# CHAPTER 7 – ANIMAS BASIN SYSTEM

## INTRODUCTION

Emphasis in this chapter is on the relationship between groundwater flow and the hydrogeologic framework of basin-fill aquifers in the Animas Basin system. 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 6). Discussions here will, therefore, primarily focus on aspects of basin-fill hydrogeology and groundwater flow that distinguish the Animas Basin from contiguous basins of the region. The chapter concludes with an overview of groundwater quality in the context of hydrogeologic controls on the basin's groundwater flow regime.

Perhaps the most important distinguishing feature of the Animas Basin system is the presence of *closed*, playa-lake depressions at both the southern and northern ends of the system that are *drained* to *partly drained* in terms of regional groundwater flow. The southern Cloverdale Subbasin (San Luis) straddles the New Mexico-Chihuahua-Soñora boundary and appears to contribute underflow both to the Yaqui-Batepito-San Bernardino fluvial system to the southwest (Chapter 9), and northward to the southern end of the (Upper and Lower) Animas Basin system. The *closed* and *drained* "alkali-flat" area of the Lower Animas Subbasin in turn makes a significant underflow contribution to the groundwater-flow regime in the Virden-Duncan reach of the upper Gila River Valley (Chapter 8).

## LOCATION AND PHYSIOGRAPHIC SETTING

### Overview

The Animas Basin system (Figure 7-1) comprises an interconnected group of four subbasins (Lordsburg, Lower and Upper Animas, and Cloverdale) with a total surface watershed of about 6,340 km$^2$ (2,448 mi$^2$), and a groundwater-flow system area of about 6,025 km$^2$ (2,326 mi$^2$). Very small portions of the system extend into Arizona and Mexico, 35 km$^2$ (14 mi$^2$) and 90 km$^2$ (35 mi$^2$), respectively. The remaining 6,215 km$^2$ (2,400 mi$^2$) is located in southwestern New Mexico, including parts of Hidalgo, Grant and Luna counties. The three northern subbasins have a combined surface drainage area of about 5,860 km$^2$ (2,263 mi$^2$). The *open* and *drained* Upper Animas Subbasin is a *semibolson* with an area of about 1,130 km$^2$ (436 mi$^2$). Its north-flowing axial stream, Animas Creek, contributes surface runoff to the *closed* and *drained* Lower Animas Subbasin, a "classic" *bolson* with an area of about 2,300 km$^2$ (888 mi$^2$). The *open* and *drained* Lordsburg Subbasin, in the northeastern part of the basin system, has an area of about 2,430 km$^2$ (938 mi$^2$). This *semibolson* also contributes flood runoff via Lordsburg Draw to the Lower Animas Subbasin. The most distinctive features of the latter area are the extensive playa-lake plains (North and South Alkali Flats) and the relict shoreline features of pluvial Lake Animas (Schwennesen 1918) that occupy much of the basin floor. It should also be noted here that about 315 km$^2$ (122 mi$^2$) of the eastern Lordsburg Subbasin watershed (China Draw section adjacent to the Continental Divide) is underlain by an aquifer system that discharges to the Deming and Hermanas subbasins of the Mimbres Basin system (cf. sections on groundwater flow in Chapter 4).

The *closed* and *drained* Cloverdale Subbasin at the south end of the Animas Basin system is a smaller *bolson* landform with an area of about 480 km$^2$ (185 mi$^2$). About 390 km$^2$ (150 mi$^2$) of this subbasin is in New Mexico, and the remaining 90 km$^2$ (35 mi$^2$) in Mexico includes parts of Chihuahua and Soñora. Cloverdale Playa and relict shorelines of pluvial Lake Animas (Schwennesen 1918) are the most distinctive landforms in the central part of the subbasin. *Note that this area is also referred to as the San Luis Valley (Valle de San Luis) in reports by Schwennesen (1918), Reeder (1957), O'Brien and Stone 1981-1984, and others.*

The Animas Basin system is entirely in the Mexican Highland section of the Basin and Range physiographic and structural provinces. The Cloverdale, and Upper and Lower Animas components of the basin system are distinct hydrogeologic units which form a north-south aligned group of intermontane basins that are continuous in a general structural sense. The Lordsburg Subbasin has a northwest-southeast structural grain and merges with the Lower Animas Subbasin north and west of Lordsburg. The most extensive landforms of the basin system are broad piedmont slopes that extend out from the mountain fronts. These coalescent alluvial-fan surfaces (bajadas) grade to basin-floor areas, which range from narrow alluvial flats along axial drainageways to broad bolson plains comprising both alluvial flats and playa-lake depressions (e.g., Lower Animas Subbasin).

An area of particular concern in this report is the Cloverdale Subbasin. While it is not a major contributor to transboundary groundwater flow, it is located in an upland area which includes parts of New Mexico, Chihuahua, and Sonora. Furthermore, it appears to overlie a divide in the regional groundwater-flow system that separates northward (Animas-Gila) underflow from southwestward subsurface and surface flow in the San Bernardino (Cajon Bonito) Basin system. The latter groundwater-flow components ultimately contribute to the Rio Batepito-Yaqui drainage basin to the southwest.

### Basin Boundaries

The eastern border of the Animas Basin system follows the Continental Divide and forms common watershed boundaries (from south to north) with the San Basilio, Playas, Hachita-Moscos, and Mimbres basins (Figure 3-1). Crest elevations of the Continental Divide commonly exceed 2,000 m (6,600 ft) in the Sierra San Luis-southern Animas Mountain area. As noted in Chapter 6, this range is the northern extension of the Sierra Madre Occidental of northwestern Mexico, and, together with the Guadalupe-Peloncillo range to the west, it is 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 summer and early fall, but lower magnitude (but very effective) precipitation pulses occur during the winter and early spring in some years (cf. section on Climate).

The low-lying San Luis Mountains in the transboundary area form most of the eastern border of the Cloverdale Subbasin. Continuing northward, the Upper Animas Subbasin is bounded on the east by the southern and central parts of the Animas range, with the highest elevation on the Continental Divide reaching about 2,500 m (8,200 ft) at Animas Peak (elevation 2,600 m, 8,531 ft). The range decreases markedly in width and height north of Animas Peak, with Gillespie Mountain (2,228 m, 7,310 ft) marking the high point of the central Animas uplift. The northern section of the Animas Mountains is located north of Whitmire Pass (elevation 1,516 m, 4,945 ft), and forms the southeastern border of the Lower Animas Subbasin. At its north end, the range is abruptly terminated by a broad topographic and structural saddle, here designated the "Animas-Pyramid Gap" (Chapter 6), that is bounded on the north by the southern Pyramid Mountains. The Pyramid Mountains extend northward from South Pyramid Peak to the Lordsburg area and separate the central parts of the Lower Animas and Lordsburg subbasins (Figures 3-1, 7-1).

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, here informally named the "Brockman-Pyramid Gap." This Divide segment separates the Lordsburg Subbasin from the northern Playas Basin, and its lowest elevation is about 1,347 m (4,419 ft). As already noted in Chapter 6, the "Animas-Pyramid" and "Brockman-Pyramid" gaps east of Animas and southeast of Lordsburg are important physiographic as well as geohydrologic features. In addition to marking the lowest points on the Continental Divide between southern Mexico and western Canada they coincide with buried bedrock saddles (or fracture zones) that allowed predevelopment underflow to move northwestward from the Lower Playas Subbasin to the Lower Animas groundwater-flow system.



The southeastern boundary of the Lordsburg Subbasin follows two short segments of the Continental Divide, first along the crest of the Coyote Hills, and then eastward across another topographic and structural saddle north of Hachita (elevation about 1,380 m; 4,530 ft) to the northwestern Cedar Mountain Range. The latter part of the Divide separates the Lordsburg Subbasin from northern Hachita-Moscos Basin system. North of the Cedar Mountain Range, the eastern border of the Lordsburg Subbasin is along a long segment of the Continental Divide, that separates the surface-flow regimes of the western Mimbres and eastern Animas Basin systems. This area includes the broad "Antelope Plains" and the I-10 and the Southern Pacific Railroad routes, located between Deming and Lordsburg. *Note that the China Draw section of the eastern Lordsburg Subbasin contributes groundwater-underflow to the Deming and Hermanas subbasins (Figure 7-1).*

The Continental Divide segment of the Animas Basin border ends in the Big Burro Mountains, near Burro Peak (2,449 m; 8,035 ft), and the northern border of the basin system follows the surface drainage (and groundwater-flow) divide between the northeastern Lower Animas Subbasin and the Gila River Basin (Chapter 8). It has a westward trend across another broad alluvial-fan piedmont that extends from the front of the Burro uplift to Lordsburg


**Figure 7-1.** Land Use in the Animas Basin

Mesa, a relict fluvial plain (ancestral Gila River) flanking the Summit Hills (Figure 7-1). The lowest elevation (1,292 m; 4,239 ft) on the basin perimeter is at Summit (Southern Pacific railroad siding) on the rim of the Virden (Duncan) Valley west of the Summit Hills. At the northwest corner of the basin system, the Gila River-Lower Animas divide continues up to the piedmont-slope that flanks the northern part of the Peloncillo Mountains.

The boundary between the Lower and Upper Animas subbasins, and the (southern) San Simon and (northern) San Bernadino Basin systems to the west follows the crest of the north-south-trending Peloncillo Mountains for about 120 km (75 mi). The hydrogeologic framework and groundwater system of the San Simon Subbasin of the Safford Basin (Figure 3-1) is not described in this report. Information on this area, which includes a small part of Hidalgo County, New Mexico, is covered in a map report by Barnes, 1991. The San Bernardino Basin is described in Chapter 9.

Rather than being a single structural and topographic unit, the Peloncillo Mountains is a chain of individual range blocks with peak elevations of no more than 2,000 m (6,560 ft), and the altitude of most of the mountain area is between 1,525 and 1,825 m (5,000 to 6,000 ft). The three major passes that separate individual range blocks are (from north to south): (1) Steins Pass (about 1,325 m; 4,350 ft) located west of Lordsburg, and crossed by I-10 and the Southern Pacific Railroad, (2) Granite Gap crossed by U.S.-80 west of Cotton City, and (3) Antelope Pass (1,345 m; 4,415 ft) crossed by NM-9 west of Animas (and a former route of the Southern Pacific Railroad). The eastern slope of the Peloncillo Mountains south of Antelope Pass is part of the Upper Animas Subbasin watershed.

The southern segment of the basin system perimeter follows the crest of the Guadalupe Mountains south to near the head of Guadalupe Pass (elevation 1,645 m; 5,395 ft), which is located about 2 km (1.3 mi) north of the International Boundary. This basin-border segment marks the surface-water divide between the Cloverdale Subbasin and the eastern San Bernardino Basin system. The high point on the divide is 1,966 m (6,450 ft) at Guadalupe Mountain near the head of Cloverdale Canyon. To the south, the Cloverdale Subbasin borders the upper drainage basin of Cajon Bonito (shown in Figure 3-1 as a subbasin of the San Bernardino Basin system). This stream joins the Rio San Bernardino at Cuchuverachi, Soñora. Together with Rio Agua Prieta (heading north of Douglas, AZ), they form important headwater tributaries of the Rio Yaqui system via Rio Batepito. The low point on the Cloverdale-Cajon Bonito subbasin divide (about 1,605 m; 5,265 ft) is located 0.6 km (0.4 mi) south of the New Mexico-Soñora border in the area crossed by Mexico Federal Highway 2. This is less than 30 m (100 ft) above the high shoreline of pluvial Lake Cloverdale about 7 km (4.3 mi) to the northeast. The extreme southeastern part of the Animas Basin perimeter is along the Divide between the Cloverdale Subbasin and the San Basilio Basin system at the northern end of Sierra San Luis.

**Drainageways**

There are no major perennial streams in the Animas Basin system with the exception of short perennial to intermittent reaches of Animas Creek and a few of its major headwater tributaries, all of which are located in the southern part of the Upper Animas Subbasin. Upper Animas Creek occupies a well-defined valley extending from the north rim of the Cloverdale Subbasin to a point about 8 km (5 mi) south of Animas, and it contributes runoff and aquifer recharge to downstream areas in both Upper and Lower Animas subbasins. Its major tributaries include Whitmire Creek and Clanton, Foster, and Horse Camp Draws, heading in the Southern Pelonciollo Range, as well as Indian and Double Adobe creeks, heading near Animas Peak (Figure 7-1). The stream-channel system rapidly loses its identity in the Animas area. Some parts of the basin floor are occupied by a prominent (partly relict) pattern of shallow distributary channels (cf. 1936 series U.S. Soil Conservation Service air photos), while other basin-floor surfaces appear to be mainly sites of sheet flooding during very high storm-runoff events. This ill-defined surface drainage pattern ultimately grades to the (South Alkali Flat) playa-lake plain near and north of I-10.

The other major axial drainageway of the Animas Basin system is Lordsburg Draw (Figure 7-1). It delivers storm runoff from much of the Lordsburg Subbasin watershed to the floor of the Lower Animas Subbasin. Most surface flow contributed to Lordsburg Draw is derived from drainage basins that head in mountainous areas along the northeastern and southeastern (Continental Divide) margins of the subbasin. Burro Cienega (draw), with headwaters in the southern Big Burro Mountains is the major tributary to Lordsburg Draw.

**Pluvial Lake Features in the Lower Animas and Cloverdale Subbasins and their Paleoclimatic Implications**

Pluvial Lake features of the study region were briefly discussed in Chapter 3 (Table 3-1), and they are present in all the basin systems described in Chapters 4-6. However, they have only been studied in detail in the Animas Basin system (Fleischhauer and Stone 1982, and Krider 1998), and it is therefore appropriate to further describe these features and their paleoclimatic significance in this chapter.

***Pluvial Lake Animas***

As originally recognized by Schwennesen (1918), a large permanent lake, which he named Lake Animas, flooded much of the Lower Animas Subbasin floor in Latest Pleistocene time (Figure 3-1, Table 3-1). Recent detailed mapping and soil-geomorphic studies by Fleischhauer and Stone (1982) document a Late Pleistocene Lake Animas high stand at 1,278 - 1,279 m (4,193 - 4,196 ft), and two, slightly lower stands (~1,276 and 1,273 - 1,274 m; 4,187 - 4,177 ft) that are characterized by prominent beach ridges that flank much of the interior playa-lake plain area. Two large playas (South and North Alkali Flats) occupy much of the northern lake-basin floor, and an extensive fluvial deltaic complex extending north from the mouth of Animas Creek forms the southern part of the former lake plain near Cotton City. Eolian deposits with dune fields cover lake beds and alluvium northeast of the Alkali Flats near the lower end of the Lordsburg Subbasin (Plate 1, Figures 7-2a and 7-2b) (Drewes et al. 1985).

Fleischhauer and Stone (1982) show that Animas beach-ridge soils are weakly developed in comparison to soils of fan-piedmont surfaces predating the 1,279 m (4,196 ft) lake stage. Fan-piedmont soils commonly have well-developed calcic horizons and occur in both relict-surface and buried landscape positions. On the basis of correlation with Late Quaternary soils of the Desert Project (Gile 1975, Gile et al. 1981) and the regional paleoenvironmental record, Fleischhauer and Stone (1982) suggest that (1) the high-shore ridge is of Late Wisconsin age, with a "minimum probable date" of about 11 ka, and (2) the two lower beach ridges formed during a short Holocene interval as late as 6 to 3 ka. It is also possible that all three shore ridges could have been deposited during the 20 to 8 ka interval, because active fluvial and pluvial-lake systems are known to have existed in nearby areas of Sulphur Springs Valley, AZ at about this time (Schreiber 1978, Waters 1985, 1989). Recent work by Krider (1998) on Lake Cloverdale, however, supports the possibility of a still younger (Late Holocene) interval of lake expansion, in addition to the well-documented, Late Pleistocene high stand of pluvial Lake Cloverdale discussed below.

