CHAPTER 8 – GILA RIVER BASIN SYSTEM

INTRODUCTION

The Gila River Basin system in New Mexico does not contribute to the transboundary aquifer systems in New Mexico and therefore is not covered at the level of detail of the other basins in the study area. Most of the basic concepts and interpretations of how groundwater-flow systems function in the intermontane basins of the transboundary region have already been described in considerable detail (Chapters 3 to 7). Discussions here will primarily focus on aspects of basin-fill hydrogeology and groundwater flow that distinguish the Upper Gila Basin system from the contiguous Mimbres and Animas Basin systems. Remick (1989) describes the general groundwater-flow system in the "Duncan-Virden Valley" of Arizona and New Mexico (Virden-Duncan Subbasin of this report, Figure 8-1) that is located in the downstream end of the Gila River Basin system covered in this Chapter. Water quality is also not discussed; however, an evaluation of the geochemistry of the Gila River regional groundwater system is included in Robertson (1991, Figure 14).

LOCATION AND PHYSIOGRAPHIC SETTING

Gila River System

This chapter emphasizes the hydrogeologic framework of the Upper Gila River Basin in the context of the geomorphic evolution of the Gila River Valley in New Mexico and adjacent parts of Arizona. The Gila River drainage basin comprises about 212,380 km^2 (82,000 mi^2) of the Basin and Range, Colorado Plateau, and Transition Zone physiographic provinces in the United States. It includes over half of the state of Arizona and small areas of California, Nevada, and New Mexico. The Gila River is joined by the Verde and Salt rivers west of Phoenix, by the San Pedro River near Winkelman, Arizona and the Santa Cruz River south of Phoenix on its way to join the Colorado River at Yuma, Arizona. The Upper Gila River watershed comprises about 33,411 km^2 (12,900 mi^2) in southwestern New Mexico and southeastern Arizona above Coolidge Dam (near San Carlos, Arizona). The basin covers about 14,504 km^2 (5,600 mi^2) in New Mexico (including the San Francisco River watershed). The portion of the Gila River system included in this study excludes the San Francisco River watershed and has a surface extent of about 9,300 km^2 (3,590 mi^2) (Figure 8-1).

Physiographic Setting

The headwaters of the Gila River are in the Datil-Mogollon section of the Transition Zone physiographic province and have an area of about 7,780 km^2 (2,645 mi^2). The (informal) Upper Gila Subbasin unit shown on Figure 8-1 is located in the Datil-Mogollon section, as are the northern parts of the Cliff Redrock and Virden-Duncan subbasins to the west. Only the low lying southern part of the basin system is in the Basin and Range province. The southern Cliff-Redrock and Virden-Duncan subbasins and the entire Mangas Subbasin are in the Mexican Highland section, which covers an area of about 1,520 km^2 (945 mi^2) in New Mexico.

The southeastern, eastern and northern parts of the Gila River Basin are bounded by the Continental Divide and are adjacent to the Mimbres, Rio Grande, and San Agustin basin systems. Major highlands along the Continental Divide include parts of the Big and Little Burro uplifts, the Silver City, Pinos Altos and Black ranges, as well as the high plateaus and ranges of the northeastern Mogollon-Datil volcanic field. Major peaks on or near the Continental Divide are Reeds Peak (elev. 3,051 m; 10,011 ft) in the Black Range, Black Mountain (elev. 2,751 m; 9,025 ft) in the Pinos Altos Range, and Pelona Mountain (elev. 2,805 m; 9,204 ft). Highlands in the western portion of the basin system include the Mogollon Range, Summit Mountains, Northern Big Burro uplift, Mule Mountains, and the Black and Summit Hills (Figures 8-1 and 8-2). Whitewater Baldy in the Mogollon Mountains (elev. 3,320 m; 10,892 ft) is the highest peak in the basin system.

