960) based on records of irrigation-well performance yielded a range of specific capacity values of 107 to 734 $m^3/d/m$ (6-41 gpm/ft). His estimated range of transmissivity values were from 220 to 960 m^2/d (2,660 - 10,640 ft^2/d), with an intermediate value of about 620 m^2/d (6,650 ft^2/d; 50,000 gpd/ft). Assuming a productive aquifer thickness of about 100 m (330 ft), a rough estimate of the horizontal hydraulic conductivity of combined hydrostratigraphic units UG/MG would be about 6 m/d (20 ft/d). All the above values indicate that this particular part of the Upper Playas Subbasin does have relatively good potential for irrigation agriculture (or for other large volume groundwater uses) compared to most, if not all, of the rest of the Playas Basin system.

The conceptual model of the Playas Basin's hydrogeologic framework provides an explanation for the better than average aquifer conditions in the Upper Playas Subbasin. Section FF' (Plate 1) illustrates the half-graben structure of this particular area that developed during Neogene crustal extension. Eastward tilting of the (hanging-wall) basin block toward the Big Hatchet horst block, and

Playas and San Basilio Basin System

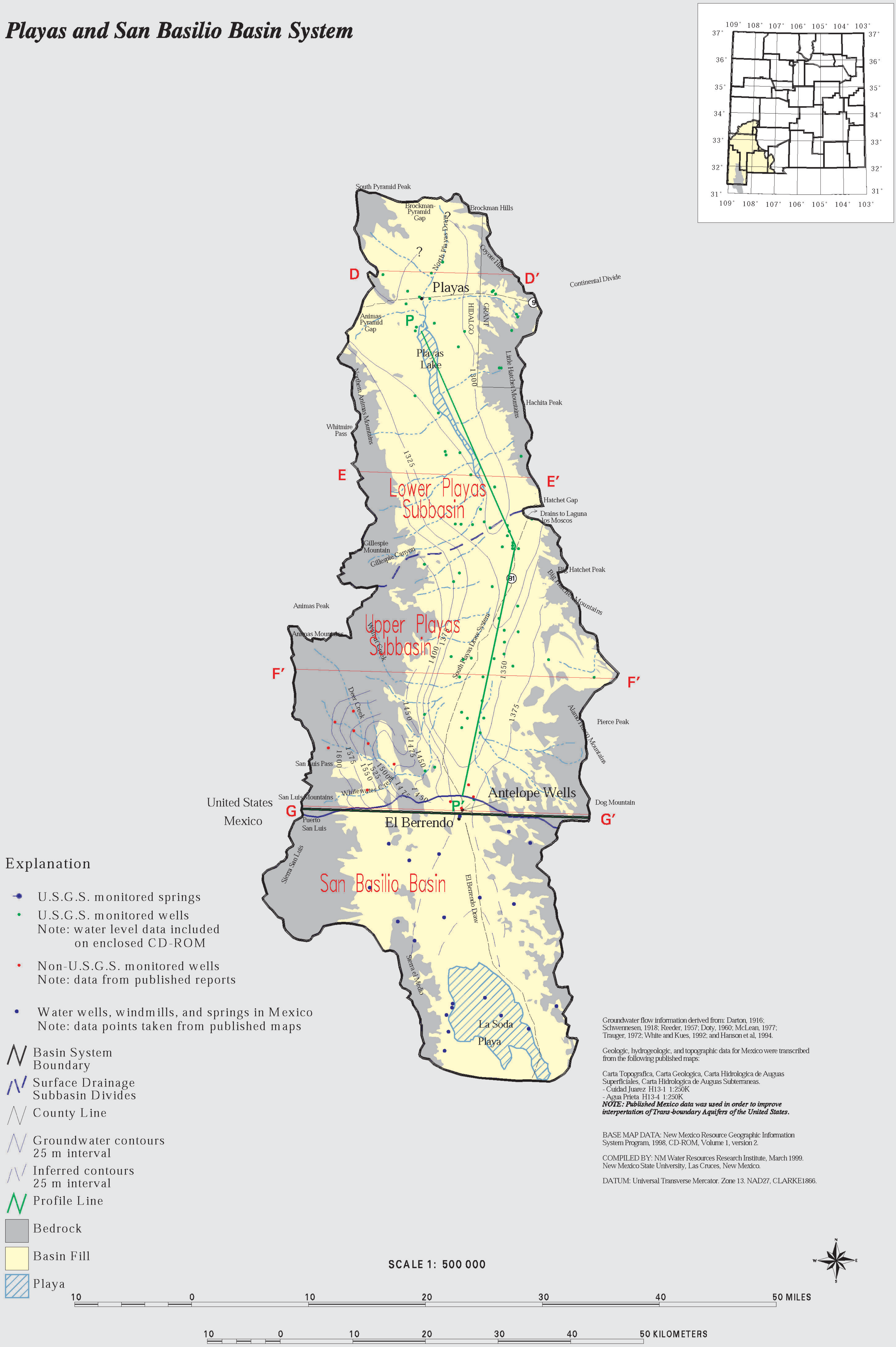


Figure 6- 3. Playas and San Basilio Basin groundwater contours, flowdirection, and aquifer- stream relationsips.

rapid basin subsidence has provided a large amount of space for accumulation of thick basin-fill deposits (primarily Middle Gila Group). It also is probable that an even deeper basin area persisted in the Lower (northern) Playas Subbasin that provided a regional "sink" for the master axial stream that flowed northward through the Upper Playas Subbasin. The primary headwaters for this fluvial system (ancestral South Playas Draw) were the emerging highlands of the southern Animas range. The major drainages there were precursors to the present large streams of the area, including Deer, Whitewater and Walnut creeks. As noted previously, these watersheds now head at elevations ranging from 2,000 to 2,500 m (6,600 to 8,200 ft).

As the Upper Playas half graben tilted eastward, axial stream (fluvial) deposits, with coarse clasts derived from the Animas volcanic terrane (rather than from the carbonate and other sedimentary units of the Big Hatchet range), accumulated in the structurally deepest part of the basin near the Big Hatchet frontal fault zone. Over time the combination of eastward basin tilting and progradation of the large alluvial fans of Walnut Creek and Deer-Whitewater Creek "forced" major fluvial channels of the ancestral South Playas Draw "system" into a relatively narrow aggradational belt. The resulting thick stack of complexly interbedded gravel, sand, silt and clay deposits form the Upper and Middle Gila Hydrostragraphic sequence of HSUs: MG2-1 and UG2-1, and their component lithofaces assemblages *1* to *5*, and *7*.

It is also suggested here that flow down the ancestral fluvial-channel complex (now mostly buried by the present South Playas Draw "system") was probably directed to a series of fan-delta distributaries that prograded northward into the *closed* Lower Playas Subbasin. Inferred early-stage lake and/or playa environments in the northern Playas Basin system probably also extended farther north beneath the area now occupied by North Playas Draw. *Note the high sodium sulfate values in the latter area (discussed in the final section of this Chapter).* Furthermore, basin filling probably did not reach the level of the bedrock "sill" at Hatchet Gap until the latest stages of Playas Basin aggradation. The hydrogeologic model of Schwennesen (1918, Figure 17) and flow estimates made in Chapter 5, suggest that only a very small amount of groundwater (less than 10,000 m^3, 8 ac-ft annually) appears to "leak" out of the Upper Playas Subbasin through Hatchet Gap. Schwennesen also documented that most groundwater flow from the Upper Playas Subbasin in the 1910-1915 period continued northward toward the Playas Lake depression.