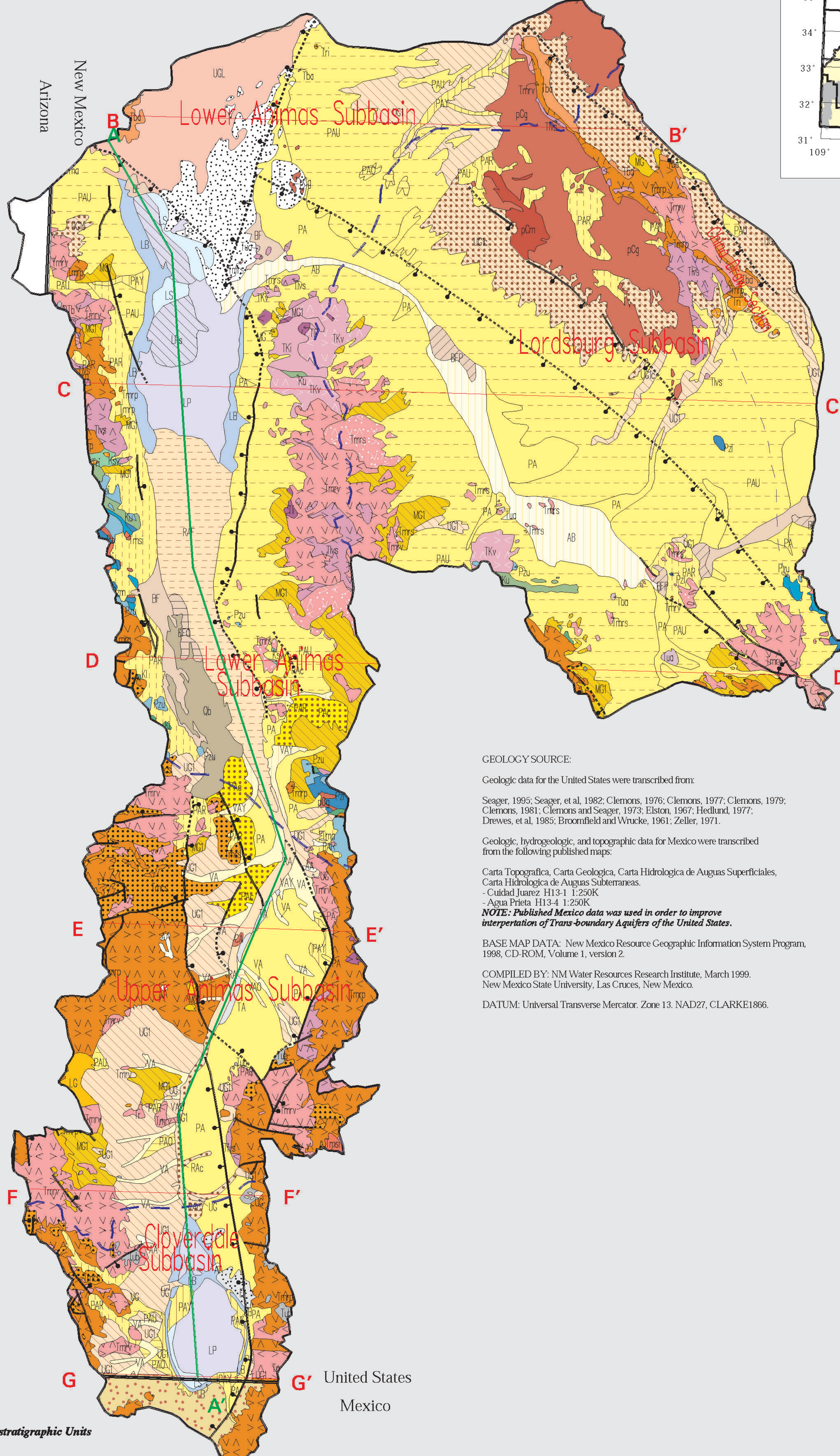
The highest Lake Animas shoreline (1,279 m; 4,196 ft) and the lowest drainage divide on the Animas Basin perimeter (1,292 m; 4,239 ft at Summit) precludes any surface discharge into the Gila River Basin system (Chapter 8) during the Late Quaternary. However, groundwater discharge into the Virden-Duncan Subbasin probably has occurred since initial Gila River Valley entrenchment in Early-Middle Pleistocene time. Axtell (1978, Figure 3-2) proposed that a single, "Early Pleistocene Lake Morrison" inundated the floors of the Virden-Duncan and Lower Animas subbasins, and he suggested that Morrison's (1965) "lake-gravel 5" was deposited at that time. However, neither Morrison nor Fleischhauer and Stone have found any evidence that a deep lake in the Virden-Duncan Subbasin coalesced with any Early to Middle Pleistocene lakes in the Lower Animas Subbasin (Fleischhauer and Stone 1982, p. 9). In any case, thick, fine-grained basin-floor facies of the Upper Gila Group (Conglomerate) do underlie Middle to Upper Quaternary deposits in the Lordsburg Mesa area of both subbasins (Drewes et al. 1985), and it is possible that shallow lakes or interconnected systems of ponds and marshes (cienegas) extended across present basin boundaries during parts of the Pliocene and Early(?) Pleistocene.

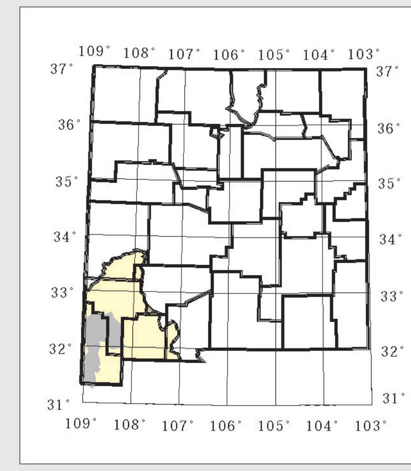
***Pluvial Lake Cloverdale***

The Cloverdale (San Luis) Subbasin (Figure 7-1) and adjacent parts of the Lower Animas Subbasin are the site of recent detailed investigations of surficial geology and soil-geomorphic relationships by Vincent and Krider (1998). Six complete and six partial 1:24,000-scale quadrangles have been mapped in the Gray Ranch-Cloverdale area extending north from the International Boundary. Vincent (personal communication, July 1998) is continuing studies of neo-tectonic features, primarily frontal faults of the Peloncillo and Animas ranges, and Krider (1998) has recently published a report on the "paleoclimatic significance of Late Quaternary lacustrine and alluvial stratigraphy" in the Cloverdale Subbasin area originally described by Schwennesen (1918). Highest Late Pleistocene lake stands of pluvial Lake Coverdale reached 1,578 m (5,177 ft) during the last glacial maximum (Table 3-1). According to Hawley (1993) and Krider (1998), this lake did not spill northward into the pre-existing upper valley of Animas Creek. As will be discussed in sections of this chapter dealing with groundwater flow, a shallow "perched" aquifer zone exists a few meters (< 10 - 15 ft) below the existing playa-lake plain surface (elevation about 1,561 m, 5,120 ft) but the regional water table is at an elevation of about 1,405 m (4,610 ft). (See Plate 4 of Reeder (1957) for a pre-1955 profile of groundwater surface elevations along the entire basin length.)

Krider (1998, p. 283) concludes that "Four separate stands of Late Quaternary Lake Cloverdale in the southern Animas Valley are recorded by lacustrine shoreline

# Animas Basin System



**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

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.

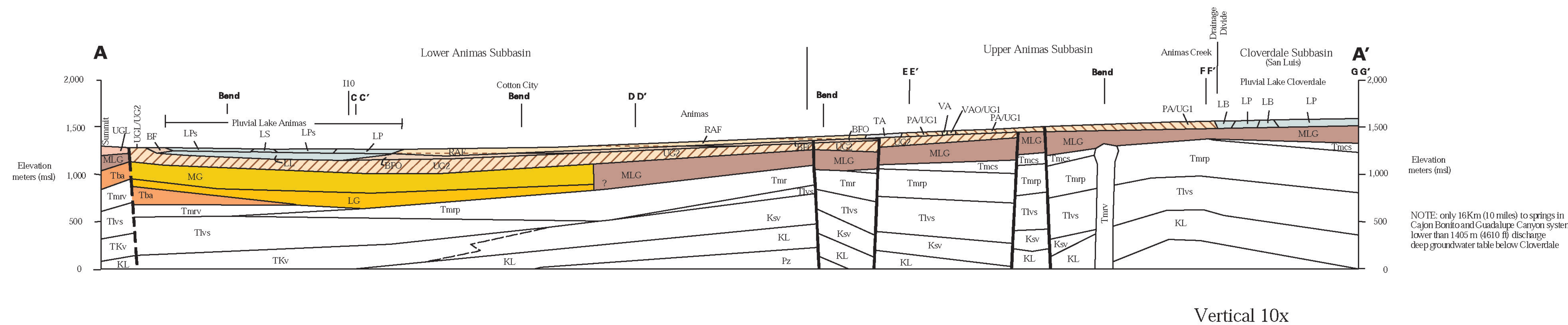
DATUM: Universal Transverse Mercator. Zone 13. NAD27, CLARKE1866.

SCALE 1: 500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

**Figure 7-2a.** Hydrogeologic map of the Animas Basin System.




Tba - Oligocene: Basaltic andesites interbedded with and underlying LG

## Profile Explanation

- LL - Lacustrine plain sediments deposited like LP unit; combines units LB, LP, LS, and LPs; includes Middle Quaternary deposits in subsurface that are mostly saturated; up to 30m thick?
- BFO - Alluvial flat, channel and floodplain deposits of ancestral Mimbres and Animas fluvial systems, and local "playa" depression fills; as much as 20 m thick and partly in vadose zone; mostly facies *c*, with local areas of gypsiferous sediments
- BF - Undivided alluvial flat deposits, including fills of small "playa" depressions; as much as 30 m thick and primarily in vadose zone; mostly facies *c;* gradational to or intertonguing with map units BFY, BFO, BFU, RMF, and RAF
- UG1 - Proxiaml to distal, Upper Gila Hydrostratigraphic Units, piedmont slope facies, undivided; locally underlies PA and VAV, mostly facies *5*
- UG2 - Upper Gila HSUs, undifferentiated fine to medium grained basin-floor deposits; including those of ancestral Mimbres and Rio Santa Barbara systems; mostly facies *3*
- MG - Upper Tertiary: Middle Gila HSUs, undivided (includes MG1 and MG2); primarily facies *7 and 8* (mostly in zone of saturation in central basin areas)
- LG - Upper Tertiary, Lower Gila Hydrostratigraphic Units (HSUs), undivided piedmont and basin-floor facies *4, 7, 8, 9, and 10. Note that unit is mostly buried in central basin area and is saturated*
- MLG - Middle and Lower Gila undivided HSUs, only on cross-sections

*Note that non-colored units are listed on Figure 7-2a and Plate 1.*

SCALE 1: 500 000

10 0 10 20 30 40 50 MILES

10 0 10 20 30 40 50 KILOMETERS

**Figure 7- 2b.** Hydrogeologic profile of the Animas Basin.

deposits. Soils and stratigraphic evidence show that three young lake highstands occurred during the Holocene and that a higher lake stand occurred 18,000 to 20,000 $^{14}$C yr B.P. Fluvial systems aggraded the southern Animas Valley during the Middle to Late Holocene. The Late Quaternary stratigraphy shows that several periods during the Late Holocene were characterized by higher effective precipitation than at any time since the last glacial maximum." *Note that possible implications of "El Niño – Southern Oscillation (ENSO) events" on paleoclimatic conditions, which are based on tree-ring (dendrochronologic) reconstructions, are briefly covered in the following climate section.*

### Land Use

The Animas Basin system represents a moderate array of land use and landcover ranging from Ponderosa Pine forest in the higher parts of the Burro Mountains in the north and in the southern Animas, Peloncillo, and Guadalupe mountains adjacent to the Cloverdale and Upper Animas subbasins. Mixed Piñon-Juniper woodlands and grasslands on lower mountain slopes grade rapidly into semidesert-grass and desert-scrub vegetative cover in the rangelands on lower piedmont slopes and basin floors (McCraw 1985). A large playa-lake plain (Figure 7-1) including North and South Alkali Flats, dominates the floor of the Lower Animas Subbasin, and large areas have little or no vegetative cover. Rangeland accounts for the majority of the land cover in the area. Lordsburg, on I-10 and US-70 and the Southern Pacific Railroad, is the major urban center. The smaller communities of Animas and Cotton City are located in the agricultural area of the Lower Animas Subbasin. Most of the irrigated cropland is located in the lower Lordsburg and Animas "Valleys." Irrigated crop acreages were reported at 411 hectares (1,015 acres) in the Lordsburg Valley and 2,963 hectares (7,322 acres) in the Animas Valley in 1995. Water use for this irrigation in the Lordsburg Subbasin was reported at 2.5 x $10^6$ $m^3$ (2,040 ac-ft) and in the Lower Animas Subbasin at 17.9 x $10^6$ $m^3$ (14,542 ac-ft) in 1995.

### Climate

Except for the Southern Animas-San Luis range and the Guadalupe Mountains, the climate is arid with mostly clear skies and limited rainfall and low humidity. In the semiarid Cloverdale Subbasin area, the precipitation is higher and temperatures are somewhat cooler. According to (then) State Climatologist F. E. Houghton (in Cox 1973, p. 86-87): "The monthly totals of precipitation in the [Animas Basin area] are greatest in the summer and early in fall. Half the annual precipitation generally falls during the period of July through September, when moisture from the Gulf of Mexico follows the general circulation about the westward-displaced Bermuda high pressure area. Spring and fall generally receive light total amounts of precipitation, but a small increase in precipitation generally takes place in winter because of moisture flowing eastward from the Pacific Ocean in the general circulation [pattern] of that season." Houghton (p. 7) further notes that the highest annual precipitation recorded through 1970, was 74.35 cm (29.27 in) at Cloverdale Ranger Station (elevation about 1,645 m; 5,400 ft). In July 1931, 25.7 cm (10.12 in) of rainfall was recorded at Dunagan Ranch (elevation about 1,463 m; 4,800 ft), which is about 32 km (20 mi) north of Cloverdale, and on 7/21/31, 14.38 cm (5.66 in) of rain fell at the ranch.

The climate reporting stations with long-term records in the Animas Basin system are at Cureton Ranch, Lordsburg, Animas, Gray Ranch, and Eicks Ranch (Cox 1973, Maker et al. 1970b, Gabin and Lesperance 1977, NCDC 1999). The Cureton Ranch station is located in the northern part of the basin system, and the Eicks and Gray Ranch stations are near Cloverdale. Average annual precipitation is 38.2 cm (15.03 in) at Eick's Ranch, with 27 years of record (pre-1970), and 36.6 cm (14.4 in) at the Gray Ranch (elevation 1,558 m, 5,110 ft), which has a record period of 8 years (1962-1969). Highest recorded snowfalls prior to 1970 (Cox 1973 p. 87) were 97.3 cm (38.3 in) near Cloverdale in 1918, and 67.3 cm (26.5 in) at Eicks Ranch in January 1946. Animas (elevation 1,346 m; 4,415 ft) reported average annual precipitation of 27.9 cm (11.0 in), and Lordsburg (elevation 1,294 m; 4,245 ft) reported 27.7 cm (10.9 in). At Cureton Ranch precipitation averaged 32.3 cm (12.7 in) annually. Most of this annual precipitation is from thunderstorms that occur from July through September (NCDC 1999).

Large diurnal changes in temperature are common (about 19° C , 35° F) with the average mean air temperature at Lordsburg for the period 1948-1995 reported at 16.1° C (60.9° F). Average minimum temperatures were 6.4° C (43.5° F) and average maximum temperatures were 25.8° C (78.5° F). Pan evaporation records are only available for the Animas station which had an average class A pan evaporation of 253.2 cm (99.7 inches).

Current information on both historic and Late Holocene paleoclimate in the study area incorporates not only modern weather station data, but also historic observations and dedrochronologic (tree-ring) records that now cover more than one thousand years (Quinn et al. 1987, Diaz and Markgraf 1992). This information, which is particularly applicable to the parts of the study area centered in the Cloverdale and Upper Animas subbasins, documents a pattern of short-term (annual to decadal) deviations from "normal" precipitation patterns when conditions are either much wetter (El Niño events) or much drier (La Niña events) than "normal."