The perennial Gila River flows for most of its course through a series of alluviated troughs outlined principally by north or northwest trending mountain ranges that alternate with narrow canyons. Narrow strips of alluvium (Figure 8-2) exist along the River and its tributaries. In New Mexico, wider valley segments are present near Cliff, Redrock, and Virden and have been developed locally for irrigation agriculture. Major tributaries to the Gila River in New Mexico (from west to east) are Carlyle Canyon, Blue Creek, Mangus Creek, Duck Creek, Bear Creek, Mogollon Creek, Sapillo Creek, Beaver Creek, and the West and Middle Fork (USDA 1954). In the Upper Gila Subbasin mountains and high plateaus form a much larger part of the watershed than the valleys, which commonly include deep canyon segments. Valley floors range from about 2,033 m (6,670 ft) in the upper river basin at Beaverhead to about 1,500 m (4,920 ft) at the mouth of the Gila River Canyon above Cliff (Gila River-Mogollon Creek confluence) (Figure 8-2). Near the New Mexico-Arizona stateline at Virden, the Gila Valley floor elevation is about 1,152 m (3,780 ft), and the low point on the Animas-Gila basin system divide in the Lordsburg Mesa-Summit Hills area is 1,292 m (4,239 ft).

Land Use

The two major land use/landcover categories in the Gila River Basin system are extensive forest areas at higher elevations, primarily in the Upper Gila Subbasin and Big Burro Mountains, and rangeland in most of the remaining area (Figure 8-1). Small urban communities are present in only two places along the Gila River Valley, in the Gila-Cliff area and at Virden. Most cropland is located in the Virden Valley, and near Buckhorn and Cliff. Cropped acreages in these areas were reported at 817 hectares (2,019 acres) irrigated in 1995. Water use for this cropland was reported at 3.6 x 10^6 m^3 (2,924 ac-ft) from surface water sources and 2.33 x 10^6 m^3 (1,887 ac-ft) from groundwater sources (Wilson 1997).

Climate

Average annual precipitation ranges from about 23.1 cm (9.1 inches) at the Virden station to 41.7 cm (16.4 inches) at the Gila Hot Springs station, elevation 1,707 m (5,600 ft) in the upper Gila River Canyon (NCDC 1999). The station at Buckhorn (elev. 1,463 m; 4,800 ft) reported average annual precipitation of 35.1 cm (13.8 inches). Cliff (about 13 km [8 mi] southeast of Buckhorn near the Gila River) reported 36.8 cm (14.5 inches). Redrock, which is north of Lordsburg and east of Virden, reported average annual precipitation of 32.8 cm (12.9 inches) over the 1958-1996 period. Nearly half of the annual precipitation is from thunderstorms that occur from July through September (NCDC 1999). Significant winter precipitation, however, is recorded in the Continental Divide area, amounting to about 35% of the average annual precipitation of 51 cm (20 in) measured between 1929 and 1973 at the Pinos Altos station (elev. 2,134 m; 7,000 ft) on the Gila-Mimbres basin border (Gabin and Lesperance 1977).

The average mean air temperature at Redrock for the period 1958-1996 is reported at 15.1° C (59.1° F). Temperatures are cooler at the Cliff station which reported a mean of 13.5° C (56.3° F) and the Gila Hot Springs station reported a mean of 11.6° C (52.9° F) (NCDC 1999).

HYDROGEOLOGIC FRAMEWORK

Introduction

Lithostratigraphic units in the Gila River Basin system range in age from Quaternary to Precambrian (Figure 8-2 and Plate 1). Quaternary and Neogene basin-fill and local interbedded volcanics comprise the most extensive aquifer system, and they are subdivided into the major hydrostratigraphic-unit classes described in Chapter 3 (Figure 3-5, Tables 3-2 and 3-3). Previous workers have included most of this material in the Gila "Conglomerate" of Gilbert (1875) and in more broadly defined Gila Group units. As emphasized in Chapter 3 (Figure 3-5), Gila Group lithostratigraphic terminology varies greatly throughout the region (cf. Trauger 1972, Seager et al. 1982, Seager 1995, Drewes et al. 1985, and Clemons 1998). However, most investigators have made a clear distinction between (1) upper, poorly-consolidated basin-fill deposits, with thicknesses in the 100 to 300 m range (330 to 990 ft), and (2) lower conglomeratic units that are locally as much as 1,000 m (3,280 ft) thick. The lower, partly indurated zone is commonly designated the Gila Conglomerate even though much of this older basin-fill is made up of sandstones and mudstones (e.g., QTg map-unit of Hanson et al. 1994 in the Mimbres Basin system). Clemons (1982, 1984, 1998) recommended that the bulk of the younger basin-fill (which is mostly poorly consolidated alluvium of Pliocene to Early Pleistocene age) be included in an informal Upper Gila Group mapping unit, the Mimbres Formation, while Seager (1995) maps this formation as a formal lithostratigraphic unit. Trauger (1972, p 40-43) also recognized informal "upper and lower parts" of the Gila Conglomerate in both the Gila River and Mimbres Basin systems. Trauger's "upper Gila" unit comprises poorly consolidated, younger basin-fill that appears to correlate with Seager's (1995) Mimbres Formation.