Taking a still broader view of the Upper Playas Subbasin, it seems worthwhile to gain at least some perspective on the amount of groundwater that could move northward across the entire width of the subbasin toward the discharge areas between Hatchet Gap and the north end of Playas Lake. Very rough calculations of groundwater flow across east-west section FF', which crosses the subbasin axis (section PP', Figure 6-2) near the south end of the irrigated area, provides some insight on the behavior of at least some of the larger-scale components of the flow system. Limiting assumptions of this calculation are:

1. Width and thickness of saturated zone are 10,000 m (32,800 ft) and 200 m (660 ft), respectively, giving an estimated cross section area of 2.0 x 10^6 m^2 (2.15 x 10^7 ft^2).
2. The hydraulic gradient is about 0.002 (from Doty 1960).
3. Estimated basin-fill hydraulic conductivity (prorated between UG1-2 and MG1-2 HSUs, is 4 m/d (13 ft/d), assuming UG-HSUs: 100 m thick with K=6 m/d, and MG-HSUs: 100 thick with K=2 m/d.
4. Calculated flow across section EE' (Plate 1) of about 5.84 x 10^6 m^3 (4,730 ac-ft) per year.

This discharge rate is about twice as large as Doty's (maximum) annual recharge rate for the entire Upper Playas Subbasin. However, this rough calculation does indicate the range of hydrogeologic conditions that must be defined in a semiquanitative fashion before valid numerical models can be developed that capture the basic reality of the groundwater flow system. In the above example, only the hydraulic gradient is accurately defined, while the gross assumption of cross-section area is at best an educated guess, which may involve a significant overestimation of the width and thickness of active flow-system components. Moreover, hydraulic conductivity values probably only approach hydrogeologic reality in the central part of the cross section, with major overestimation of flow rates occurring near the basin margins.

If the entire Playas Basin aquifer system is considered, even more assumptions have to be made in rough calculations of the amount of recoverable groundwater (of presumed potable quality) that is stored in the middle to upper part of the basin-fill sequence. Limiting conditions include: (1) areas where basin fill appears to be less than 200 m (660 ft) thick are excluded, (2) the remainder of the basin underlain by productive aquifer zones has an area of about 6 x 10^8 m^2 (6 x 10^2 km^2; 1.5 x 10^5 acres), (3) the aquifer system has an average saturated thickness of 100 m (330 ft), (4) the system is primarily unconfined, and (5) its specific yield is 0.1. Based on these assumptions, a very "liberal" estimate of available groundwater stored in the productive portion of the basin-fill aquifer system is about 6 x 10^9 m^3 (6 km^3; 4.86 x 10^6 ac-ft).

There is historical evidence (based particularly on the work of Schwennesen 1918, Reeder 1957, and Doty 1960) for at least a small amount of predevelopment groundwater discharge to the Animas and Gila Basin flow systems west of the Continental Divide. The potentiometric surface approaches the land surface in only one area, which is along the southwestern edge of Lake Playas. There, a series of springs and seeps discharge at or slightly above the level of the Playas Lake plain (Schwennesen 1918, Doty 1960). At the north end of the playa, however, the potentiometric surface was as much as 16 m (50 ft) below the surface at the time of the early U.S. Geological Survey investigations described by Schwennesen (1918). His observation of the early groundwater-flow regime, which is a close approximation of predevelopment conditions in much of the Playas Basin area, supports the premise that the groundwater-flow system, originally had *partly drained* characteristics. However, groundwater development for mineral processing and urban-domestic uses in the immediate area of Playas Lake has significantly altered the flow system in recent decades. Groundwater flow is now toward major pumping centers within the Lower Playas Subbasin, and there appears to be no underflow component that *drains* to the northern Animas Basin system.

There is also historical evidence that the Playas Basin has had a very distinctive groundwater-flow regime in the recent past (prior to about 1900-1910). The Playas Basin is the place with the highest pressure head in the entire regional groundwater-flow system east of the Continental Divide (about 1,290 - 1,300 m, 4,235 - 4,165 ft). The basin is essentially filled to the "brim" with groundwater, which in predevelopment time was discharged (1) to the surface at Playas Lake (with evapotranspiration as the major system loss), and (2) by underflow "leakage" at Hatchet Gap (definite, but minor loss), Animas-Pyramid Gap (probable, but minor loss), and Brockman-Pyramid Gap (possible, but very minor loss). The inferred Continental Divide in terms of *cerca 1900 groundwater-flow* would have followed the crests of the Coyote Hills, the Hatchet uplift (including the "spill-out" point at Hatchet Gap), and the Alamo Hueco-Dog Mountain uplift to the Playas-San Basilio basin divide. It would have then continued westward to rejoin the main surface-flow divide (between the Gulf of California and Rio Casas Grandes drainage basins) at the north end of Sierra San Luis (Figure 3-1).

The "silled" basins described above are typical features throughout the study area. The effects of structural and bedrock constrictions on regional and local groundwater flow has already been noted in Chapter 4 descriptions of the Deming and San Vicente subbasins. While very large quantities of groundwater are stored in the thick basin fills that characterize the study area, much of this water appears to be "ponded" behind these shallow buried bedrock "sills." Furthermore, most of the stored groundwater has been "sitting there" for thousands to tens of thousands of years. It is also important to point out that this groundwater was effectively recharged during major glacial-pluvial cycles that have recurrence intervals ranging from 10,000 to 100,000 years.

GROUNDWATER QUALITY

General Hydrochemistry

General water quality in the Playas and San Basilio Basin systems is shown in the regional stiff map (Figure 6-4). Groundwaters in the Upper Playas Subbasin are less than 500 mg/L TDS. Most of the samples in the upper subbasin have dissolved solids concentrations less than 250 mg/L TDS. The southern half of the Lower Playas Subbasin is also characterized by groundwater with salinities less than 500 mg/L TDS. Several of the samples in the southern half of the lower basin are even more dilute, often less than 250 mg/L TDS. Groundwater salinities in the northern half of the Lower Playas Subbasin are greater than 250 mg/L TDS, with several samples exhibiting salinities greater than 500 mg/L TDS. Near and extending across the international border into the San Basilio Basin, groundwater salinity is less than 500 mg/L TDS. Several samples in Mexico are less than 250 mg/L TDS.

The Piper diagram (Figure 6-5) and stiff map (Figure 6-4) indicate that the hydrochemical facies are mostly Ca-Mg-Na-HCO_3 type waters in the Upper Playas Subbasin. The hydrochemical facies change from Ca-Mg-Na-HCO_3 to Na-HCO_3 type waters near the boundary between the Upper Playas and Lower Playas Subbasins. Nearly all groundwaters are Na-HCO_3 dominated in the Lower Playas Subbasin. One very concentrated sample, represented by the red stiff pattern, is a Na-SO_4 type water (Figure 6-4). Another sample on the eastern edge of the lower basin is a Ca-HCO_3-SO_4 type water.

Groundwaters in the San Basilio Basin are represented by Ca-Na-HCO_3 type waters and Na-HCO_3-SO_4 to Na-Ca-HCO_3-Cl type waters. Hydrochemical patterns are not as clearly discernible in Mexico. Groundwaters at the north-central part of the basin are more dilute, Na-HCO_3 type groundwaters. Chloride is the dominant anion in groundwaters in the southwestern segment of this San Basilio Basin.