El Niño and La Niña events (originally observed in Ecuador and Peru) occur, respectively, when surface-water temperature of the equatorial Pacific Ocean, is anomalously warm or cold. El Niño – Southern Oscillation (ENSO events) are characterized by eastward to northward moving oceanic and coastal air masses that accumulate relatively large amounts of moisture. General west-to-east circulation of this moist air over western North America (the Southern Oscillation) commonly results in higher than average precipitation during "El Niño years." The cold sea surface of the equatorial Pacific during La Niña events has the opposite effect.

Highland areas of western Chihuahua, southeastern Arizona, and southwestern New Mexico (which are proximal to the Gulf of California) are in an ideal position to capture the higher precipitation associated with ENSO events. *See D'Arrigo and Jacoby (1992) for a long-term reconstruction of winter precipitation in New Mexico based on tree-ring measurements and its relationship to these events. El Niño-La Niña phenomena, as they relate to the climate of western North America during the 1997 to 1999 interval, are particular well illustrated in the cover article of the 12/10/99 issue of Science (Chavez et al. 1999) and a report by Thunell and others (1999).*

## HYDROGEOLOGIC FRAMEWORK

### Introduction

Emphasis here is on the hydrogeologic framework of individual structural basins of this part in the southern Basin and Range tectonic province. The first part of this section deals with bedrock- and structural-geologic controls on basin-fill aquifer composition and groundwater-flow system behavior. The major published sources of information on the geologic setting of the Animas Basin system are maps and reports by Reeder (1957), Zeller (1959, 1962), Zeller and Alper (1965), Wrucke and Broomfield (1961), Trauger (1972), Erb (1979), Fleischhauar and Stone (1982), Elston and others (1983), Drewes and others (1985), Hayes (1982), and Bryan (1995). Recent detailed mapping of surficial deposits, and Pliocene-Quaternary geomorphic and tectonic features by Vincent and Krider (1998 ) in the Upper Animas and Cloverdale subbasins have been very useful in development of the hydrogeologic framework concept presented in this report.

Supplemental geophysical and geologic interpretations of deep-subsurface conditions by DeAngelo and Keller (1988), Klein (1995), Corbitt (1988), Thompson (1982), and O'Brien and Stone (1982b, 1984) were used in preparation of the hydrogeologic cross sections (Figure 7-1, AA', and Plate 1, BB' to GG'). Geologic and geohydrologic information on the southern Cloverdale subbasin was compiled from the DGGTN (nd) mapping of the Agua Prieta (2°) sheet. The reconnaissance work on basin-fill deposits in the Animas "Valley" area by Schwennesen (1918), Reeder (1957), O'Brien and Stone (1982b), Raines and others (1985), Machette and others (1986), and Stone and O'Brien (1990) 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, 5, and 6), however, 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.

### Structural Boundary and Bedrock Components

The major geologic features of the Animas Basin system 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 direction) hydrogeologic cross sections (Plate 1, BB' - GG', Figure 7-2, AA'), 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.

Structural interpretations presented on Plate 1 and Figure 7-2 cross sections primarily relate to Neogene extensional features (cf. Chapter 5 discussion). Precursor (Laramide and pre-Laramide) tectonic features are mainly associated with continental plate convergence in pre-Oligocene time, and are still a matter of great debate. Portrayals of Eocene and older structures are therefore very general, but information on lithology and thickness of major bedrock units is shown as accurately as possible considering the map-compilation scales (1:125,000 to 1:500,000) used in this study. For example, zones of inferred Cordilleran-style thrust-belt tectonism are not indicated on Plate 1, and the internal structure of many range blocks simply suggests an overlay of extensional tectonic style on precursor (Laramide) basement-cored compressional uplifts (cf. Drewes et al. 1985, Seager and Mack 1986, Mack and Clemons 1988, and Corbitt 1988).

As already noted, there are four major subbasin components in the area under discussion: Cloverdale (San Luis), Upper Animas, Lower Animas, and Lordsburg. The first three are linked along a south to north structural trend (Figure 7-2, AA'). The Lordsburg Subbasin follows the northwest to southeast trend of its major bounding uplifts, Big Burro to the north, and Coyote Hills and Cedar Mountain Range to the south. This complex group of basin fault blocks, includes both symmetrical (graben) and asymmetrical tilt-block (half-graben) forms. Individual subbasins appear to be open northward (toward the Gila River Basin), and are mostly closed southeastward (toward the Continental Divide).

The more complex Cloverdale-Animas series of subbasins, comprises (1) a right-stepping, half-graben and graben pair in the Cloverdale-Upper Animas area (Plate 1, sections GG' - EE'), (2) a major graben structure that forms most of the Lower Animas Subbasin (sections CC' and DD'), and (3) a composite graben and (east-tilted) half-graben zone at the extreme north end of the basin system (section BB'). The northwest trending structural depression that underlies most of the Lordsburg Subbasin is here interpreted as a northeast-tilted, half-graben block that is bounded by the well-defined frontal fault zone of the Burro uplift (Plate 1, CC') (Machette and others 1998, no. 2094).

The tectonic *accommodation zone* concept as applied to extensional basins was introduced in Chapter 6, and it is described in detail by Faulds and Varga (1998) and Stewart (1998). The *accommodations zones* described in this report belong to a class of Basin and Range deformational features that mark relatively abrupt changes in extensional style along major structural trends, (e.g., the inferred change in direction of half-graben tilt and overlapping boundary-fault terminations between the San Basilio and Playas subbasins discussed in Chapter 6). With respect to the half-graben to (full) graben structural style of the Cloverdale and Upper Animas subbasins, which is well documented on Plate 1 (map and sections GG' - EE'), the east-tilted (Cloverdale - Upper Animas) half-graben block terminates abruptly at a northwest-trending cross-basin horst midway between sections EE' and FF'. This narrow buried structural high and basin constriction is here classed as a major *accommodation zone*. The Upper Animas Subbasin area to the north steps eastward and has a full graben form, that is bounded on both sides by major faults (Machette and others 1998, fault nos. 2025, 2095 and 2096).

A second northwest-trending, cross-basin structure is located about 10 to 16 km (6 to 10 mi) south of Animas. This complex graben and northeast-tilted horst forms the next major *accommodation zone* along the Cloverdale-Animas basin trend and marks the boundary between the Upper and Lower Animas subbasins (Figure 7-1). The buried bedrock high at the northern edge of the zone is expressed in the bordering Animas and Peloncillo mountains (north of Whitmire Pass and south of Antelope Pass, respectively, Figure 7-2) as an abrupt transition from a Middle Tertiary volcanic terrane (to the south) to the mixed bedrock terrane of the northern Animas and Peloncillo uplifts. The latter area is characterized by crystalline basement, sedimentary, plutonic, and volcanic rocks of Precambrian to Middle Tertiary age. The vent for the extensive Animas basalt field of Middle to Late Pleistocene age (Luedke and Smith 1978, Machette et al. 1986) is located in this structurally high *accommodation zone* at the eastern base of the Peloncillo range (Plate 1, Figure 7-2).

The inferred symmetrical graben structure of the Lower Animas Subbasin north of the Animas area is shown on sections CC' and DD' (Plate 1). Note that the eastern part of section CC' also shows a northeast-tilted Lordsburg Subbasin block with inferred half-graben structure. Section BB', at the far north end of the Animas Basin, suggests the presence of a narrow graben west of a Summit Hills horst block, and a broader half-graben to the east that tilts toward a major buried (Precambrian) basement high. The latter feature appears to be shallowly buried beneath an apron of piedmont-slope alluvium derived from the northern Big Burro Mountains.

Longitudinal profile AA' (Figure 7-2b), extending from the International Boundary at Lake Cloverdale to the Gila-Animas basin divide at Summit, illustrates the important role that *accommodation zones* play in the flow system. This topic will be discussed in sections that follow. Down-to-the-south boundary faults of the graben and horst *accommodation-zone* structures, which obliquely cross the line of section in the northern and central parts of the Upper Animas Subbasin are clearly shown on Figure 7-2. Bedrock highs associated with these faults function as buried "sills" that obstruct northward groundwater flow. In addition, conglomerate and mudstone facies (*7* and *8*) of the Middle to Lower Gila HSU: MLG act as "perching" layers for shallow groundwater flowing through Upper Gila or younger basin and valley fills of the Upper Animas - Cloverdale subbasins. Finally the section schematically illustrates the northward thickening of the entire Gila Group and overlying lacustrine and fluvial-deltaic units in the central part of the Lower Animas Subbasin.

**Bedrock Components**

In addition to the 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). The dominant lithologic and structural components of the San Luis, Animas and other uplifts on the eastern border of the Animas Basin system (along the Continental Divide) have already been described (Chapter 6). Attention here is focused on the Peloncillo and Guadalupe ranges along the western side of the basin system, and on the Pyramid Mountains in the north-central basin area south of Antelope Pass (Figure 7-1). The latter range has a core of Lower and Middle Tertiary intrusive rocks of intermediate to silicic composition, with associated volcanic and sedimentary units, that is exposed in the area of North and South Pyramid peaks (Plate 1, section CC'). Silicic volcanics of Middle Tertiary age (including flow and pyroclastic units) are also a major component of the central and southern parts of the uplift, and Upper Cretaceous sedimentary rocks locally crop out south of North Pyramid Peak.

The Peloncillo and Guadalupe mountains comprise a complex suite of Middle and Lower Tertiary silicic volcanic rocks, including pyroclastic and flow units. Numerous small basalt flows and vent units of Late Miocene and Pliocene age are also exposed in the Guadalupe Mountain area. An Upper Oligocene conglomerate and sandstone unit (correlative with the OK Bar Conglomerate of Zeller and Alper 1965) locally crops out near the summit of the southern Peloncillo and Guadalupe mountains west of the Cloverdale and Upper Animas subbasins (map unit Tmcs-Plate 1). The eastward dip of this unit coincides with the general tilt of the Peloncillo-Guadalupe range block that merges eastward with the (Upper Animas-Cloverdale) half graben (Plate 1, EE').

As schematically shown on section EE' and GG', "Pre-Gila" conglomerate and sandstone (map unit-Tmcs) directly underlies the Lower Gila Hydrostratigraphic Unit-LG (also a conglomeratic sandstone) in parts of the southern Animas Basin system. Moreover, as was noted in Chapter 6, these two units 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 map unit-Tmcs (OK Bar conglomerate) occurs on high mountain summits, both in the Peloncillo-Guadalupe range and the southern Animas Mountains, and in contiguous structural basins, it clearly predates Basin and Range tectonism. Therefore, map unit Tmcs must be excluded from Gila Group basin-fill, even when their lithologic composition may be essentially identical.

A significant structural and lithologic component of the Animas Basin perimeter (also noted in Chapter 6) is formed by the Animas-Pyramid and Brockman-Pyramid "Gaps," which are located east of Animas and southeast of Lordsburg (Figures 3-1 and 7-1). These broad topographic saddles along the Continental Divide contain locally thick Gila Group deposits that cap a very irregular buried bedrock surface (primarily formed on silicic volcanic rocks, Plate 1). Andesitic volcanics are also exposed at South Pyramid Peak at the southern end of the Pyramid Mountains, and Lower Cretaceous clastic rocks (mostly shales and sandy silt-stones) form the Brockman Hills to the east.

As will be emphasized in the section on the Conceptual Model of Groundwater-Flow, observations on the predevelopment shape of the potentiometric surface (water table of Schwennesen 1918, Reeder 1957, and Doty 1960) indicate that a small component of the regional groundwater flow was contributed to the northern basin system through either or both the Animas-Pyramid and Brockman-Pyramid "Gaps." It is here suggested that the predevelopment under-flow model is indeed reasonable solely on the basis of interpretations of bedrock (lithologic and buried topographic) and structural conditions made during the present study.



Finally all previous hydrogeologic studies of the area (Schwennesen 1918, Reeder 1957, O'Brien and Stone 1983, 1984) have noted that a significant amount of underflow discharge moves from the Lower Animas Subbasin to the Gila River Basin system through basin-fill deposits and/or volcanic rock units in the Summit Hills-Lordsburg Mesa area (Plate 1, sections BB'; Figures 7-1, 7-2a, 7-2b). Inter-basin discharge here appears to be primarily through basaltic unit Tba (and interbedded "older" Gila or pre-Gila conglomerates) and the Gila Group Hydrostratigraphic Units described below.

**Basin-Fill Aquifer System**

***Major Hydrostratigraphic Subdivisions***

Neogene and Quaternary (Miocene and Holocene) basin and valley-fills form the only important aquifers in the Animas Basin system. They 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 "Animas and Lordsburg Valley" areas with the Gila conglomerate of Gilbert (1875).

Except for Trauger's (1972) report on the Grant County portion of the basin system, most workers have not specifically identified "upper" and "lower" Gila-type basin fill subdivisions (e.g., Schwennesen 1918, Reeder 1957, O"Brien and Stone 1982b, 1983, and Drewes et al. 1985). Trauger (1972) reports depths to Gila "conglomerate" in the central Lordsburg Subbasin as ranging from 177 to 240 m (580 - 780 ft), with much of the overlying unconsolidated basin fill being fine grained. The thickest basin fill deposits penetrated in oil test borings range from greater than 438 m (1,438 ft) about 19 km, (12 mi) northwest of Lordsburg to 576 m (1,890 ft) in about 11 km, (7 mi) northeast of Cotton City (Thompson 1982, O'Brien and Stone 1983). At the latter drill site, the basin fill is underlain by Tertiary volcanics.

Preliminary interpretations of geophysical data compiled by Klein (1995) along transects across the transboundary area 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 6), however, most of the deposits exclusive of the upper 100-300 m (300-1,000 ft) beneath the central bolson plains are Middle and Lower Gila Hydrostratigraphic Units.

The hydrostratigraphic-unit (HSU) classification introduced in this report is also used provisionally in the Animas Basin system to subdivide Early Quaternary and older basin fill into (informal) Upper (UG), Middle (MG), and Lower Gila (LG) Hydrostratigraphic Units, which 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 RA, AB, BF, and LP are post-Gila stream, playa, and lake deposits, which are also important valley- and basin-fill hydrostratigraphic components in that they locally play an important role in recharge and discharge of the groundwater-flow system. *Note again that Gila Group basin-fill is undivided south of the International Boundary (map unit Tug section GG').*

***Major Lithofacies Assemblages***

Since the component subbasins of the Animas Basin system are complex graben and half-graben tectonic features, with both *closed* and *open* (*bolson* and *semi-bolson*) surface-flow elements, a wide variety of depositional environments and lithofacies assemblages are present. In a *semibolson* setting, coarse fan-piedmont facies grade to relatively coarse-grained fluvial deposits of axial drainageways, while in a *bolson* setting piedmont-slope facies grade to fine-grained playa and lake deposits (with or without evaporites). In addition, sandy to silty eolian sediments are typically deposited on basin floors and piedmont slopes downwind from ephemeral-lake plain surfaces. These facies relationships are particularly well expressed in this basin system.

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 BB' - GG', AA'). For example, the dominant lithofacies assemblages of Upper Gila HSUs (UG1, UG1c) throughout the Animas Basin system are poorly consolidated piedmont-slope facies units *5* and *6*, while underlying Middle and Lower Gila HSUs (MG1, MG1c, MLG, LG) are primarily 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 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 are present (e.g., Tmr, Tmrp; sections EE' and GG', Plate 1; Figure 7-2b).

Considering the probability that most of the Lordsburg and Upper Animas subbasins have had axial drainage for much of Neogene and Quaternary time, basin floors should be underlain by a significant amount of conglomeratic 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 *semi-bolsons* during earlier climatic regimes (such as Pleistocene "pluvials") that had much more effective runoff than during most of Holocene time.