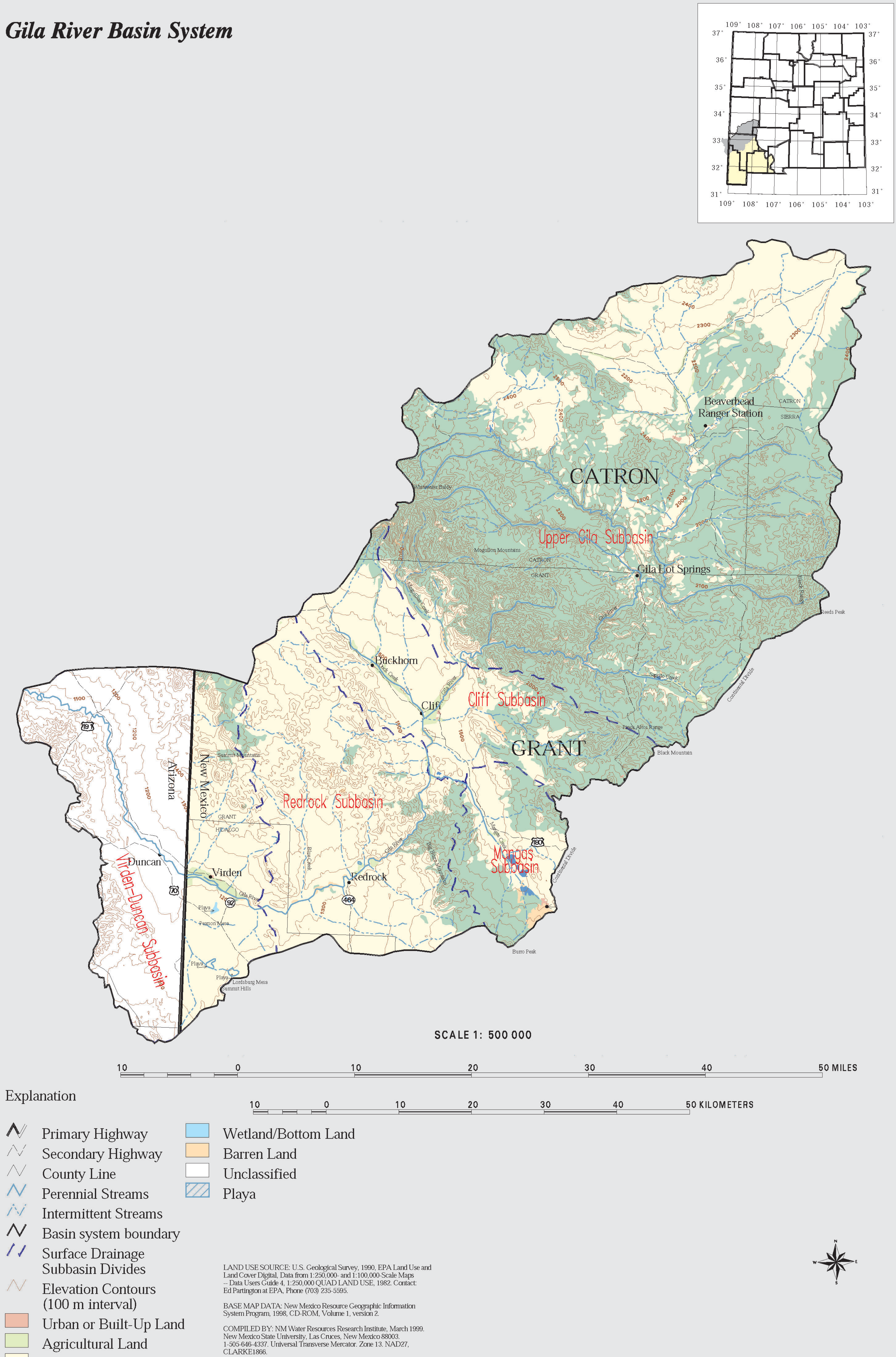