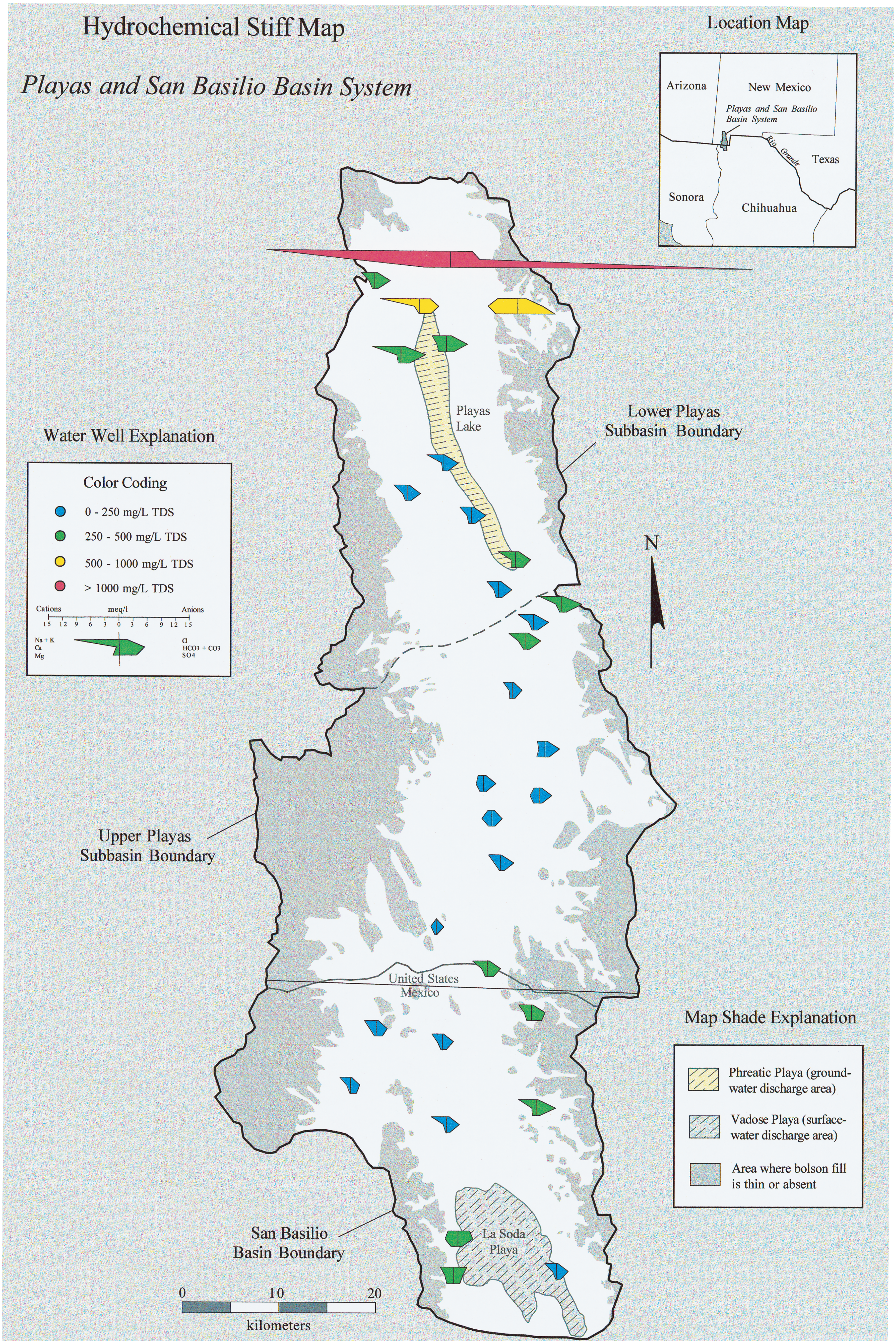


Figure 6-4. Hydrochemical stiff map for the Playas and San Basilio Basin System, showing stiff diagrams color coded by TDS ranges (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

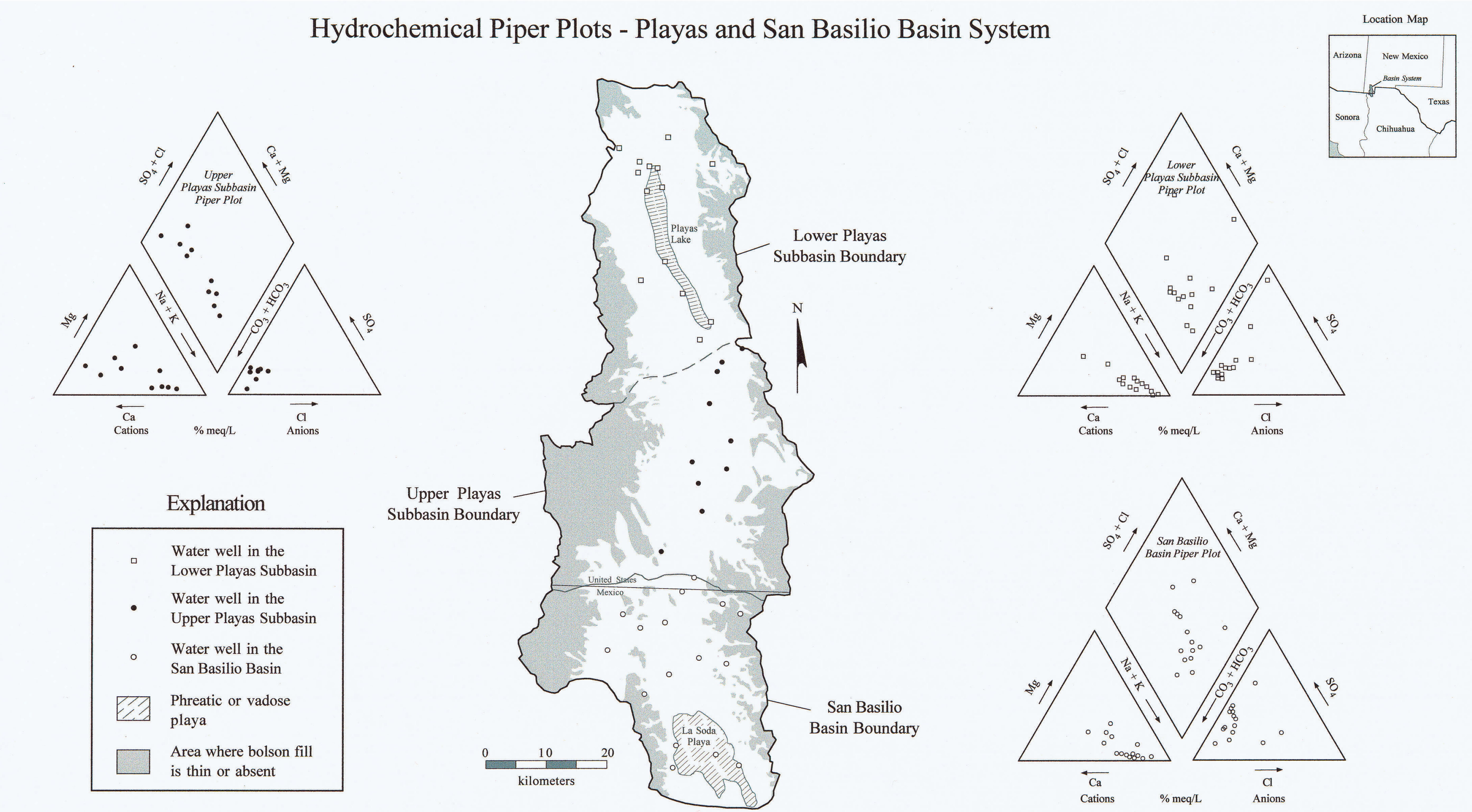


Figure 6-5. Hydrochemical Piper plots for groundwater in the Lower Playas Subbasin, Upper Playas Subbasin, and San Basilio Basin. These plots indicate variable hydrochemical facies and evolution from calcium and bicarbonate rich waters to sodium, sulfate, and chloride rich waters (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