Basin-floor and distal piedmont-slope facies assemblages (*1-4, 5, 7, 9, 10, c*) are major basin-fill components in the Lower Animas and Cloverdale subbasins. These facies are major components of Upper Gila and post-Gila HSUs: UG2, UG1, RA, AB, BF, and LP. Fine grained basin-floor facies (*3, 8, 9*) may form much of the Gila Group basin fill sequence (HSUs: MG2, MLG, LG) directly beneath the relict lake plain of pluvial Lake Animas, however, early-stage lacustrine deposits may not be present in the Cloverdale Subbasin area.

**Hydraulic Properties of Major Aquifer System Components**

O'Brien and Stone (1983) and Reeder (1957) provide a good overview of information collected on general well performance and hydraulic properties of the basin-fill aquifer in the Lower Animas Subbasin area, and Trauger's (1972) Grant County report covers part of the central Lordsburg Subbasin. However, Schwennesen's (1918) water-supply paper is still the best synoptic view of the entire basin system. Maximum depth of water wells in the basin system is about 300 m (1,000 ft), but most are less than 150 m (500 ft) deep. The zone of saturation is close to the surface in lower parts of the Lordsburg and Lower Animas subbasins (commonly less than 15 to 30 m, 50 to 100 ft). On upper to middle piedmont slopes throughout the basin system, however, the potentiometric surface (top of the regional groundwater-flow system) may be more than 150 m (500 ft) below the land surface. The regional aquifer system is usually referred to as being "unconfined," but it is probably better classified as semiconfined to confined in many parts of the basin system.

The shallow zones of saturation that are commonly observed in the Upper Animas and Cloverdale subbasins, particularly in the inner valley of Animas Creek (HSU:RAc), have been identified as "perched" aquifers by Schwennesen (1918) and Reeder (1957, Plate 4). As noted in the preceding section and illustrated on Figure 7-2b and Plate l (sections AA' and EE' to GG'), the "perching" layer (or negative confining zone) is formed by dense conglomeratic mudstones and sandstones of the Middle and Lower (?) parts of the Gila Group (HSUs: MGl and MLG). Depths to the regional "aquifer" in this area locally exceeds 150 m (500 ft). The limited amount of "perched" water historically available for livestock, domestic, and small irrigation agriculture uses occurs in coarse channel gravels that are only present in the inner valleys of Animas Creek and a few major tributaries with intermittent flow regimes. These fluvial deposits generally have high hydraulic conductivity (tens of meters per day) but low storage capacity. The entire "perched" system is restricted to the Upper Animas Subbasin. Bedrock constrictions related to the presence of the above-mentioned *accommodation zones*, coupled with the high structural and topographic position of the subbasin (as well as the adjacent Cloverdale Subbasin), are the primary factors controlling the marked divergence of the "perched" and "deep" regional aquifer system first documented by Reeder (1957, Plate 4).

Much of the water pumped for irrigation during the past half century has been produced from the upper 150 m (500 ft) of basin fill. Yields of 545 to 2,725 $m^3$/d (100 to 500 gpm) are common in central basin areas (Trauger and Doty 1965). Most of these deposits are here included in basal Animas Valley-fill (RA) units and Upper Gila HSUs: UG2 and UG1. Underlying basin 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 hydrostratigraphic units. General hydraulic properties of these units can be determined for the dominant facies components of individual HSUs by using the explanation of Plate 1 as a key to facies composition and Table 3-5 for estimated ranges of hydraulic conductivity and other aquifer properties.

Almost all of the quantitative information on hydraulic properties of the basin-fill aquifers has been obtained from the main area of irrigated farmland between Animas and I-10, which centers around Cotton City in the southern part of the Lower Animas Subbasin (Figure 7-1). The most recent compilations and interpretations used here are from O'Brien and Stone (1983), but other very useful references include Reeder (1957), Hawkins (1981), Hawkins and Stephens (1983), and Kernodle (1992a). As already noted, this particular part of the Animas Basin system is not representative of most of the subbasins described in this chapter. The major aquifer between Animas and the South Alkali Flat is formed by medium-to coarse-grained, fan-delta deposits of ancestral Animas Creek. This unit (HSU: RAF) was deposited on an extensive fluvial-deltaic plain marginal to pluvial Lake Animas. The lake expanded and contracted over an estimated vertical range of about 30 m (100 ft), with a maximum high-stand elevation of 1,279 m (4,195 ft) during Latest Pleistocene (Late Wisconsin) time.

Because the most recent interval of Lake Animas formation has been preceded by earlier cycles of lake–basin flooding since the Early Pleistocene, the resulting succession of fluvial-deltaic deposits in the Cotton City area are relatively thick, extensive, and coarse grained units compared to basin fill in other parts of the Animas Basin system. The only analogous units in the study area are the fluvial and fluvial-deltaic deposits of the lower (ancestral) Mimbres River system described in Chapter 4. A contrasting sequence of very fine-grained lacustrine sediments extending north from the South Alkali Flat area (Figure 7-2b, Plate 1, CC') represents the main body of Lake Animas basin fill (complex lake, playa, and eolian facies) that was deposited over a long interval of Middle and Late Quaternary time (HSU: LL, facies *3*, and *9*). Fine-grained lake-basin fill is locally as much as 90 m (300 ft) thick according to O'Brien and Stone (1982b), however, the basal part of this complex playa-lake deposit is probably correlative with Upper Gila HSU: UG2.

Specific information on basin-fill hydraulic properties compiled by Reeder (1957) and O'Brien and Stone (1983) are derived from aquifer-performance (pumping) tests and well specific-capacity measurements. Highest reported irrigation well discharge is about 10,000 $m^3/d$ (2,000 gpm), but most wells yields were in the 2,725 to 5,450 $m^3/d$ (500 to 1,000 gpm) range. Calculated transmissivity values range from 273 to 3,059 $m^2/d$ (2,940 to 32,890 $ft^2/d$; 22,000 to 246,000 gpd/ft) with an average value of about 620 $m^2/d$ (6,685 $ft^2/d$, 50,000 gpd/ft). Year-1955 specific-capacity values compiled by Reeder (1957) range from about 90 to 1,250 $m^3/d/m$ (5 to 70 gpm/ft) of drawdown, and the average specific-capacity for the 45 wells measured in 1955 is about 519 $m^3/d/m$ (29 gpm/ft). Reeder also noted that earlier well performance tests for the 1948 to 1950 period showed somewhat higher irrigation-well specific capacities that ranged from about 286 to 1,788 $m^3/d/m$ (16 to 100 gpm/ft) and averaged about 1,250 $m^3/d/m$ (70 gpm/ft). Note that transmissivity and specific-capacity ranges reported here are quite similar to the best performing aquifer zones and wells in the Upper Playas Subbasin (Doty 1960, Chapter 6). The specific yield value of 0.11 selected by O'Brien and Stone (1983) for the (unconfined) Lower Animas "Valley" aquifer sys-tem, was based on Reeder's (1957) calculation of average storage coefficient values that range from 0.07 to 0.14.

## MAJOR COMPONENTS OF THE GROUND-WATER FLOW SYSTEM

### Surface-Water Components

Surface flow in the Animas Basin system has three components that directly interface with groundwater flow: (1) short reaches of intermittent streams in Upper Animas Subbasin, (2) springs, seeps, and wetland (cienega) areas at higher elevations, and (3) ephemeral streams in arroyos and draws.

The major areas of locally intermittent mountain streams (in the southern Animas and Peloncillo Mountains), and the larger draws and arroyos were briefly described in the physiographic setting section. The only large axial drainageways in the basin system are Animas Creek in the Upper Animas Subbasin and Lordsburg Draw in the Lordsburg Subbasin. Both occasionally contribute storm runoff to the Alkali Flats in the Lake Animas depression. Flood waters commonly move as sheetflows down Lordsburg Draw and the lower Animas basin floor area north and south of Cotton City. 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 Animas Basin system show a few springs and seeps in higher mountain valleys and uppermost piedmont areas. These localized discharge points probably support very short reaches of intermittent stream flow in down-valley areas. However, none of these springs have been described in terms of discharge, and only a few have detailed water-quality measurements. As discussed in the next section and previously noted (Chapters 4, 5, and 6), 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). Additional information on springs in the area can be found in Schwennesen (1918) and White and Kues (1992).

### Recharge

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, central, 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 southern part of Basin system, however, higher watersheds in the southern Animas and San Luis mountains range from 2,000 to 2,597 m (6,550 - 8,521 ft) in elevation. Pine forest vegetation in these places and previously discussed climate records indicate that annual precipitation may locally range from 38 to 50 cm (15 to 20 in). A second small area of higher precipitation is near Burro Peak (2,434 m, 7,985 ft) in the Big Burro Mountains.

A general approximation of basinwide recharge is based on the following assumptions: (1) the upper basin system that drains to the broad bolson plains of the Lower Animas Subbasin (primarily a discharge zone) has an area of about 4,500 $km^2$ (1,740 $mi^2$); (2) this area receives 1.58 x $10^9$ $m^3$ (1,275,750 ac-ft) of unevenly distributed annual precipitation of about 35 cm (14 in); and (3) one percent of this precipitation (1.58 x $10^7$ $m^3$; 12,758 ac-ft) contributes to groundwater recharge. This approximation is very close to the recharge estimate of about 1.57 x $10^7$ $m^3$ (12,700 ac-ft) for the entire Animas Valley area by O'Brien and Stone (1983), and it also generally agrees with recharge-value ranges reported for other basins of the study area (cf. Chapters 4-6, 9).

The mountain-front-recharge component, as already noted, varies 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 higher parts of the Burro Mountains, and most notably, the southern and central Animas Mountains, Sierra San Luis, and the Guadalupe and southern Peloncillo mountains. The controls by various rock types on effectiveness of mountain-front-recharge discussed in Chapter 5 also pertain to the Animas Basin system.

The other major source of recharge in the basin-fill aquifer system is water percolating through thinner parts of the vadose zone beneath the stream channel and flood plain of the system's only major axial drainageway, (upper) Animas Creek. This component is termed "tributary recharge" by Kernodle (1992a) in distinction from "mountain-front-recharge." O'Brien and Stone (1983) calculated that the Upper Animas "Valley" contributed about 5.7 x $10^6$ $m^3$ (4,600 ac-ft) of recharge to the lower Animas "Valley" aquifer. A significant, but smaller source of tributary recharge is from the ephemeral Lordsburg Draw-Burro "Cienega" drainage system.

The broad piedmont slopes that separate range fronts from axial drainageways and alluvial flats are not considered to be significant places for recharge (Trauger and Herrick 1962). The water table in these areas is commonly very deep, locally exceeding 150 m (500 ft); the coalescent fan-piedmont deposits (Gila Group: UGl/MGl/MLG; facies assemblages *5-9*) are very poorly sorted and partly indurated (including carbonate and zeolite cements), and the vegetative cover of desert scrub and semiarid-zone grasses is very effective in capturing most of the annual precipitation. However, major snow-melt and flood-runoff events from drainage basins heading in the southern and central Animas Mountains, Sierra San Luis, Guadalupe Mountains, and southern Peloncillo Mountains could occasionally make substantial contributions to recharge sites on piedmont slopes and along major draws (e.g., the canyons and valleys of Whitmire, Indian and Double Adobe creeks, and Clanton, Foster and Horse Camp Draws - Figure 7-1).

### Movement and Discharge

The primary use of groundwater in the Animas Basin system is irrigated agriculture. O'Brien and Stone (1983, Table 1) observed that since 1950, the irrigated area (with some shift in location) tends to average from about 4,855 to 5,665 hectares (12,000 to 14,000 acres) with groundwater withdrawals averaging about 2.5 x $10^7$ $m^3$ (20,000 ac-ft) per year. Almost all the irrigated-cropland area reported for Hidalgo County in Table 1-1 of 14,720 hectares (36,370 acres) is in the Lower Animas Subbasin. Likewise, most of the irrigated agricultural water use for Hidalgo County (reported in Table 1-3) of 2.7 x $10^7$ $m^3$ (21,770 ac-ft) in 1995 was in this subbasin.

The shape of the potentiometric surface (water table) and the general direction of groundwater flow (Figure 7-3) clearly indicates that the Animas Basin system, while topographically *closed*, fits the *drained* basin category illustrated by Figure 3-2 (Schwennesen 1918, Reeder 1957). Groundwater movement in most of the basin system mimics the direction that surface water flows across the topography. Groundwater flow is generally northward in the "perched" and "deep" aquifers of the Cloverdale and Upper Animas subbasins north of the U.S./Mexico border, and it continues through the Lower Animas aquifer system toward the Lake Animas-Alkali Flat depression (Figure 7-3). Groundwater also flows to this depression from the southeast through the basin-fill aquifer system of the Lordsburg Subbasin.

Doty (1960) and Reeder (1957) both recognized the potential for a small amount of underflow contribution to the Lower Animas Subbasin area in the predevelopment period through the Animas-Pyramid Gap. Schwennesen (1918, p. 112) suggested that the Brockman-Pyramid Gap was the most likely underflow zone, with limited discharge from the lower Playas "Valley" contributing to groundwater flow in the Upper Lordsburg Subbasin.

The potentiometric surface is near the basin floor in only one part of the basin system. This area is in the Lower Animas Subbasin about 8 to 16 km (5 to 10 mi) south of I-10 and 8 km (5 mi) north of Cotton City. The water table profiles and maps in Reeder (1957, Figures 3-5, Plate 4) show that the potentiometric surface was about 4.5 to 6 m (15 to 20 ft) below the surface in that area between 1948 and 1955. Schwennesen (1918) noted that in 1913, depths to the water table in this area ranged from 3 to 4.5 m (10 to 15 ft). He further noted that the vadose zone thickened in all directions from that part of the basin floor. His most important observations, however, were (1) that the slope of the potentiometric surface was northward, being progressively deeper under the South and North Alkali Flats, and (2)

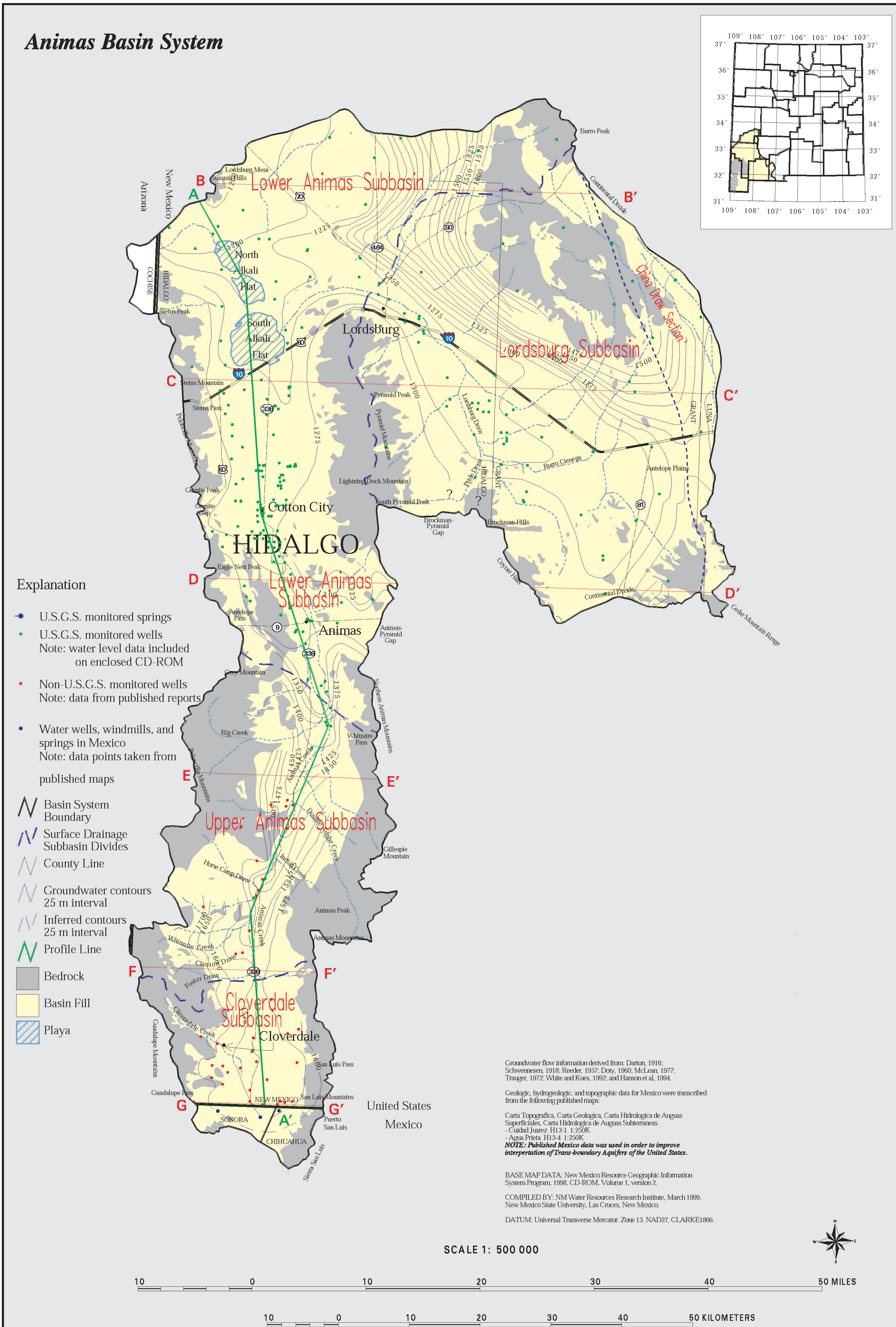



**Figure 7-3.** Animas Basin System groundwater contours, flow direction, and stream- aquifer relationships.

that this northward slope continued past the Summit Hills into the deeply entrenched Gila River Valley (Chapter 8). Reeder (1957, Plate 4) shows the profile of the 1955 water table and documents a significant steepening of gradient beneath the Gila Valley border a short distance north of the Summit Hills. The predevelopment groundwater-flow model of O'Brien and Stone (1983) produces an outflow estimate of about 1.6 x $10^7$ $m^3$/yr (12,700 ac-ft) for groundwater discharging to the Gila Valley through one or more zones of thick basin-fill (HSUs: UG/MLG) and/or rock fractures (unit Tba) that bypass the Summit horst block in the Lordsburg Mesa area (Figures 7-1 to 7-3, Plate 1).