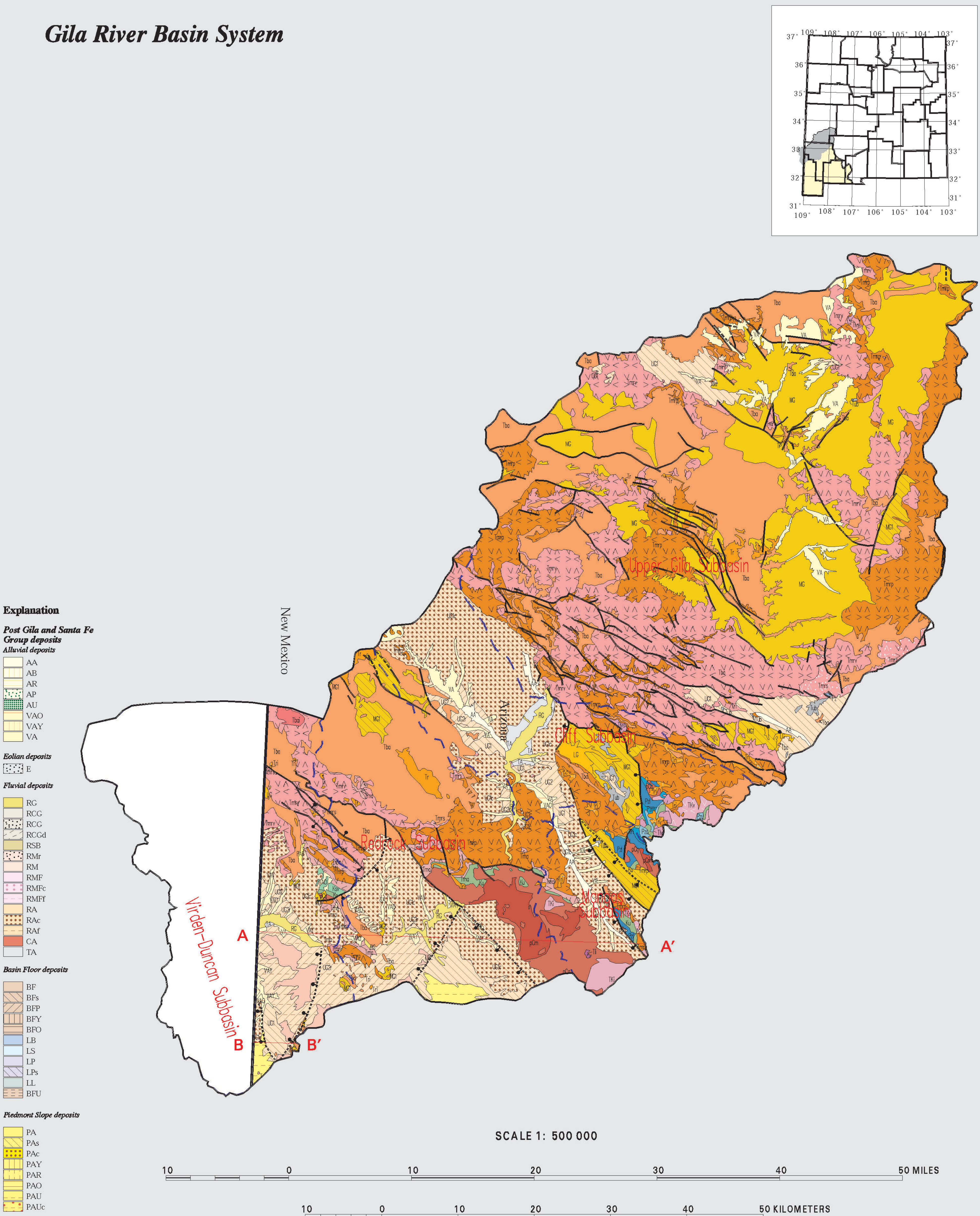