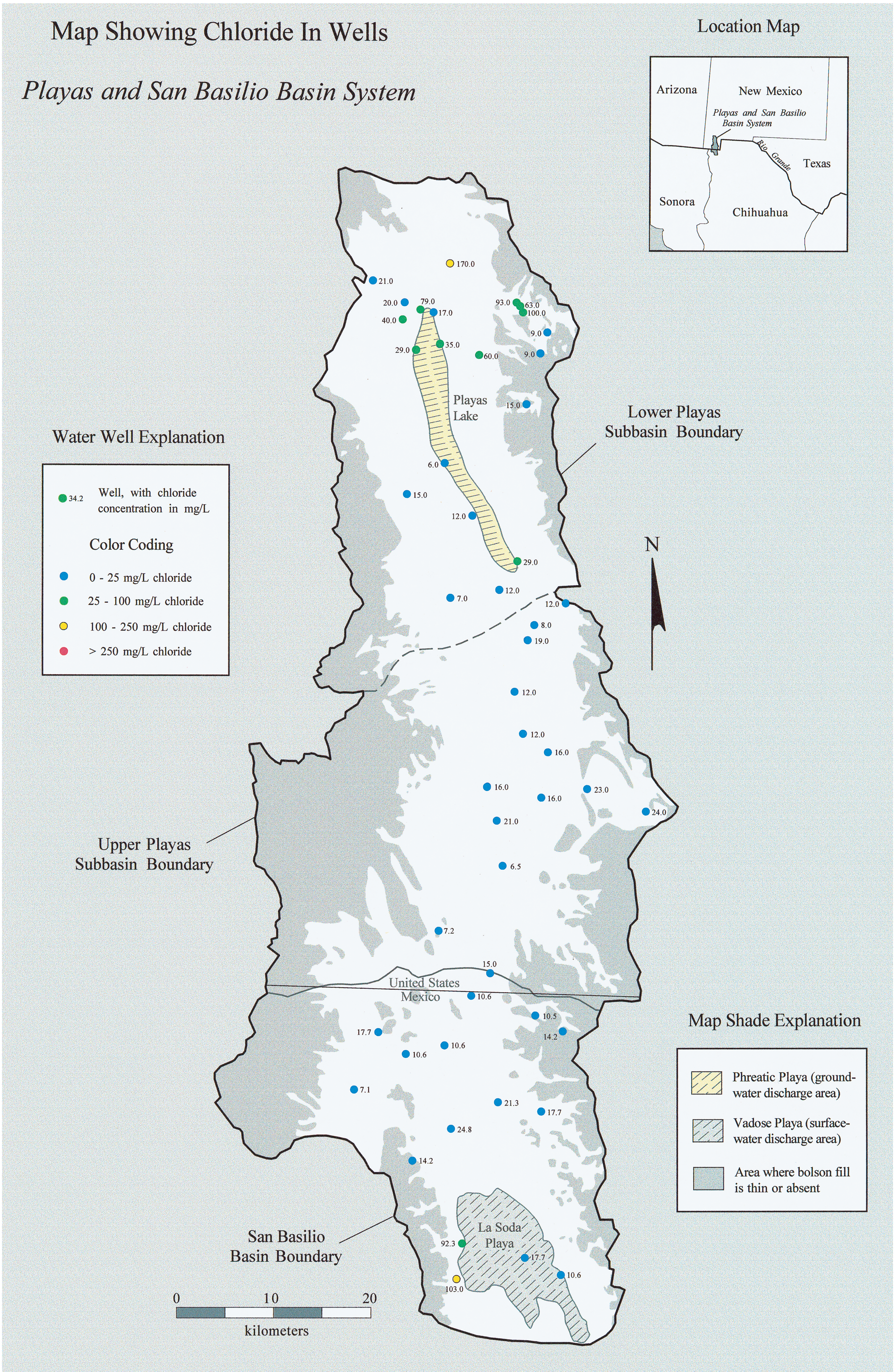


Figure 6-6. Map for the Playas and San Basilio Basin System, showing chloride concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