Water-level measurements dating back to the observations made in 1913 by Schwennesen (1918) and the 1948-1955 investigations of Reeder (1957, Plate 4) clearly show that the shallow aquifer system of the Cloverdale and Upper Animas subbasins discharges northward into the Lower Animas Subbasin (Figure 7-3). However, at least one deep well drilled in the center of Cloverdale Playa encountered a "deep aquifer" unit, presumably in older Gila Group deposits (HSU: MLG, section AA' and GG'), in which the reported elevation of the "water table" is about 1,405 m (4,610 ft). This elevation is 156 m (510 ft) below the (locally *phreatic*) *playa* floor and the top of the thin "perched" zone of saturation. It is here suggested that there could be a small component of near-vertical leakage through the thick Gila Group "perching layer" that recharges the deep aquifer. However, much of this recharge may move laterally into the basin-fill from adjacent mountain blocks (cf. Figure 3-3).

Emphasis here is on the fact that the "perched" aquifer system in the central Cloverdale Subbasin is the highest topographic unit and has the largest pressure-head values relative to all other basin floors in the study area (Table 3-1, Figure 7-2b, Plate 1, section GG'). It is also important to note that the area of steep topography immediately west and southwest of the Cloverdale playa depression descends rapidly into deeply dissected terrain drained by Guadalupe Canyon (New Mexico, Arizona and Sonora) and Cajon Bonito (New Mexico, Sonora). The highest springs shown on topographic maps of this transboundary area are within 16 km (10 mi) of the western rim of the Cloverdale Subbasin and are also at an elevation of about 1,400 m (4,600 ft). It is therefore possible that the divide in the regional groundwater-flow system below the *closed* and *drained* Cloverdale Subbasin may not coincide with the surface-water divide marking the southern edge of this subbasin. However, considering the very low permeability of the Gila Group "perching layer" and underlying bedrock units, amounts of transboundary underflow also are probably very low.

## CONCEPTUAL MODEL OF GROUNDWATER FLOW

The conceptual model of groundwater flow in the Animas Basin aquifer system is examined briefly here 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 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.

In the context of this study, groundwater-flow models developed to date for the Animas Basin system (Hawkins and Stephens 1983, O'Brien and Stone 1983, 1984) have two major limitations. First they cover only a small part of the basin system, namely the Lower Animas Subbasin. Second and more important, the primary modeling effort by O'Brien and Stone (1983) involved a two-dimensional approach that fails to capture the marked vertical changes of the basin-fill hydrostratigraphic and lithofaces properties. As noted in Chapter 4 and by Kernodle (1992a), the two-dimensional modeling approach is only a valid first step in characterizing the groundwater-flow regime in a basin-fill aquifer system. However, reasonable approximations of geohydrological "reality" require more sophisticated three-dimensional conceptual and numerical modeling approaches that better incorporate information on the aquifer system's hydrologic framework.

Except for part of the Cloverdale Subbasin, the Animas Basin System is a *closed* and *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 Animas and southernmost Lower Animas subbasins, and possibly the Lordsburg Subbasin; (3) widespread fluvial-deltaic deposits in the Lower Animas Subbasin immediately south of pluvial Lake Animas; and (4) sediments of the lake plain itself. Units 3 and 4 comprise a complex of alluvial-flat, fan-delta, lake, playa, and eolian sediments.

Even though the 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 fine-grained or partly indurated to well consolidated. This material has low porosity and permeability and comprises Neogene subdivisions of the (informal) Middle and Lower Gila lithostratigraphic groups. Upper Gila hydrostratigraphic units (UG1-2) and post-Gila fluvial-deltaic deposits of ancestral Animas Creek (HSU: RAF) form the dominant aquifer system beneath the Lower Animas "Valley" floor that extends as far north as the southern end of South Alkali Flat (near I-10). Underlying Upper to Middle Gila Group Hydrostratigraphic Units (UG1-2/MG1-2) 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 Animas Basin system outside the Lower Animas Subbasin and the west-central Lordsburg Subbasin. A reasonable conceptual model of groundwater flow in the basin-fill aquifer system can be constructed, however, on the basis of (1) hydrogeologic maps and cross sections (Plate 1, Figure 7-2), 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 BB' to GG' that are roughly normal to the axis of the Animas-Cloverdale Subbasin structural trend. Sections DD' to FF' cross the valley of Animas Creek, the main axial drainageway of the Lower and Upper Animas subbasins, and all three cross sections illustrate the half-graben to full-graben structural framework of this group of (*open*) *semibolson* and (*closed*) *bolson* landforms, which are characterized by a *drained* groundwater-flow system.

Longitudinal section AA'(Figure 7-2) closely follows the zone of axial surface drainage (and the basins of pluvial lakes Cloverdale and Animas) from the U.S./Mexico border (at Cloverdale Playa) to the drainage divide with the Gila River Basin north of Lake Animas. This cross section approximates the principal south to north line of groundwater flow in the Animas Basin system. Section AA' crosses two major *accommodation zones* bounding half-grabens and graben structures in the Upper Animas Subbasin, which are characterized by bedrock constrictions and shallow depths to Middle and Lower Gila Hydrostratigraphic Units (MGl and MLG). These units form thick "perching" layers (negative confining beds) that separate a shallow "perched" aquifer zone in the valley of Animas Creek from a very deep "aquifer" zone with very limited groundwater-production potential. Total thickness of Gila Group Hydrostratigraphic Units (UG, MG, LG or UG and MLG) along the line of section AA' ranges from less than 100 m to at least 600 m (300 - 2,000 ft) in the Upper Animas Subbasin, with no more than 200 m (660 ft) of saturated Upper Gila and post-Gila Hydrostratigraphic Units (UG1, UG2, and RA) being present.

In the Lower Animas Subbasin, saturated fluvial, fan-delta, and lacustrine deposits of Middle to Late Quaternary age cap the Upper Gila Group in much of the basin-floor area. Major hydrostratigraphic units and lithofacies assemblages are HSUs: RA, RAF, BF, LP; facies *a* and *b*. These deposits are probably no more than 50 to 100 m (165 to 330 ft) thick. Surficial lake and playa sediments of the Alkali Flats area (LP-facies *c*) are unsaturated and *phreatic playa* conditions have not been observed. The ephemeral-lake plain occupied by the North and South Alkali Flats should therefore be classed as a *vadose playa*. Groundwater in the Lower Animas Subbasin discharges as underflow to the Gila River Basin (Chapter 8) in the Lordsburg Mesa area adjacent to the Summit Hills (horst). The Mesa is a remnant of a fluvial (deltaic?) plain constructed by the ancestral Gila River in Late Pliocene to Early Pleistocene time (map unit UGL, Plate 1).

Maximum basin-fill thickness, probably exceeding 600 m (2,000 ft), appears to be near the western frontal-fault zone of the Pyramid Mountains (section CC' Plate 1). Sections EE' and FF' illustrate the complex half-graben to (full) graben structural framework of the Upper Animas Subbasin and flanking ranges (Kirk Vincent, written communication 7/98). Cross section GG' shows the (east-tilted) half-graben structure of the Cloverdale Subbasin along the International Boundary, with the San Luis uplift forming the eastern basin boundary. Much of the Lower Animas Subbasin is interpreted as a (full) graben, with Alkali Flats and Pluvial Lake Animas basin being located over its deepest part.

The single area with a history of moderate to large amounts of groundwater production (for irrigation and small urban-domestic uses) is located in the southern part of the Lower Animas Subbasin at the lower end of the Animas Creek drainage system. This area has been investigated by Reeder (1957) and O'Brien and Stone (1983, 1984). Reeder (1957) 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. Reeder (1957) further supplemented personal observations on the geohydrologic behavior of the basin-fill aquifer system with interpretations on regional hydrogeology by Schwennesen (1918), Doty (1960), and other U.S. Geological Survey and New Mexico Office of the State Engineer associates (including Zane Spiegel, who prepared the section on geology in Reeder's report).

The hydrogeologic framework of this part of the Lower Animas Subbasin is illustrated by cross sections CC' and DD' (Plate 1) where they intersect with longitudinal section AA' (Figure 7-2b). The total productive aquifer zone appears to have a maximum thickness of about 200 m (660 ft). However, most of the groundwater production comes from unconsolidated, post-Gila Group fan-delta deposits, of ancestral Animas Creek, and underlying fluvial facies of the Upper Gila Group (HSUs: RAF and UG2; facies assemblages *a-b and 1-5*) that are no more than 200 m (660 ft) thick.

Pumping-test and well-production data interpreted by Reeder (1957) based on records of irrigation-well performance, yielded a range of specific capacity values of 90 to 1,788 $m^3/d/m$ (5-100 gpd/ft). His estimated range of transmissivity (T) values was from 273 to 3,059 $m^2/d$ (2,940 - 32,890 $ft^2/d$), with a reasonable intermediate value of about 620 $m^2/d$ (6,685 $ft^2/d$; 50,000 gpd/ft). Assuming a productive aquifer thickness of about 100 m (330 ft), a very rough estimate of the hydraulic conductivity of combined hydrostratigraphic units RAF/UG would be about 6 m/d (20 ft/d). All the above values indicate that this particular part of the Lower Animas Subbasin may still have potential for continued irrigation agriculture (or for other large volume groundwater uses) compared to most, if not all, of the rest of the Animas Basin system. *Note also that hydraulic characteristics of Lower Animas "Valley" aquifer are very similar to aquifer properties noted by Doty (1960) in the Upper Playas Subbasin (Chapter 6).*

Taking a still broader view of the Lower Animas Subbasin, it seems worthwhile to gain some perspective on the amount of groundwater that could move northward across the entire width of the subbasin toward the zone of underflow to the Gila River Basin in the Lordsburg Mesa-Summit Hills area (Figure 7-1, 7-3). Very rough calculations of potential predevelopment groundwater flow across a east-west section between CC' and DD' (Plate 1), which crosses the subbasin axis (section AA', Figure 7-2b) near Cotton City, 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. Only Upper Gila basin-fill units that are capable of producing moderate to large amounts of groundwater are considered (about 300 $m^3/d$, 50-60 gpm).
2. Width and thickness of saturated basin fill are 10,000 m (32,800 ft) and 200 m (660 ft), respectively, giving an estimated cross section area of 2.0 x $10^6$ $m^2$ (2.16 x $10^7$ $ft^2$).
3. The hydraulic gradient is 0.001 (from Reeder 1957).
4. Estimated horizontal hydraulic conductivity (distributed between RAF and UG2-HSU, is 10 m/d (33 ft/d), assuming UG-HSUs: 150 m thick with K=6 m/d, and RAF-HSU: 50 m thick with K=22 m/d.
5. Calculated (predevelopment) flow through cross section between DD' and EE' (Plate 1) of about 7.3 x $10^6$ $m^3$ (5,913 ac-ft) per year.

This discharge rate is very close to estimates of rates of mountain-front and tributary recharge for the central Lower Animas Subbasin (O'Brien and Stone 1983). This rough calculation also suggests the range of hydrogeologic conditions that must be defined in a semiquantitative fashion before numerical models can be developed that capture the basic reality of the groundwater-flow system. In the above example, only the hydraulic gradient is well defined, while the assumption of cross-section area is at best a general estimate that probably involves some 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 significant overestimation of flow rates possible near the basin margins.

If the entire Animas 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 saturated basin fill appears to be less than 100 m (330 ft) thick are excluded; (2) the remainder of the basin underlain by productive aquifer zones has an area of about 12 x $10^8$ $m^2$ (1,200 $km^2$; 3 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 1.2 x $10^{10}$ $m^3$ (12 $km^3$; 9.5 x $10^6$ ac-ft).

It is here also suggested that parts of the Animas Basin system have a very distinctive groundwater-flow regime both now and in the recent historical past (prior to about 1900-1910). Like the Playas Basin to the east of the Continental Divide (Chapter 6), the floor of the Cloverdale Subbasin is the site with the highest pressure head in the entire regional groundwater-flow system west of the Continental Divide (about 1,560 m; 5,120 ft). This small basin is essentially filled to the "brim" with groundwater, which is discharged (1) to the surface of the present "perched" *phreatic playa* by evapotranspiration, (2) by underflow northward into the Upper Animas Creek Valley "perched aquifer system," and (3) vertically downward to the regional aquifer through a perching layer that is part of a 500-ft thick vadose zone (possible, but minor underflow loss).

## GROUNDWATER QUALITY

### General Hydrochemistry

General water quality in the Animas Basin system is highly variable (Figure 7-4). Groundwater analyses in the Cloverdale (San Luis) Subbasin are limited to only four samples (Figure 7-4). These are all less than 250 mg/L TDS. Groundwaters in the Upper Animas Subbasin are similarly dilute, maintaining concentrations less than 250 mg/L TDS. Groundwater in the northern part of the Lower Animas Subbasin has TDS concentrations that vary from dilute to moderately saline (Figure 7-4). The Lordsburg Subbasin has variable groundwater salinities that range from dilute to moderately saline. TDS concentrations vary irregularly in the Lordsburg Subbasin and no particular patterns are evident.

The Piper diagram (Figure 7-5) and stiff map (Figure 7-4) indicate that the hydrochemical facies in the San Luis Subbasin are mostly Mixed Cation-$HCO_3$-$SO_4$ type waters. The hydrochemical facies in the Animas Basin are extremely variable, ranging from Ca-$HCO_3$ type waters in the upper basin that are dilute, to Na-$HCO_3$ type waters in the middle basin, to Na-Cl-$SO_4$ waters in the lower basin that have relatively high TDS. The Lower Animas Subbasin is characterized by variable groundwater chemistries, the Na-Cl-$SO_4$ facies representing only one end-member type. The Lordsburg Subbasin exhibits considerable variability of hydrochemical facies. These include Ca-$HCO_3$ and Na-$HCO_3$ type waters that are quite dilute–Na-$HCO_3$ to Na-$HCO_3$-$SO_4$ type waters that have higher TDS, and Na-Cl-$SO_4$ waters that have the highest concentrations of TDS, sometimes exceeding 1,000 mg/L.