Figure 8-1. Land use in the Gila River Basin System.

Gila River Basin System



GEOLOGY SOURCE:

Geologic data for the United States were transcribed from:

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

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

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

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

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

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

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

Figure 8-2. Hydrogeologic map of the Gila River Basin System.

Basin-Fill Aquifer Systems

Major Hydrostratigraphic Subdivisions

The hydrostratigraphic-unit classification of the Gila Group used in this report (including HSUs: LG, MG, UG) provides a logical mechanism for subdividing basin-fill deposits into mappable units, thus facilitating geohydrologic characterization of basin-fill deposits and determination of their aquifer potential. The surficial layer of Upper Quaternary valley fill associated with larger stream systems (including deposits of the Upper Gila River, and Sapillo, Mogollon, and Duck creeks) is also recognized by most workers. This shallow aquifer unit, with saturated thicknesses of up to 30 m (100 ft), is locally also an important recharge zone. Hydrostratigraphic units RG and AA are the major components of surficial alluvial deposits designated Qal by Trauger (1972).

Major Lithofacies Assemblages

Lithofacies assemblages described in Chapter 3 (Figure 3-6, Tables 3-4 to 3-6) are the basic building blocks of the individual hydrostratigraphic units that form the basin-fill aquifer system. The explanation of Plate 1 provides a key to the lithofacies composition of the hydrostratigraphic units that are schematically depicted on hydrogeologic maps and cross sections in this report. As illustrated on Figure 8-2 and Plate 1, coarser-grained piedmont-slope facies assemblages (*5-8*) in hydrostratigraphic units: UG1, MG, and LG are the major basin-fill components in the western part of the basin system (most of the Cliff and Mangas subbasins, and parts of the southern Redrock and Virden subbasins). Sandy to clayey basin-floor facies (*1-3, 9, 10*) in hydrostratigraphic units: UGL and UG2 form most of the exposed Gila Group in the southernmost Redrock and Virden-Duncan subbasins.

Emphasis here is on the fact that the upper part of the basin-fill sequence (primarily Middle and Upper Gila hydrostratigraphic units) and overlying surficial deposits of the Gila River Valley system) include a gradually increasing amount of fluvial (facies *1-3, a*), and playa lake (*9, 10*) deposits as one moves southwestward along the dominant groundwater-flow paths toward the New Mexico-Arizona border (Figures 8-2, 8-3). Furthermore, with the exception of local aquifers in interbedded, basaltic volcanics (units Tba and Tub), overall permeability of the entire basin-fill sequence decreases with depth, primarily due to increases in consolidation and cementation, and increasing proportion of fine-grained material (e.g., transition from facies assemblages *1* and *2*, through *3* and *4*, to *9* and *10*; and gradation from facies *5* and *6* to *7* and *8*). Permeability decreases are also associated with lateral transitions from basin-floor to piedmont-slope facies assemblages (e.g., facies *1-4* to *5* and *7*). Hydraulic property characteristics of Gila Group aquifer systems are further discussed in Chapter 4.

Geomorphic Evolution of the Gila River Valley System

Introduction

The distinguishing hydrogeologic feature of the Gila River Basin system is the deeply entrenched network of valleys and canyons cut by the Gila River and its major tributaries. Except in the southern Virden-Duncan subbasins, Upper Gila Group and younger basin fills, which form the major aquifer in the Mimbres and Animas Basin systems (Chapters 4 and 7), are primarily in the vadose zone. In fact, the entire Gila Group only serves as a major aquifer-system component in the Cliff and Mangas subbasins and the southern parts of the Redrock and Virden-Duncan subbasins. The hydrogeologic significance of the river valley system discussed here relates to the fact that deep valley and canyon incision during the past several million years has created a regional *sink* for groundwater *draining* from bedrock and basin-fill aquifers west of the Continental Divide.