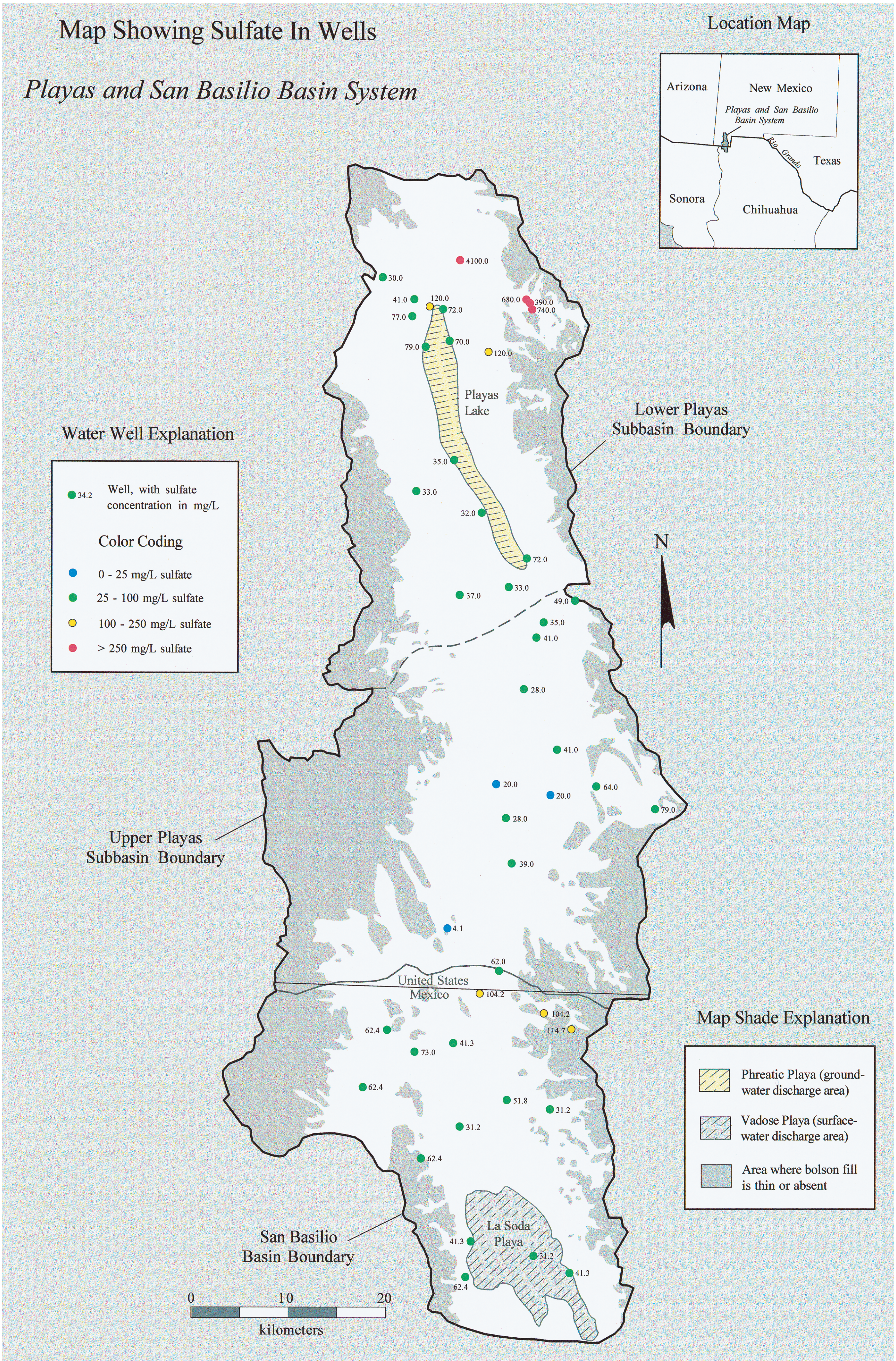


Figure 6-7. Map for the Playas and San Basilio Basin System, showing sulfate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

The anion maps show concentrations of chloride and sulfate in groundwaters in the Playas and San Basilio Basin systems (Figures 6-6 and 6-7). None of the analyses exceed the recommended USEPA drinking water standard of 250 mg/L for chloride (Figure 6-6). Chloride concentrations are less than 25 mg/L in many of the analyses in the Lower Playas Subbasin. Most of the other analyses in the lower basin vary from 25 to 100 mg/L Cl. The Upper Playas Subbasin is marked by better quality groundwater with respect to chloride. All analyses in the upper basin are less than 25 mg/L Cl. Similarly, the San Basilio Basin is characterized by good quality groundwater with low chloride. Only two analyses exceed 25 mg/L Cl in this system. These samples (respectively, 92 and 103 mg/L Cl) are located in the southwestern segment of the basin (Figure 6-6).

The sulfate map indicates that sulfate exceeds the recommended USEPA drinking water standard of 250 mg/L in 4 of the 18 analyses in the Lower Playas Subbasin (Figure 6-7). Two analyses vary between 100 and 250 mg/L SO_4. Other samples in the basin are less than 100 mg/L SO_4. All analyses are less than 100 mg/L SO_4 in the Upper Playas Subbasin (Figure 6-7. Near and extending southward across the international border, several groundwater samples are slightly greater than 100 mg/L SO_4. None of the sulfate analyses in the San Basilio Basin exceed recommended USEPA drinking water standards. Other samples in Mexico vary from 25 to 100 mg/L SO_4 (Figure 6-7).

Saturation indices

Saturation indices were computed for 7 groundwater analyses in the U.S. portion of the Playas and San Basilio Basin systems (Figure 6-8). These were the only analyses that included both temperature and pH measurements, the requisite index parameters for use of the geochemical reaction path model PHREEQC (Parkhurst 1995). The absence of temperature data precluded the use of Mexican data for computation of saturation indices.

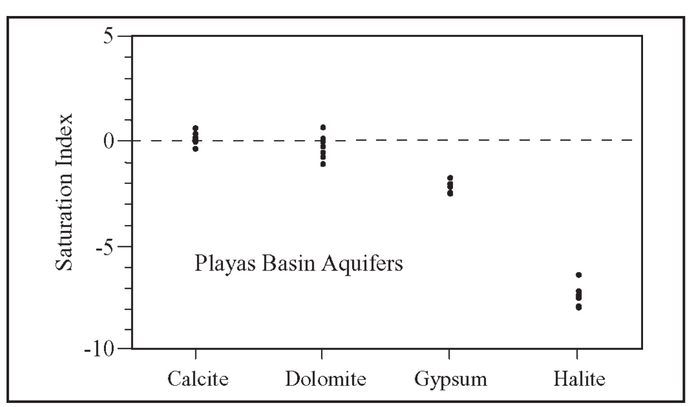


Figure 6-8. Range of saturation indices of calcite, dolomite, gypsum, and halite for the Playas Basin aquifers.

PHREEQC analyses indicate that groundwater is typically saturated with respect to calcite in the Playas Basin system. Groundwater is close to saturation with respect to dolomite, although there is a wide range of values for dolomite saturation (Figure 6-8). All groundwaters are moderately undersaturated with respect to gypsum. Waters are greatly undersaturated with respect to halite. These interpretations are based on limited data that may not necessarily reflect average saturation states in the basin.

Origin of Solutes

The stiff map (Figure 6-4) and Piper plots (Figure 6-5) indicate an apparent evolutionary hydrochemical trend as groundwater flows north from the Upper Playas Subbasin into and through the Lower Playas Basin. Superposition of the Piper plots for the Upper and Lower Playas subbasins illustrates the evolutionary trend (Figure 6-9). The groundwaters evolve from calcium, magnesium and bicarbonate rich waters in the Upper Playas Subbasin to sodium, bicarbonate, and sulfate rich waters in the Lower Playas Subbasin. These changes suggest dissolution of calcite and dolomite in the upper basin, followed by the exchange of Ca and Mg for Na on clay particles, and simultaneous dissolution of gypsum as groundwater moves northward into the lower basin. Halite dissolution does not appear to be an especially dominant process in either basin, as chloride concentrations are proportionately very low (Figure 6-9).

Limestones and dolomite rocks of Permian and Cretaceous age are abundant in the Upper and Lower Playas subbasins, especially along the eastern edges of these basins. These rocks, along with caliche and calcite cement in basin-fill, probably account for much of the calcium, magnesium, and bicarbonate in groundwaters. Clay minerals are important weathering products of silicate rocks and impure carbonate rocks, and provide the exchange sites for divalent-monovalent cation exchange. Gypsum is present at and near Playas Lake and accumulated as a result of evaporation of groundwater (Schwennesen 1918). Sulfate is redissolved from gypsum deposits when soil water and groundwater come into contact with this evaporite mineral. Halite is present in very small quantities in the unsaturated zone, having accumulated as a result of precipitation in soils when rainwater evaporates (Hem 1985, Richter and Kreitler 1991). Small amounts of chloride probably dissolve out of soil profiles when runoff percolates downward through the unsaturated zone. Saturation indices indicate a thermodynamic condition for dissolution of gypsum and halite, which are undersaturated in groundwater (Figure 6-8).

Hydrochemical trends are not as well represented south of the international border (Figure 6-5). Divalent-to-monovalent cation exchange is apparent, however, the dominant anion facies appear to evolve along two distinct trends. These are, respectively, a bicarbonate-to-sulfate evolutionary trend and a bicarbonate-to-chloride evolutionary trend. These differences probably arise as a result of the existence of different mineral assemblages along separate flow paths in the San Basilio Basin.