The anion maps show considerable variability of chloride and sulfate concentrations in groundwaters in the Animas Basin system (Figures 7-6 and 7-7). Groundwater analyses in the San Luis Subbasin are all less than 50 mg/L Cl. Groundwater in the Upper Animas Subbasin is consistently less than 25 mg/L, representing the most dilute concentrations with respect to the chloride ion. Groundwater in the Lower Animas Subbasin has a greater range of chloride concentration, ranging from less than 25 mg/L Cl to greater than 250 mg/L Cl. Four samples in the Lower Animas Subbasin exceed the USEPA drinking water standard of 250 mg/L for chloride (Figure 7-6). These are located on the northwestern side of the Lower Animas Subbasin. Only two samples exceed the drinking water standard for chloride in the Lordsburg Subbasin. Most of the samples in the Lordsburg Subbasin are less than 100 mg/L Cl.

Sulfate concentrations in the Cloverdale (San Luis) Subbasin aquifer are less than 100 mg/L $SO_4$ (Figure 7-7). Sulfate concentrations in the Upper Animas Subbasin aquifer also are less than 100 mg/L $SO_4$, with a number of concentrations less than 25 mg/L $SO_4$. Most of the analyses in the Lower Animas Subbasin are greater than 100 mg/L $SO_4$. The sulfate map indicates that sulfate exceeds the recommended USEPA drinking water standard of 250 mg/L in 14 analyses in the Lower Animas Subbasin (Figure 7-7). Most of these are greater than 500 mg/L $SO_4$. Only a few analyses in the Lower Animas Subbasin are less than 25 mg/L $SO_4$. The Lordsburg Subbasin aquifer is also characterized by variable sulfate concentrations (Figure 7-7). Four analyses exceed the USEPA drinking water standard. About half of the analyses are greater than 100 mg/L $SO_4$. Only a few analyses are less than 25 mg/L $SO_4$.

### Saturation Indices

Saturation indices were computed for 34 groundwater analyses in the Upper and Lower Animas subbasins and for 9 analyses in the Lordsburg Subbasin (Figure 7-8). The geochemical code PHREEQC (Parkhurst 1995) was used to calculate saturation indices. The absence of temperature data did not allow us to compute saturation indices for the Cloverdale (San Luis) Subbasin.

PHREEQC analyses indicate that groundwater is typically at equilibrium with respect to calcite in the Animas and Lordsburg subbasins. Groundwater is close to equilibrium with respect to dolomite, although there is a wider range of values for dolomite saturation, especially in the Lordsburg Subbasin (Figure 7-8). Groundwater in the Animas and Lordsburg subbasins is moderately undersaturated with respect to gypsum. Some waters are close to saturation with respect to gypsum in the Animas Basin. Groundwater in the Animas and Lordsburg subbasins are greatly undersaturated with respect to halite. The interpretations in the Lordsburg Subbasin are based on limited data that may not necessarily reflect average saturation states in the basin.

### Origin of Solutes

The stiff map (Figure 7-4) and Piper plot (Figure 7-5) indicate an apparent evolutionary hydrochemical trend as groundwater flows north from the Upper Animas Subbasin

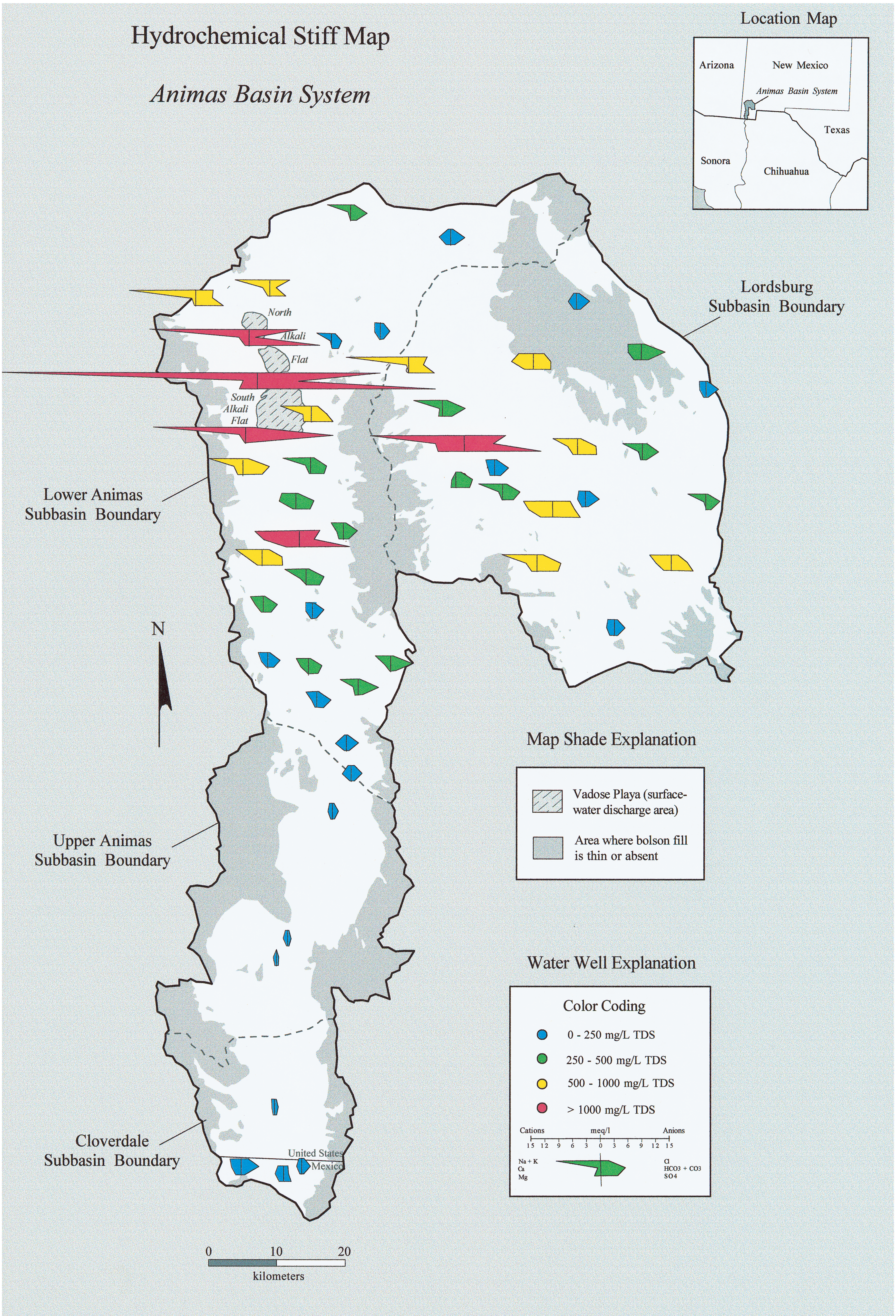



**Figure 7-4.** Hydrochemical stiff map for the Animas Basin System, showing stiff diagrams color coded by TDS ranges (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

# Hydrochemical Piper Plots - Animas Basin System

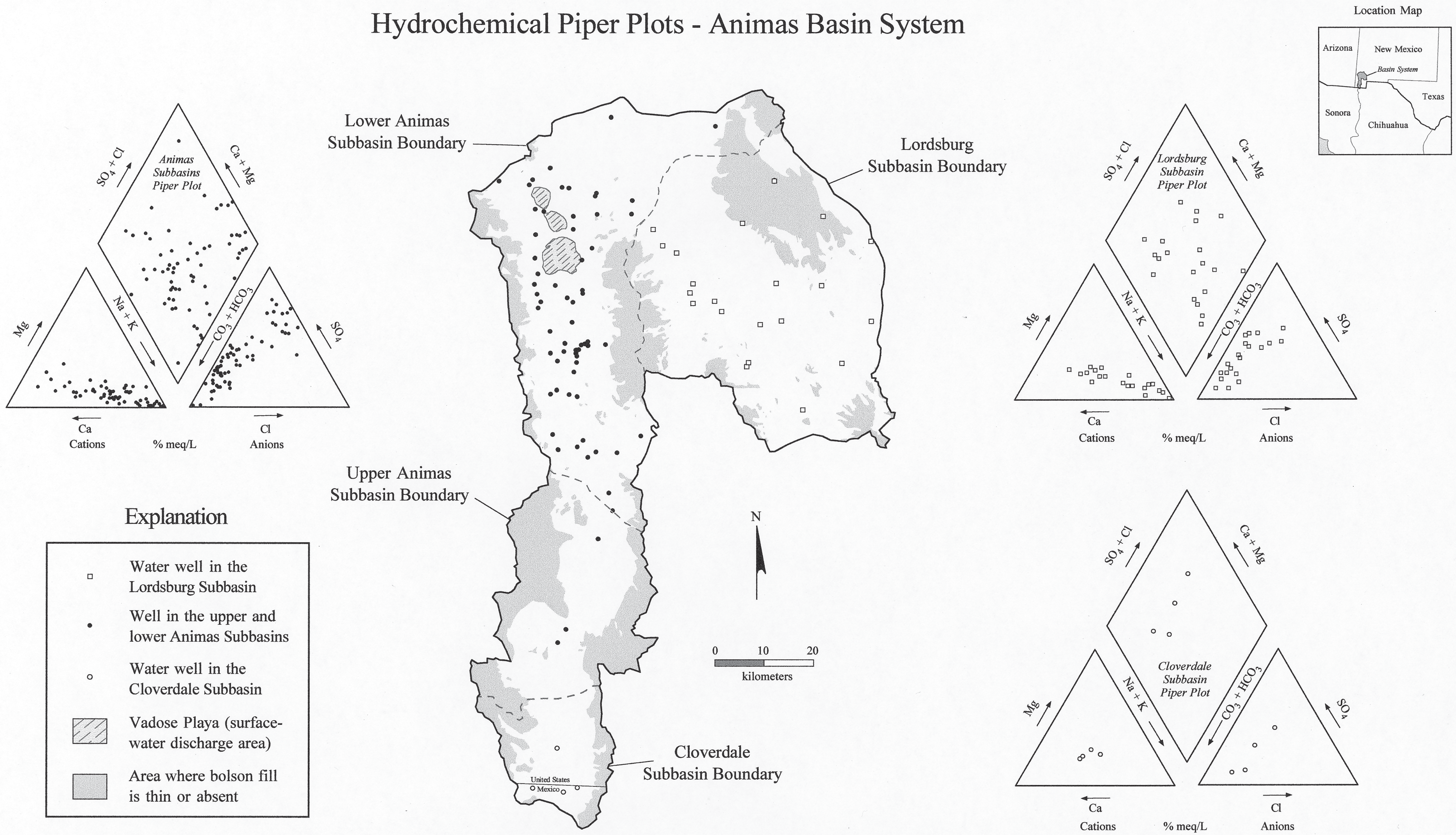



**Figure 7-5**. Hydrochemical Piper plots for groundwater in the Animas Basin System. These plots indicate variable hydrochemical facies and evolution from calcium and bicarbonate rich waters to sodium, sulfate, and chloride rich waters (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

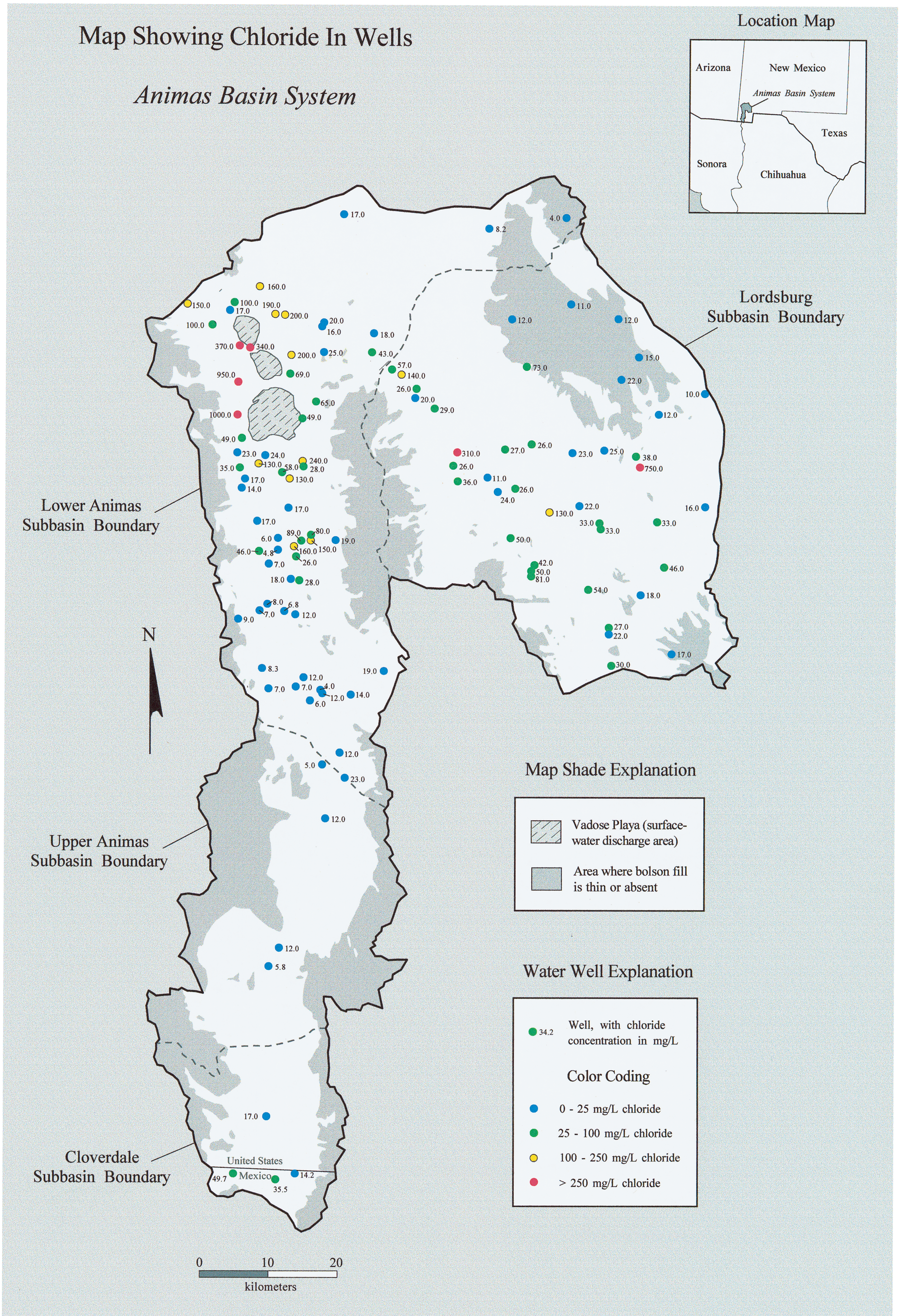



**Figure 7-6.** Map for the Animas Basin System, showing chloride concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