Datil-Mogollon Section-Cliff Subbasin Area

Geologic mapping (Figure 8-2 (Leopoldt 1981) in the southern part of the Datil-Mogollon Section documents the final phases of basin aggradation and formation of an integrated upper Gila fluvial system in Pliocene to Early Pleistocene time. The area described includes the segment of the Cliff Subbasin crossed by the Gila River between the mouths of Mogollon Creek and Mangas Creek and adjacent parts of the Mangas Subbasin (Trauger 1972). Younger basin-fills ("upper" Gila Group) contain Hemphillian and Blancan mammalian faunas and volcanic ash beds of Late Miocene to Late Pliocene age (Leopoldt 1981, Tedford 1981, Brooks and Rattè 1985, Drewes et al. 1985). Farther downstream near Red Rock, Lava Creek B Ash (about 0.66 Ma) has also been identified in an ancestral Gila River channel fill that post dates these deposits (Izett and Wilcox 1982, NM Site 5). Basin floors appear to have been occupied first by ephemeral saline-alkaline lakes and finally by a system of shallow freshwater(?) lakes and marshes, with flooding culminating in Late Pliocene or Early Pleistocene time. Uppermost Gila Group deposits are locally preserved about 215 m (700 ft) above the Gila River floodplain in the central part of the Cliff Subbasin. According to Morrison (1965) and Leopoldt (1981), this lacustrine/cienega system ultimately drained into the Virden-Duncan subbasins in the Mexican Highland section through the Middle Gila Box (Redrock Subbasin) northwest of the Big Burro Mountains (Figures 8-1 and 8-2).

Subsequent incision of Gila Group basin fill in the Cliff and Mangas subbasins has produced a prominent stepped sequence of valley-border surfaces above the floodplains of the Gila River and its major tributaries including Bear, Duck, Mangas, and Mogollon creeks (Leopoldt 1981). One Early(?) to Middle Pleistocene "fan-pediment" surface, which caps the large fan complex of ancestral Mogollon Creek, and two Middle Pleistocene "pediment-terraces" are graded to former Gila River base levels from about 150 to 90 m (500 to 300 ft) above the present floodplain. At least two inset river terraces of Middle to Late Pleistocene age range from 45 to 20 m (150 to 65 ft) above the valley floor. Gravelly fill of the 20 m (65 ft) terrace can be as much as 20-m (65 ft) thick according to Leopoldt (1981). He also describes a poorly-defined fill terrace of possible Holocene age about 6 m (20 ft) above the Gila River floodplain, and he notes that the youngest valley fill below the floodplain can be as much as 30 to 35 m (100 to 150 ft) thick. Only the most extensive terrace deposits (HSU: TA, facies *a*) are shown on Plate 1 and Figure 8-2. While small "perched aquifer" zones locally occur in basal terrace fills, nearly all of these deposits are in the vadose zone.

High-level (+225 m to 335 m; 740 to 1,100 ft) "pediment-terrace" deposits of the Late Pliocene to Early Pleistocene "upper" Gila Group are offset about 110 m (360 ft) along the Mogollon fault zone. This zone forms the topographic boundary between the Cliff and Upper Gila subbasins (Figures 8-1, 8-2), and it also separates the central Mangas structural basin of Trauger (1972) from the Mogollon Mountain block to the northeast (Ratté and Gaskill 1975). The youngest documented faulting in the area (Leopoldt 1981) is a ~3 m (10 ft) offset (along an intra-basin fault) of the youngest Middle Pleistocene "pediment-terrace" surface (about 90 m [300 ft] above Gila River base level).

Datil-Mogollon Section-Upper Gila Subbasin

Additional information on styles and rates of valley entrenchment in the southern Datil-Mogollon section and the Upper Gila Subbasin (Figure 8-1) is provided by a detailed study of the geomorphology and soils of pre-historic agricultural sites on terraces along Sapillo Creek near Lake Roberts (Sandor 1983, Sandor et al. 1986). The creek is a headwaters tributary of the Gila River. Lake Roberts is about 60 km (35 mi) up canyon from the Cliff Subbasin, and is 10 km (6 mi) west of the Continental Divide and the headwaters of the Mimbres River. In the context of this study, it is important to note that uppermost reaches of Mangas and Sapillo creeks appear to have drained to the northern Mimbres Basin system in Late Miocene to Early Pliocene time.