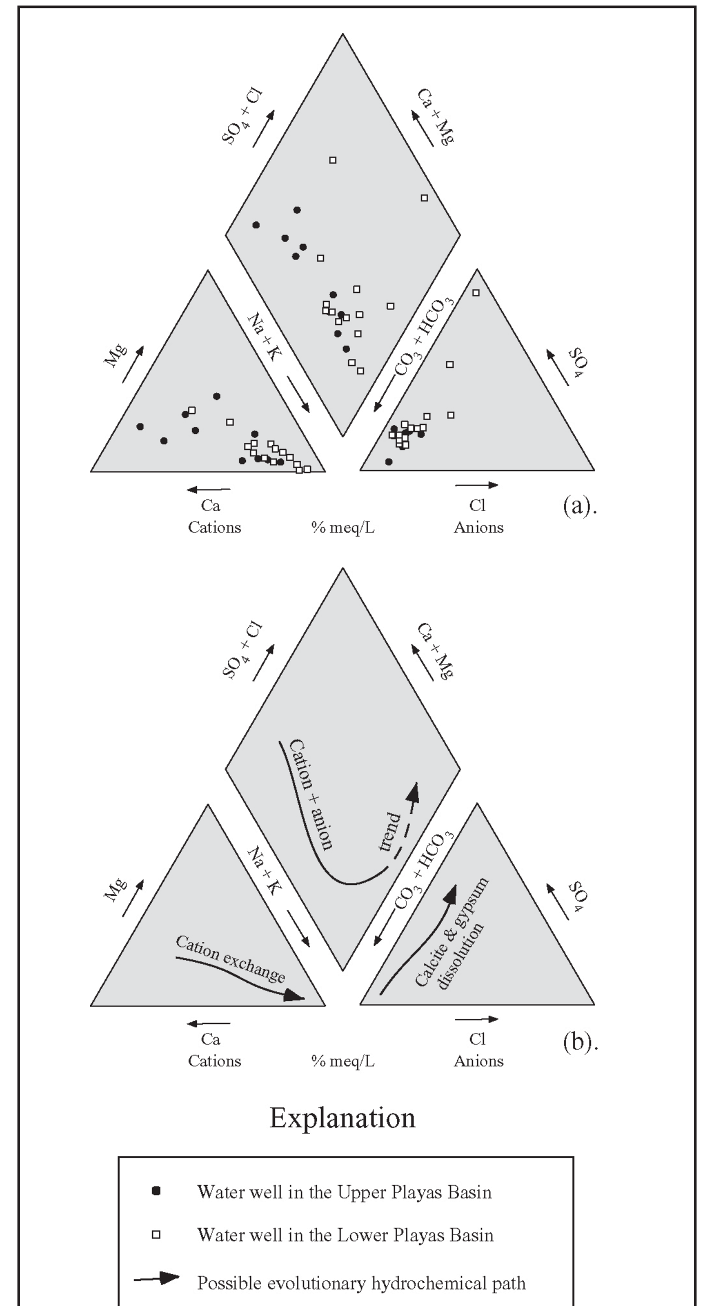


Figure 6-9. Superimposed Piper plots for the Upper and Lower Playas basins (a). Lower diagram shows possible hydrochemical evolutionary trends as groundwater flows north from the Upper Playas Basin into and through the Lower Playas Basin (b).

Irrigation Water Quality

Groundwater has low alkali hazard and low-to-medium salinity hazard in the Upper Playas Subbasin. Nearly all groundwater samples in the Lower Playas Subbasin have low-to-medium alkali hazard and medium salinity hazard (Figure 6-10). Alkali and salinity hazards are higher in this Subbasin because groundwater is probably older, having had sufficient residence times to dissolve additional mineral matter as groundwater moves from the Upper Playas Subbasin into the Lower Playas Subbasin. Most analyses indicate that irrigation water quality is fair to good in the Playas Basin system, although an anomalous sample in the lower basin has a very high alkali hazard and off-the-scale salinity hazard (Figure 6-10). South of the groundwater divide, near the international border, groundwater is characterized by low alkali hazard and medium salinity hazard. These data suggest that irrigation water quality is fair to good for most varieties of crops in the San Basilio Basin.

Nitrate in Groundwater

Nitrate is well below the USEPA drinking water standard of 10 mg/L NO_3-N in the groundwater in the Playas and San Basilio Basin systems (Figure 6-11). Most groundwater samples have less than 1 mg/L NO_3-N. These data suggest background concentrations of nitrate in groundwater. Nitrate apparently does not present a health risk to the U.S. and Mexican residents in this basin system. Nitrate data are very limited in the U.S., however, and more data are needed to verify the potential health risks to residents in the U.S.

SUMMARY

The Playas and San Basilio Basin systems are a group of north-south trending structural basins and flanking ranges that have no significant trans-international boundary aquifer component. The groundwater and surface-water divide between the southern Playas and northern San Basilio areas essentially coincides with the International Boundary segment that includes the Antelope Wells and El Berrendo ports of entry. All but about 10 km^2 of the 2,400 km^2 (925 mi^2) Playas Basin system is locate in Hidalgo County, New Mexico, and except for about 50 km^2 (20 mi^2) in the Antelope Wells area, the remaining 1,000 km^2 (385 mi^2) of the San Basilio Basin is in Mexico. The local place name "San Basilio" (historic ranch about 20 km [12 mi] south of El Berrendo and Antelope Wells) is informally used to designate this important geohydrologic basin.