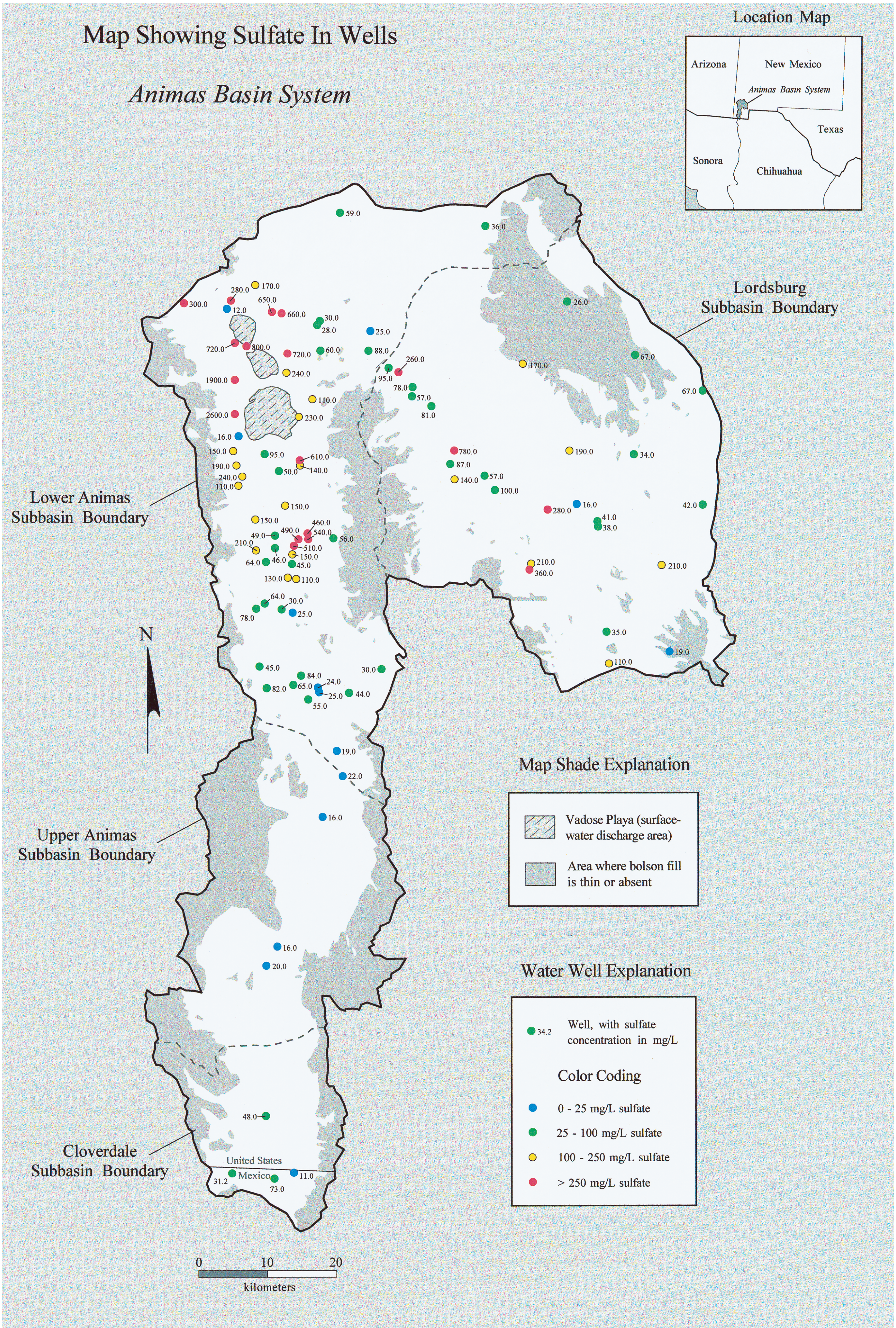



**Figure 7-7.** Map for the Animas Basin System, showing sulfate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

into the Lower Animas Subbasin. This trend is especially evident when the groundwaters in the Animas Basin are subdivided into three groups (Figure 7-9). The groundwaters evolve from calcium and bicarbonate rich waters in Group 1, to sodium, calcium, bicarbonate, and sulfate rich waters in Group 2, to sodium, sulfate, and chloride rich waters in Group 3. These changes suggest dissolution of calcite in the Upper Animas Subbasin, followed by the exchange of Ca for Na on clay minerals, and simultaneous dissolution of gypsum as groundwater moves northward into the Lower Animas Subbasin. Infiltration of runoff along flanking mountain fronts may dissolve chloride in soil profiles and carry the salts into the basin-fill aquifer.

Caliche and calcite cement in basin-fill probably account for much of the calcium and bicarbonate in groundwaters. Clay minerals are important weathering products and provide the exchange sites for divalent-monovalent cation exchange. Gypsum and some halite are present at and near Alkali Flats and accumulated as a result of evaporation of groundwater (Schwennesen 1918, Reeder 1957). Groundwater flowing through the Alkali Flat and adjacent areas redissolves the gypsum deposits and halite minerals. Small amounts of chloride probably also 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 the groundwater of the Animas Basin (Figure 7-8).

Hydrochemical trends are not easily recognized in the Lordsburg Subbasin due to irregular spatial variability of hydrochemical facies (Figure 7-4). The limited data and irregular trends do not allow us to evaluate the origin of solutes in the Lordsburg and Cloverdale (San Luis) subbasins.

**Irrigation Water Quality**

Groundwater in the Cloverdale (San Luis) Subbasin has low alkali hazard and low-to-medium salinity hazard (Figure 7-10). Groundwater samples in the Upper Animas Subbasin and southern half of the Lower Animas Subbasin (Animas Basin "south") generally have low alkali hazard and medium salinity hazard (Figure 7-10). Alkali and salinity hazards are frequently higher in the northern half of the Lower Animas Subbasin (Animas Basin "north"). Groundwater in the northern half of the basin is older and has dissolved evaporite minerals from regions at and near Alkali Flats. In the northern part of the basin, groundwater generally varies from low-to-very high alkali hazard, and from medium-to-very high salinity hazard. Groundwater samples in the Lordsburg Subbasin have mostly low alkali hazard and medium salinity hazard (Figure 7-10). A few samples have medium-to-very high alkali hazard and high-to-very high salinity hazard.

**Nitrate in Groundwater**

Nitrate is well below the USEPA drinking water standard in most of the groundwater samples collected in the Animas Basin system (Figure 7-11). Most samples have less than 1 mg/L $NO_3$-N. Only two analyses exceed the drinking water standard of 10 mg/L $NO_3$-N. These are located in the Lordsburg Subbasin. Nitrate data are concentrated in the central part of the Animas Basin, and are sparsely distributed in the Lordsburg and Cloverdale (San Luis) subbasins (Figure 7-11). More data are needed to verify the potential health risks to the residents in the area.

## SUMMARY

The Animas Basin system has no significant trans-international boundary component. The system is an interconnected group four geohydrologic subbasins that covers a watershed area of about 6,340 km$^2$ (2,448 mi$^2$), and a groundwater-flow system area of about 6,025 km$^2$ (2,326 mi$^2$). About 35 km$^2$ (14 mi$^2$) of the northwestern basin system is in Arizona, and 90 km$^2$ (35 mi$^2$) straddles the Chihuahua-Sonora border in the southernmost part of the area. Most of the surface watershed of 6,215 km$^2$ (2,400 mi$^2$) in New Mexico is in Grant and Hidalgo counties, with a small eastern border area that contributes some groundwater underflow across the Continental Divide into the Mimbres Basin system.

The entire area is in the Mexican Highland section of the Basin and Range physiographic province, and it comprises four subbasins and bordering mountain ranges. The north-south-trending, Lower Animas, Upper Animas and Cloverdale (San Luis) subbasin group on the west is bounded by the Peloncillo and Guadalupe mountain chain, which closely follows the New Mexico-Arizona border. The southeast-northwest-trending Lordsburg Subbasin is bounded on the northeast by the Big Burro uplift and on the southwest by the Pyramid Mountains. The latter range also separates parts of the Lordsburg and Lower Animas subbasins, which merge northwest of Lordsburg.

The Continental Divide forms the entire eastern border of the Animas Basin system, and in most places it marks the boundary between basin systems (Playas, Hachita Moscos, and Mimbres) with trans-international boundary aquifer components and groundwater-flow regimes that ultimately discharge to the Gila River Valley.

The *closed* and *drained* Cloverdale Subbasin at the southwestern end of the basin system has an area of about 480 km$^2$ (177 mi$^2$). This *bolson* landform is structurally open to the north and southwest. It is separated from the San Bernardino Basin to the west (Chapter 9) by the Guadalupe Mountains, and from the San Basilio Basin and Upper Playas Subbasin on the east (Chapter 6) by Sierra San Luis and the San Luis Mountains. The basin floor is the site of pluvial Lake Cloverdale and is now occupied by a large *playa* with both *vadose* and (perched) *phreatic* components. This suggests that some groundwater can discharge to both the Upper Animas Subbasin and the Rio San Bernardino Basin (to the southwest via Guadalupe Canyon and Cajon Bonito).

The Upper Animas Subbasin (*semibolson*) is an *open* and *drained* geohydrologic unit that contains the only perennial and intermittent streams in the basin system. The large watersheds in higher parts of the southern Animas and Peloncillo ranges that flank this subbasin are major contributors to both surface flow and groundwater recharge. The transitional boundary between the Upper and Lower Animas subbasins is located about 10 km (6 mi) south of Animas near the end of the entrenched valley Animas Creek.

The Lower Animas Subbasin (bolson), with an area of about 2,300 km$^2$ (847 mi$^2$), includes an extensive (Middle Pleistocene) basalt flow and broad alluvial flats, with shallow anastomosing channels of the lower Animas fluvial system in the Animas-Cotton City area. A very large playa-lake complex north of I-10 is the ultimate *sink* for much of the storm runoff in the basin system. The lowest part of the subbasin (1,259 m; 4,130 ft) is occupied by two large *vadose playas* (South and North Alkali Flats), and during wetter and cooler parts of the Lake Pleistocene basin-floor areas below an elevation of 1,279 m (4,196), about 388 km$^2$ (150 mi$^2$) were episodically inundated by pluvial Lake Animas. Lordsburg Draw, the ephemeral axial drainageway of Lordsburg Subbasin also contributes runoff to the South Alkali Flat area.

Prior to historic development of surface-water and groundwater resources for irrigation in the Upper and Lower Animas "Valleys" and western Lordsburg Subbasin a significant amount of groundwater discharged as underflow to the Gila River in the Lordsburg Mesa-Summit Hills area.

A wide variety of land use/landcover categories are present in the Animas Basin system. Rangeland is the major land use category with forest areas only located in the highest parts of the mountain ranges. Basin floors at the system's northern end include a mix of rangeland, sparsely vegetated to barren playas and dune lands, and the area's only sites of urbanization and irrigation agriculture. Lordsburg is the major urban center with the smaller communities of Animas and Cotton City located in the Lower Animas "Valley" agricultural area. Irrigated crop acreages in 1995 were reported at 411 hectares (1,015 acres) in the Lordsburg "Valley" and 2,963 hectares (7,322 acres) in the Animas "Valley." Reported groundwater pumped for irrigation in 1995 was 2.5x10$^6$m$^3$ (2,040 ac-ft) and 17.9x10$^6$m$^3$ (14,542 ac-ft) for the Lordsburg and Animas areas, respectively.

Climate of the Animas Basin system is arid to semiarid except in the highest parts of the San Luis, Animas, Guadalupe, Peloncillo and Big Burro ranges. At Animas (elev 1,346 m; 4,415 ft) average annual precipitation is 27.9 cm (11 in) and average class A pan evaporation is 253.2 cm (99.7 in). Higher parts of the Cloverdale and Upper Animas subbasins are significantly cooler and wetter than the Animas-Cotton City–Lordsburg area. Moreover, highlands flanking these subbasins also include large watersheds that contribute both runoff and mountain-front recharge to contiguous parts of the San Basilio and Upper Playas systems, and the San Bernardino Basin (Chapters 6 and 9). At Eicks Ranch (elev. 1,615m; 5,300 ft) near Cloverdale, average annual precipitation for a 27-year period was 38.2 cm (15.03 in).

The hydrogeologic framework of the Animas basin-fill aquifer system is controlled by a linked series of half-grabens and grabens with fill thicknesses probably not exceeding 600m (2,000 ft) as indicated by oil and gas exploration drilling and geophysical (seismic and gravity) surveys. East to northeast-tilted fault-block basins and ranges are the dominant tectonic features in the Cloverdale-Upper Animas and Lordsburg subbasin areas, respectively. Major basin structures in the Lower Animas Subbasin and northern end of the Upper Animas Subbasin appear to be full grabens, which define the deepest part of the Animas Basin system in the Cotton City-Alkali Flat area. Prominent basin-constrictions, and shallow depths to bedrock and older (lower Gila) basin fill in the Upper Animas and Cloverdale subbasins are associated with structurally high *accommodation zone* features that contribute to "perched-aquifer" conditions of the Animas Creek and Cloverdale Playa areas.

The primary aquifer system is formed by unconsolidated to partly indurated basin fill, which here includes surficial deposits of ancestral Animas Creek (RA, RAF), and basin-floor facies of Upper and Middle Gila Hydrostratigraphic Units (HSUs UG, MG). The aquifer system has unconfined, semiconfined and confined components. It is laterally extensive but quite variable in thickness.

## Saturation Indices

*Animas and Lordsburg Subbasins*

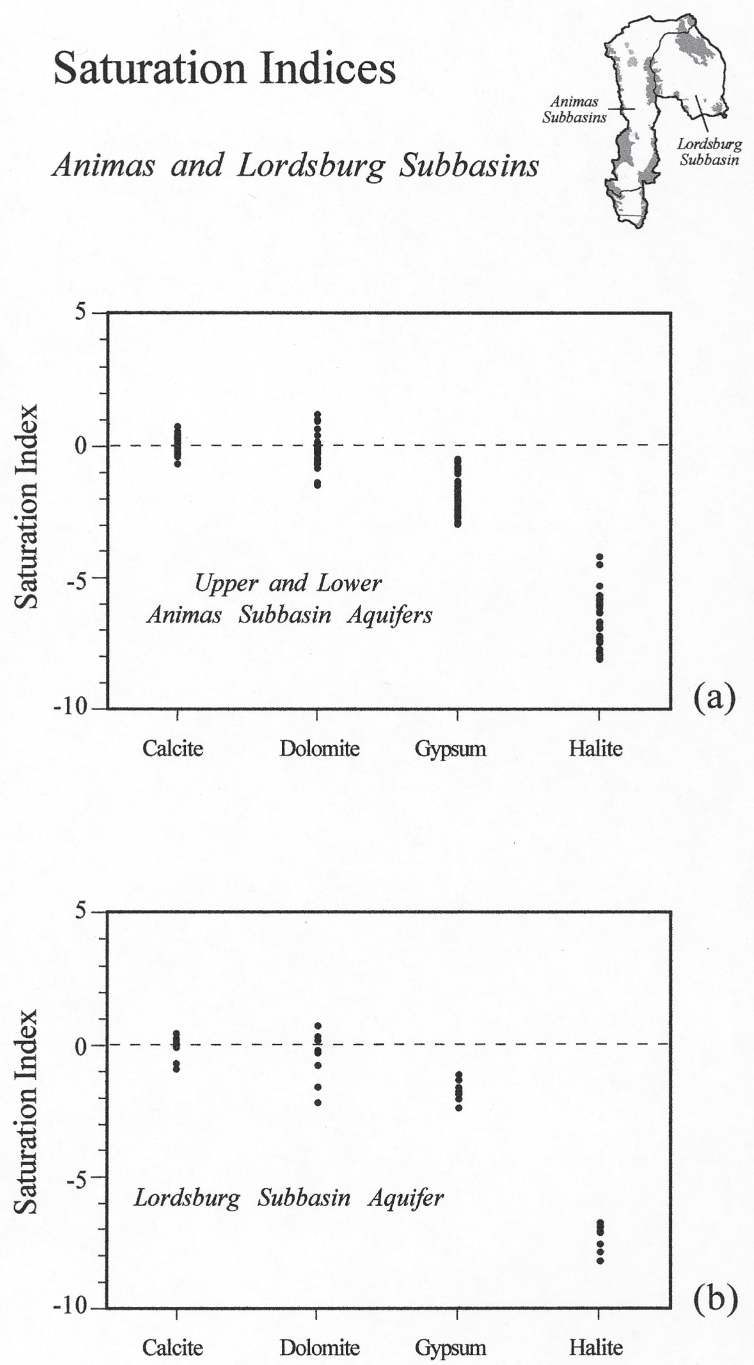



**Figure 7-8**. Range of saturation indices of calcite, dolomite, gypsum, and halite for the Animas (a) and Lordsburg (b) Subbasin aquifers.