Floodplain deposits of Sapillo Creek are thin (probably less than 5 m, 16 ft) and the longitudinal valley profile includes bedrock-controlled nickpoints. Valley-border surfaces studied by Sandor (1983, Sandor et al. 1986) include a stepped sequence of 5 erosion surfaces that range from 8 m to 60 m (25 to 200 ft) above the floodplain. Surfaces are cut on Lower Gila Group sandstone, mudstone, and conglomerate (cemented by zeolite minerals). Gravelly fills capping these (post-Gila Group) pediment and strath-terrace surfaces are less than 5 m (16 ft) thick. Soils of the four higher surfaces, grading to base levels 12 m (40 ft), 18 m (60 ft), 30 m (100 ft), and 50 to 60 m (165 to 200 ft) above the floodplain, have distinct argillic horizons and are considered to be of Pleistocene age. A horse skull (<u>Equus Conversidens</u>) collected from deposits of the 18 m terrace is probably of pre-Wisconsin, Late Pleistocene age (~100 ka; Wolberg 1980). Well-developed, clay-rich argillic horizons in soils of prominent surfaces at +30 m (60 ft) and +50 to 60 m (165 to 200 ft) indicate that terrace fills date from the Middle Pleistocene and could be as old as 200 to 400 ka (Sandor et al. 1986). As is the case in the Cliff Subbasin, essentially all terrace fills are in the vadose zone, but small "perched aquifer" zones may locally be present.

Higher valley-border surfaces have not been mapped in detail, but the inferred age of deposits on surfaces about 100 m (330 ft) above Sapillo Creek is Early to Middle Pleistocene. Thick gravelly deposits, here considered to be of Pliocene age, cap the highest erosion surfaces along canyon reaches of Sapillo Creek and the Gila River, respectively, about 8 to 16 km (5 to 10 mi) above the confluence of the two streams. These surfaces are 250 to 350 m (820 to 1,150 ft) and about 600 m (2,000 ft) above floodplain level. They are cut on Middle Tertiary volcanics as well as on Lower to Middle Gila Group (LG, MG) sandstone and conglomerate that is locally interbedded with basalt and basaltic andesite (Tba) of Miocene age. The highest surface predates canyon entrenchment. Deposits capping erosion surfaces more than 100 m (330 ft) above valley and canyon floors of the Gila River-Sapillo Creek system are here correlated with Upper Gila Hydrostratigraphic Units UGl and UGlc, but all these surficial materials are in the vadose zone.