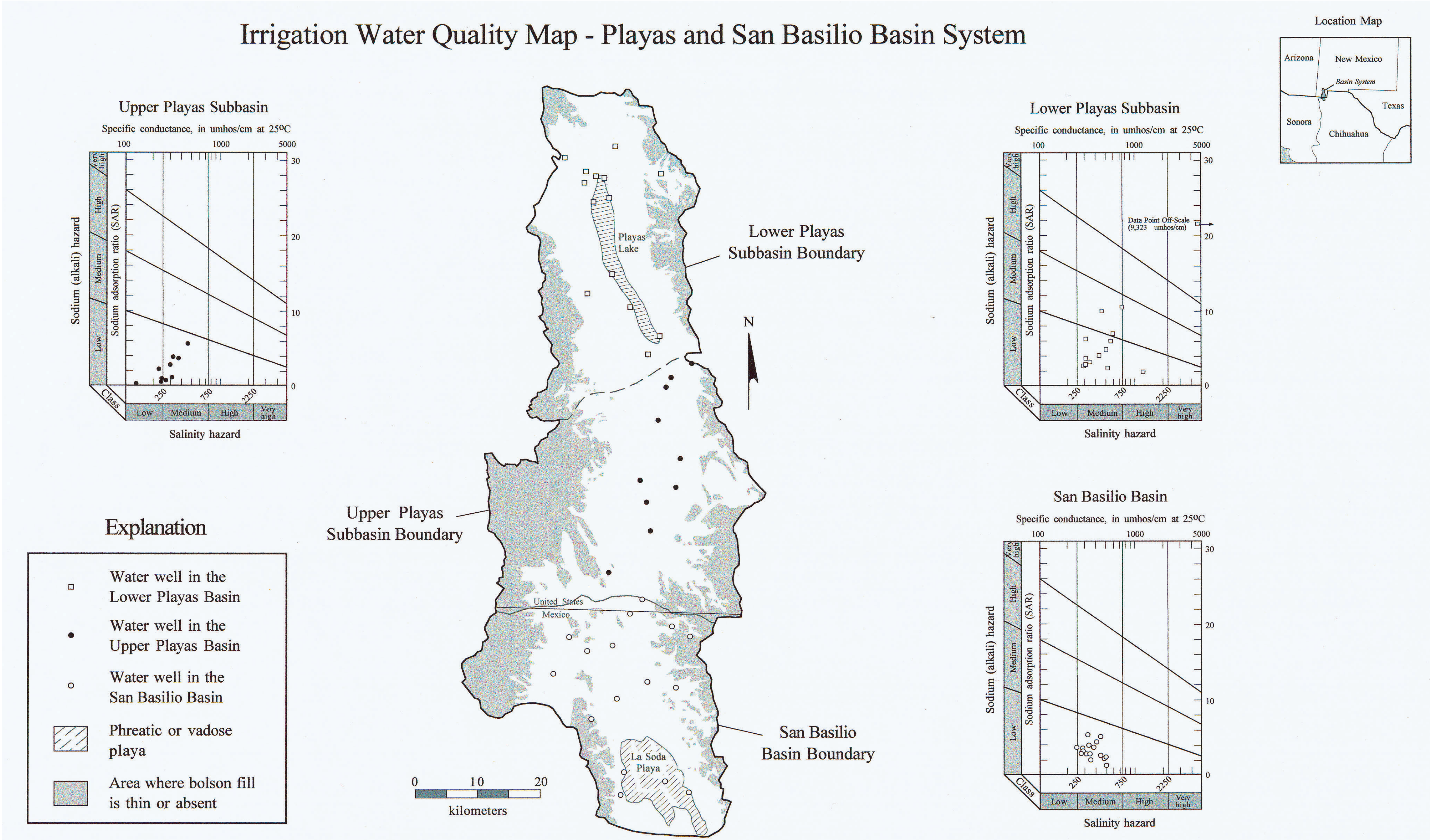


Figure 6-10. Irrigation water quality map for the Lower Playas Subbasin, Upper Playas Subbasin, and San Basilio Basin. These data indicate that water quality in these basins is generally suitable for most types of irrigation (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

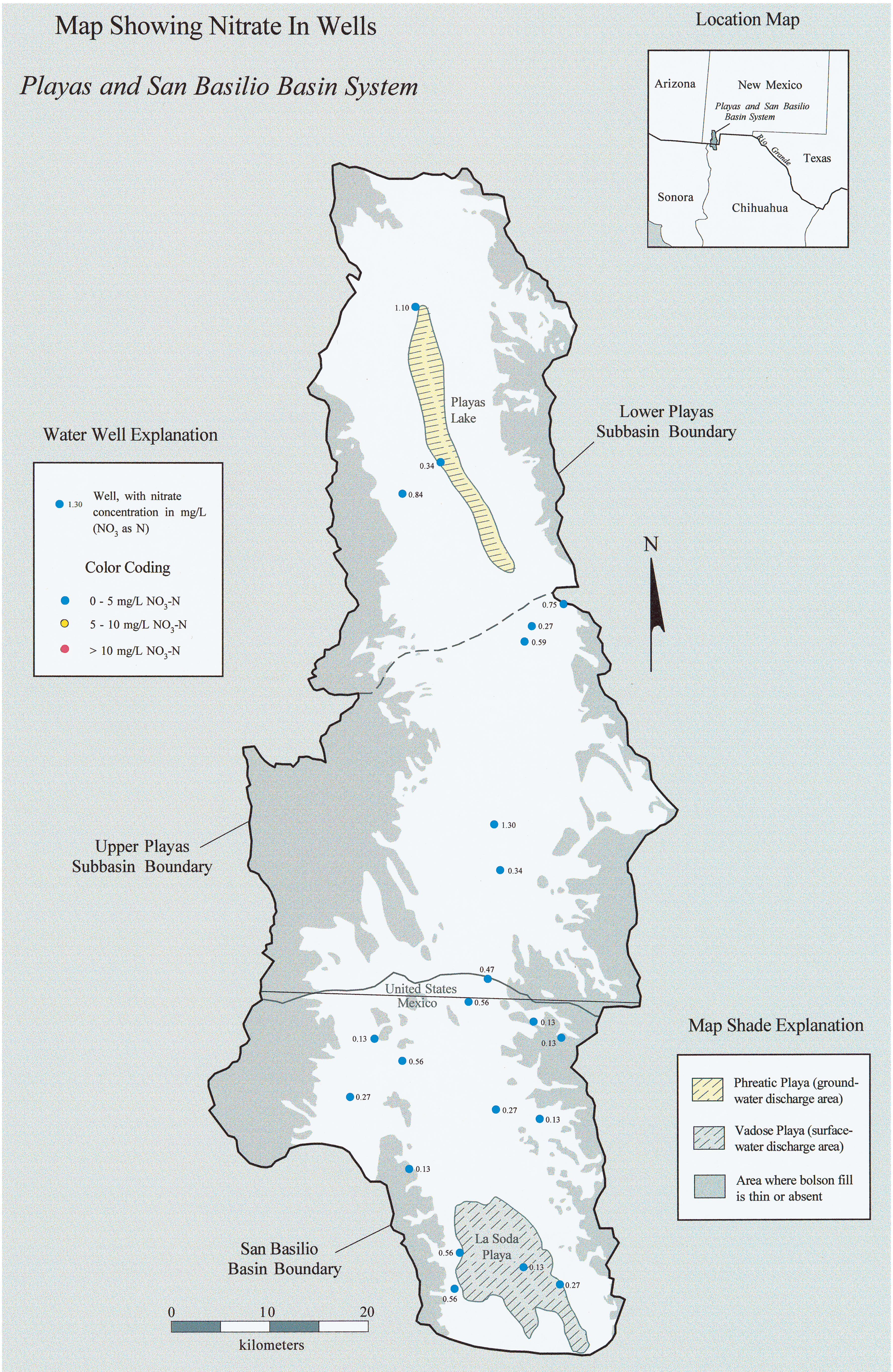


Figure 6-11. Map for the Playas and San Basilio Basin System, showing nitrate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografica e Informatica).

The Playas and San Basilio Basin systems are part of the Mexico Highland section of the Basin and Range physiographic province. The Continental Divide forms the area's western and northern border, following the crest of the Sierra San Luis and Animas Mountain ranges over much of its length. The Animas Basin system (Chapter 7) and a small segment of the Rio San Bernardino (Cajon Bonito) watershed (Chapter 9) is located west of the Divide. Major highlands separating the Playas-San Basilio Basin and Hachita-Moscos Basin systems are the Sierra de Perro, Dog and Alamo Hueco mountains, (Big and Little) Hachet uplift, and Brockman-Coyote Hills. Bedrock uplands south of Sierra del Perro separate the southeastern San Basilio Basin from the lower Rio Casas Grandes basin northwest of Ascención, Chihuahua.

The San Basilio Basin is treated separately as a *closed* (to semi-enclosed) and *drained* to *partly drained* unit in terms of both surface and subsurface flow. The *sink* for the basin is formed by a large, but shallow depression with an extensive alkali flat, here (informally) named La Soda "Playa" after a map locality in the depression center. Geologic and detailed topographic maps of the area, however, suggest that subsurface (bedrock) closure at the southern end of San Basilio Basin may be incomplete. This *playa* feature, therefore, could have both *phreatic* and *vadose* components, with some groundwater discharge leaking southward into the adjacent Rio Casas Grandes basin. Moreover, extreme flooding events may also result in rare surface spill from the La Soda depression.

The Playas Basin system makes a small contribution to trans-international boundary groundwater flow and has two subbasin components. The *open* and *drained* Upper Playas Subbasin contributes surface and subsurface flow to both the Lower Playas and Hachita subbasins (via Hatchet Gap). The South Playas Draw complex occupies much of the floor of this *semibolson* and it terminates in a broad alluvial plain west of Hatchet Gap, which forms a transition zone between the Upper and Lower Playas subbasins. The *closed* and *partly* drained Lower Playas Subbasin is the *sink* for nearly all of the surface-water and groundwater flow in the basin system. The Playas Lake depression in the central part of the subbasin is the site of "pluvial" Lake Playas. Playas Lake itself comprises a complex subsurface-flow system with *vadose* as well as phreatic playa components.