## Groundwater Types And Evolutionary Trends In The Upper And Lower Animas Subbasins

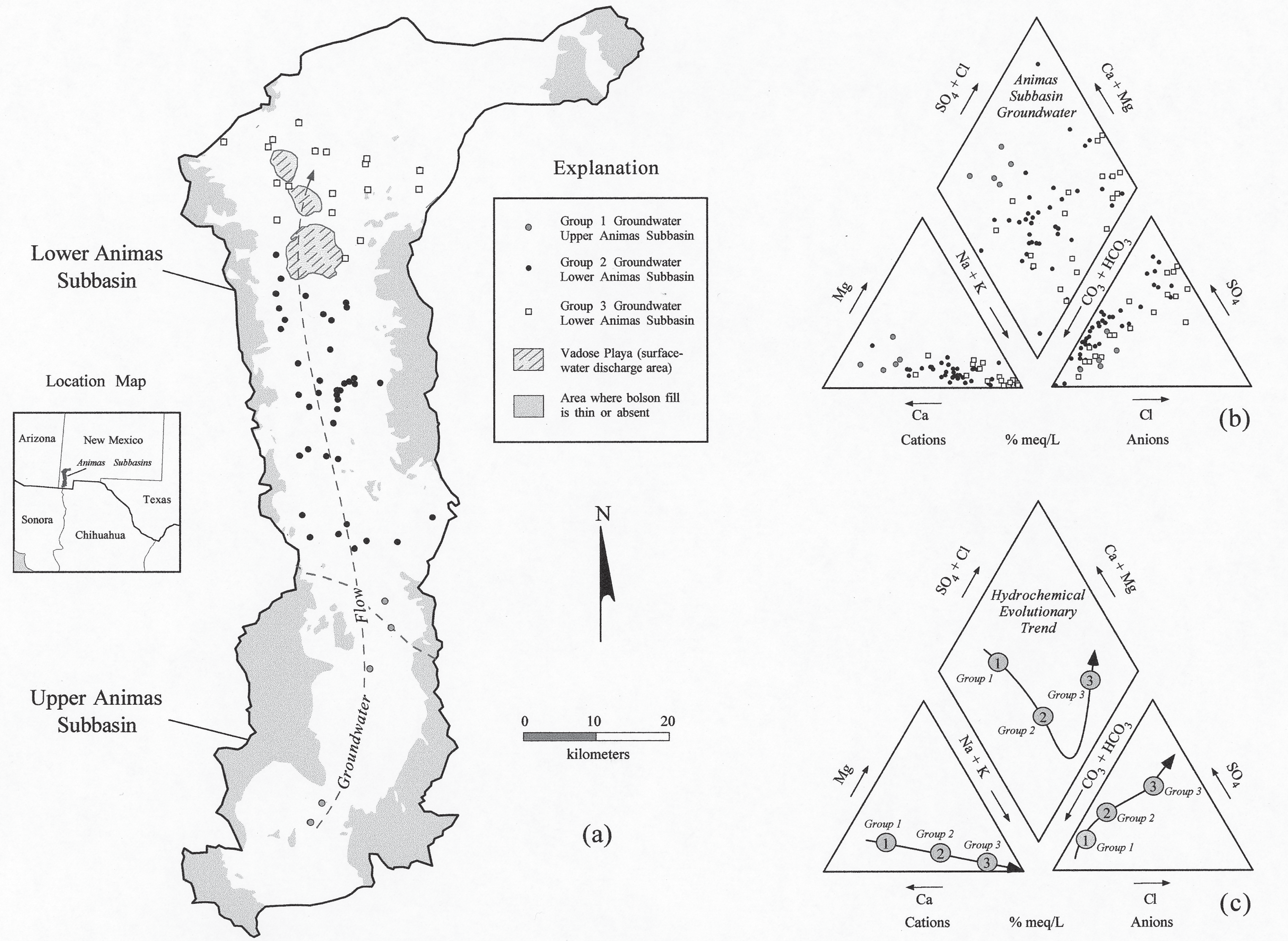



**Figure 7-9**. Hydrochemical plots for groundwater in the Animas Subbasins. Figure (a) shows well locations and direction of groundwater flow; (b) shows data for the Animas Subbasins plotted on a Piper plot for three groups of waters; (c) shows apparent evolutionary trends.

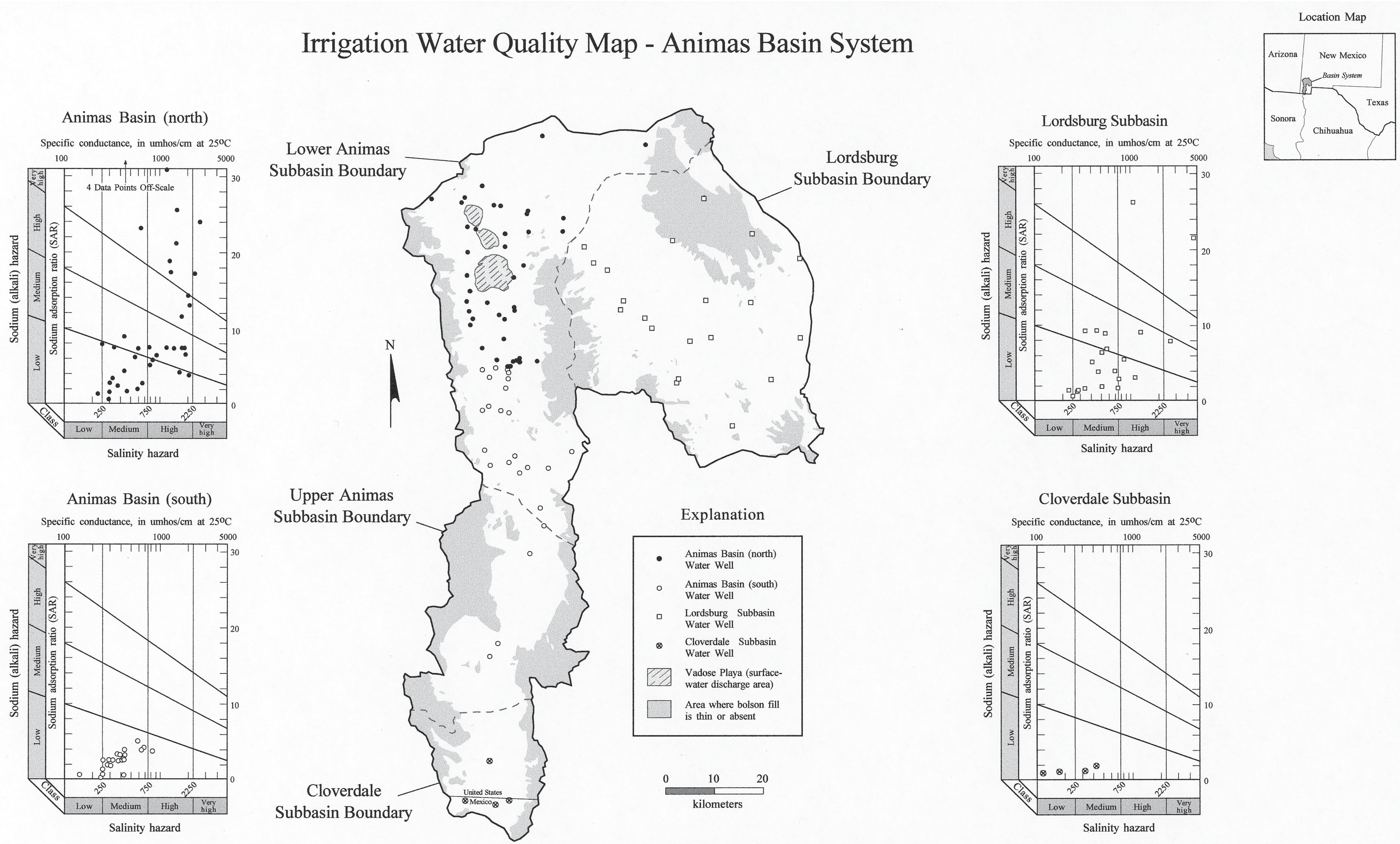



**Figure 7-10**. Irrigation water quality map for the Animas Basin System. These data indicate that water quality in these basins varies from good to marginal for most types of irrigation (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

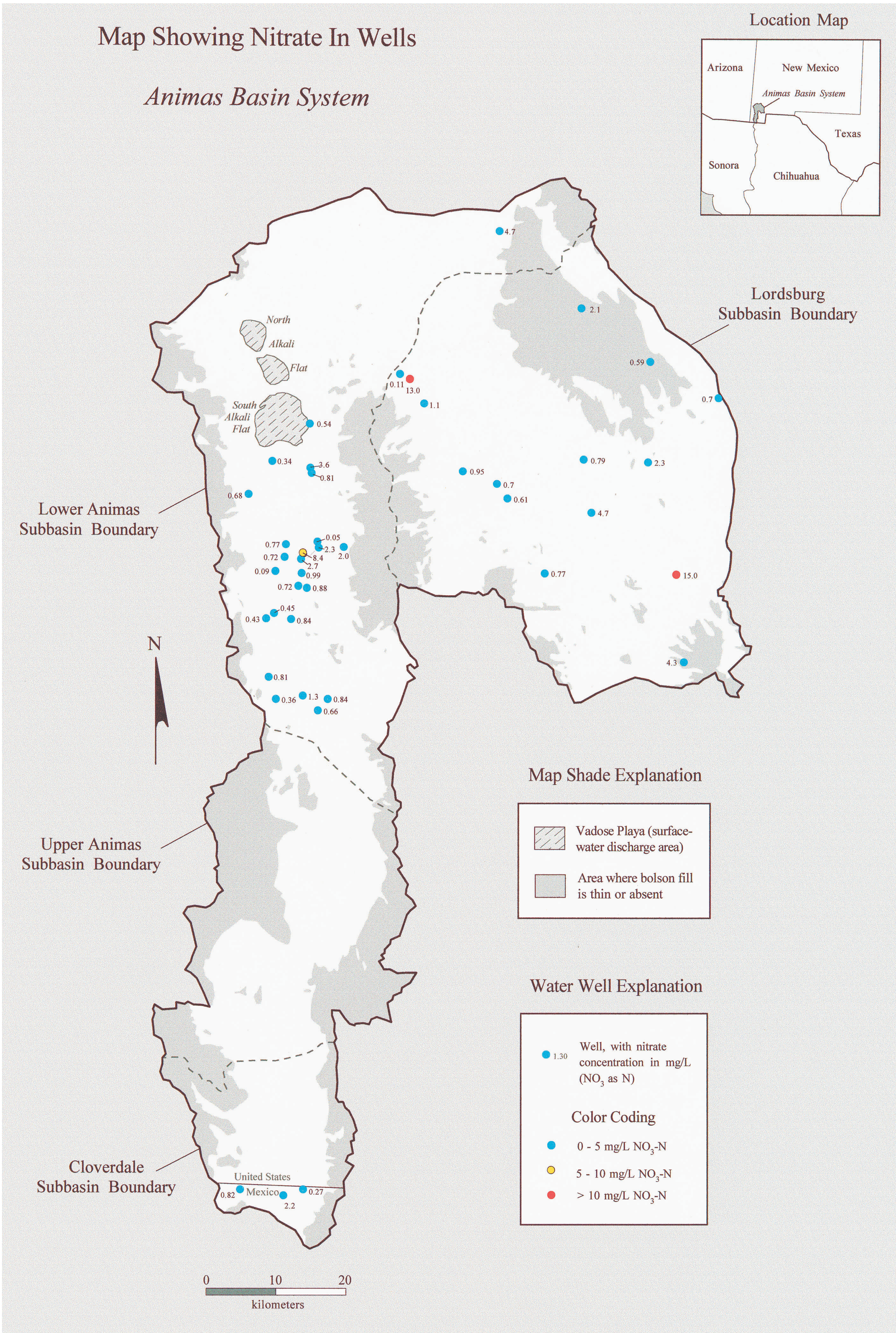



**Figure 7-11.** Map for the Animas Basin System, showing nitrate concentrations in water wells color coded by range (source of data: U.S. Geological Survey; Comision Nacional Del Agua; Instituto Nacional de Estadistica, Geografia e Informatica).

Underlying basin fill comprises well consolidated and partly indurated Middle and Lower Gila Hydrostratigraphic Units (MG, LG, MLG) that have very low hydraulic conductivities. Storage coefficients reflect semiconfined and confined aquifer conditions. A very liberal estimate of available groundwater of good quality that is stored in the Animas Basin aquifer system is about 1.2 x $10^{10}$m$^3$ (12 km$^3$; 9.5 x $10^6$ ac-ft).

The south-central part of the Lower Animas Subbasin (Cotton City area) 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, probably comes from the upper, poorly consoli-dated layer of basin fill, here correlated with post-Gila Animas Creek fan-delta deposits (HSU:RAF) and Upper Gila HSU:UG2-1. Published maximum discharge ranges for most of the wells in this area are 2,725 to 5,450 m$^3$/d (500 to 1,000 gpm). Calculated transmissivity values range from 273 to 3,059 m$^2$/d (2,940 to 32,890 ft$^2$/d or 22,000 to 246,000 gpd/ft) with an average T value of about 620 m$^2$/d (6,685 ft$^2$/d or 50,000 gpd/ft). The calculated average storage coefficient range for the unconfined part of the aquifer system is 0.07 to 0.14.

As has been observed in adjacent basin systems, only a small percentage of combined basinwide precipitation, runoff from adjacent highlands, and infiltration from axial drainageways contributes to recharge. A provisional estimate of annual recharge in parts of the Animas Basin system that contribute the bolson-plain area of the Lower Animas Subbasin is about 1.58x$10^7$m$^3$ (12,800 ac-ft).

Groundwater flow is generally northward in both the "perched" and "deep" aquifers of the Cloverdale and Upper Animas subbasins, and it continues through the Lower Animas Subbasin aquifer system toward the major center of irrigation agriculture between Animas and the Alkali Flats. Groundwater also flows northwestward toward this area through the Lordsburg Subbasin. In predevelopment time, a significant amount of underflow from the Alkali Flat (*vadose playa*) moved northward into the Virden-Duncan Subbasin of the Gila River Valley system. The published estimate of this outflow component is about 1.6x10m$^3$ (12,700 ac-ft). There is also probably a very small amount of outflow from the "deep" aquifer in the Cloverdale Subbasin that leaks southwestward across the International Boundary into the Guadalupe Canyon and Cajon Bonito drainages, which are tributary to Rio San Bernardino in Sonora.

A provisional estimate of northward predevelopment flow across the section of the Lower Animas Subbasin that includes the best documented productive aquifer in the basin system is about 7.3 x $10^6$m$^3$ (5,913 ac-ft) per year. This discharge rate is very close to published estimates of mountain-front and tributary recharge for the central Lower Animas Subbasin.

The total dissolved solid (TDS) content of groundwater sampled in the Cloverdale (San Luis) and Upper Animas subbasins are less than 250 mg/L, while water quality in the Lower Animas and Lordsburg subbasins is highly variable, ranging from dilute to moderately saline. Hydrochemical facies in the Animas Basin system are extremely variable, ranging from Ca-$HCO_3$ type waters in the basin's middle part, to Na-CL-$SO_4$ waters in the lower basin that have relatively high TDS. Na-CL-$SO_4$ waters in the Lordsburg Subbasin have TDS values sometimes exceeding 1,000 mg/L. Only four samples in the Lower Animas Subbasin (NW side) and two samples from the Lordsbrug Subbasin exceed the USEPA drinking water standard of 250 mg/L for chloride.

Sampled groundwater has low alkali and low-to-medium salinity hazards in the Cloverdale Subbasin, and it generally has low alkali and medium salinity hazards in the Lordsburg, Upper Animas, and southern Lower Animas subbasins. Groundwater in the northern half of the Lower Animas Subbasin is older and has dissolved evaporite minerals in the Alkali Flat area. In this area groundwater quality varies from low-to-very high alkali hazard, and from medium-to-very high salinity hazard. These data suggest that irrigation water quality is fair to good for most crop varieties in the Lordsburg Subbasin and southern half of the Lower Animas Subbasin.

Nitrate is well below the USEPA drinking water standard (10 mg/L $NO_3$-N) in most of the groundwater samples collected in the basin system. Most samples were less than 1 mg/L $NO_3$-N, with only two exceeding the USEPA standard near Lordsburg.