A wide variety of land use/landcover categories are present in the Playas and San Basilio Basin systems. Forest areas are present in the highest parts of the Sierra San Luis and southern Animas Mountains, but rangeland is the major category in most of the area. Basin floors include a mix of rangeland, sparsely vegetated to barren playa lake plains, and very local sites of urban and industrial activity. The border community of El Berrendo-Antelope Wells and the town for employees at the Phelps Dodge Corporation Playas Smelter are the only urban centers. Many irrigation water rights have been acquired for mineral processing at the Phelps Dodge Smelter at the south end of Playas Lake. Groundwater consumption for smelter operations and related uses was about 6.06 x 10^6 m^3 (4,913 ac-ft) in 1995.

Climate of the Playas and San Basilio Basin systems is arid to semiarid except in highest parts of the San Luis, Animas and Big Hatchet ranges. Precipitation, temperature, and pan evaporation in most of the area is like that in adjacent intermontane basins of the Animas and Hachita-Moscos Basin systems (Chapters 7 and 5).

The hydrogeologic framework of the Playas-San Basilio basin-fill aquifer system is characterized by a linked series of half-graben subbasins with fill thicknesses probably not exceeding 600 m (2,000 ft), as indicated by geophysical (seismic and gravity) surveys. Distinct domains of east- and west-tilted fault-block basins, respectively, in the Playas and San Basilio structural subbasins are separated by a transition (*accommodation*) zone marked by relatively narrow basin width and thin saturated fill. This zone crosses the basin axis about 3 km (2 mi) south of the International Boundary.

The primary aquifer system is formed by unconsolidated to partly indurated deposits of the Gila Group that here comprise basin-floor and piedmont-slope facies of the Upper and Middle Gila hydrostratigraphic units (HSUs: UG and MG). This aquifer system has unconfined, semiconfined and confined components. It is laterally extensive but quite variable in thickness. Underlying basin fill comprises well consolidated and partly indurated Middle and Lower Gila Group Hydrostratigraphic Units (MG, LG, MLG) that have low to very low hydraulic conductivities. Storage coefficients reflect semiconfined and confined aquifer conditions.

The north-central part of the Upper Playas Subbasin appears to have the greatest potential for sustained groundwater production in the entire basin system. The maximum saturated thickness of the aquifer zone is about 300 m (1,000 ft). Most production, however, comes from the upper, poorly consolidated layer of basin fill that is here correlated with Middle to Upper Gila Hydrostratigraphic Units (HSUs: UG2-1/MG2-1). These deposits are no more than 150 m (500 ft) thick. Published records of irrigation-well construction and performance in this part of the Playas Basin system during the 1948 to 1955 period show a specific-capacity range of 107 to 734 $m^3/d/m$ (6-14 gpm/ft). Calculated aquifer transmissivity ranges from 220 to 960 m^2/d (2,660 - 10,640 ft^2/d), with an intermediate value of about 620 m^2/d (50,000 gpd/ft). Assuming a productive aquifer thickness of about 100 m (330 ft), a rough estimate of the horizontal hydraulic conductivity of combined HSUs: UG/MG would be about 6 m/d (20 ft/d). A very liberal estimate of available groundwater of good quality that is stored in the Playas Basin aquifer system is about 6 x 10^9 m^3 (6 km^3, 4.86 x 10^6 ac-ft).

As has been observed in adjacent basin systems, only a small percentage (1-2%) of combined basinwide precipitation, runoff from adjacent highlands, and infiltration from axial drainageways contributes to recharge. A provisional minimum estimate of annual recharge is 7 x 10^6 m^3 (5,670 ac-ft).

The dominant direction of groundwater flow from the basin-system divide near the International Boundary is southward toward La Soda "Playa" in the San Basilio Basin and northward toward the Playas Lake depression in the Lower Playas Subbasin. The Playas Lake *sink* includes both *phreatic* and *vadose playa* components. In predevelopment time, the major discharge process was evapotranspiration loss from the *phreatic playa* zone in the southwestern part of Playas Lake.

A very small discharge component from the Upper Playas Subbasin, here estimated at less than 10,000 m^3/yr (<8 ac-ft/yr) spills across a buried bedrock sill at Hatchet Gap and contributes to recharge of the Upper Hachita Subbasin aquifer system. Prior to its interception by irrigation agriculture and mineral processing developments of the past century, a small amount of groundwater also appears to have leaked into the northern Animas Basin system from the northern end of the Lower Animas Subbasin. Northward slope of the potentiometric (water table) surface beyond the southwestern part of Playas Lake, absence of evaporites in lacustine deposits in the "pluvial" Lake Playas areas, and lower groundwater pressure heads in adjacent parts of the Lower Animas and Lordsburg subbasins suggest that "gaps" in uplands crossed by the Continental Divide east of the town of Animas mark zones of thick basin fill and/or fractured bedrock that permit interbasin groundwater flow.

A provisional estimate of northward flow across the section of the Upper Playas Subbasin that includes the best documented productive aquifer in the basin system is about 5.84 x $10^6 m^3$ (4,730 ac-ft) per year. This estimate is based on the assumptions that the aquifer's cross section is about 2.0 x $10^6 m^2$ (2.15 x $10^7 ft^2$) and its hydraulic conductivity (prorated between HSUs MG1-2 and UG1-2) is 4 m/d (13 ft/d). The hydraulic gradient is about 0.02.

The total dissolved solid (TDS) content of groundwater sampled in the Upper Playas Subbasin varies from less than 250 to 500 mg/L. The southern half of the Lower Playas Subbasin is also characterized by groundwater salinity values in this TDS range. In the northern part of the Lower Playas Subbasin several samples exhibit salinities greater than 500 mg/L TDS, as is the case in the northern San Basilio Basin. Even in these areas, however, some samples have less than 250 mg/L TDS.

Hydrochemical facies tend to shift from mostly Ca-Mg-Na-HCO_3 type waters in the Upper Playas Subbasin to Na-HCO_3 type waters near the Upper-Lower Playas Subbasin boundary. One very concentrated sample from north of Playas Lake is a Na-SO_4 type water. Groundwaters in the San Basilio Basin are represented by Ca-Na-HCO_3, and Na-HCO_3-SO_4 to Na-Ca-HCO_3-CL type waters. Chloride is the dominant anion in groundwaters in the southwestern (La Soda "Playa") segment of the San Basilio Basin.

Groundwater has low-to-medium salinity hazard and low alkali hazard in the Upper Playas Subbasin, and it has medium salinity and low-to-medium alkali hazards in the Lower Playas Subbasin. Alkali and salinity hazards are higher in the latter subbasin because groundwater is probably older, having had sufficient residence times to dissolve additional mineral matter as water moves northward in the basin system. South of the San Basilio-Upper Playas groundwater-flow divide (near the International Boundary), sampled groundwater is characterized by low alkali and medium salinity hazards. These data suggest that irrigation water quality is fair to good for most crop varieties in the basin area between La Soda "Playa" and Playas Lake.

Nitrate in all groundwater samples is well below the USEPA drinking water standard of 10 mg/L NO_3-N in the Playas and San Basilio Basin systems. Most samples have less than 1 mg/L NO_3-N.