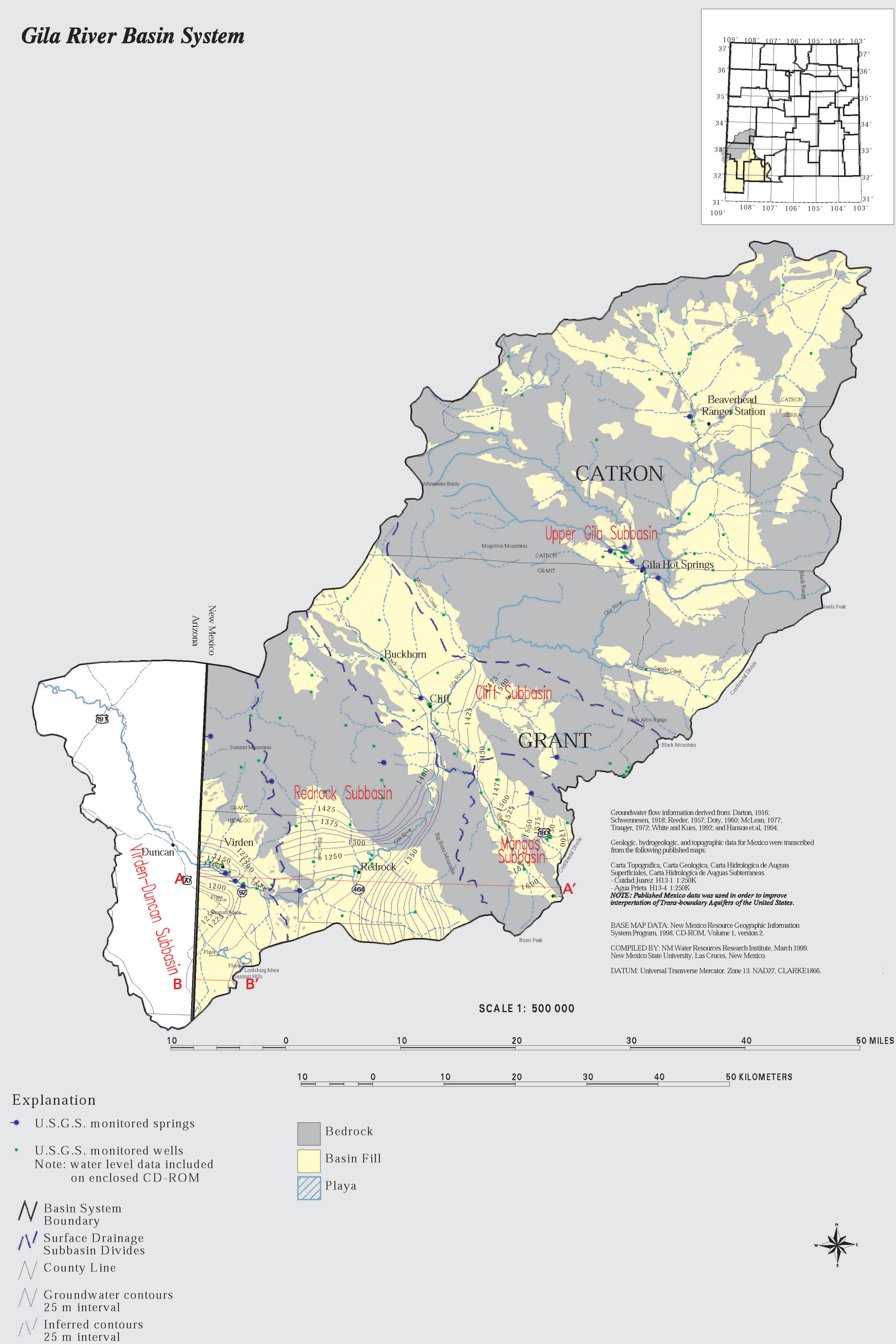


Figure 8-3. Gila River Basin groundwater contours, flow direction, and stream- aquifer relationships.

Mexican Highland Section

The Gila River enters the Mexican Highland section near Red Rock (in the south-central part of the Redrock Subbasin) after emerging from canyons through the northern Burro uplift (Figures 8-1, 8-2). The river then follows a zigzag-westward course into eastern Arizona through a series of deep valleys (Virden-Duncan, Safford, San Carlos) and intervening canyons cut across major Basin and Range structural blocks. West of the study area, larger northern tributaries (San Francisco and San Carlos rivers, and Eagle and Bonita creeks) originate in the flanking highlands of the Transition Zone province. Early work on Quaternary and Neogene stratigraphy and geomorphic evolution of parts of the Virden-Duncan and Safford "Valley" areas of the Gila River Basin includes studies by Fair (1961), Morrison (1965), Melton (1965), and Cooley (1968, 1977).

Much of the emphasis of recent research has been on the biostratigraphy, magnetostratigraphy and tephrochronology of fossiliferous basin-floor facies of Upper Gila Group basin-fill exposed in the Safford (northern San Simon Basin), and Virden-Duncan valleys (Tedford 1981, Galusha et al. 1984, Lindsay et al. 1984). The fine- to medium-grained (Upper Gila) facies are for the most part, deposited on broad alluvial plains, in complexes of ponds and marshes (cienega environments), and in ephemeral-lake depressions (playas). The other major component of this *bolson* facies assemblage comprises coarse-grained alluvial and debris-flow deposits of piedmont slopes flanking adjacent Basin-Range blocks. Until very recently the bulk of these sediments were considered to be of Early to Middle-Pleistocene age (1.8 ma). However, Upper Gila Group units are now known to be as old as Late Miocene (more than 5 ma) in many places based on radiometric ages of interbedded basalts and volcanic ash (tephra), and biostratigraphic correlations.

The only detailed mapping of younger basin fill in the area (also involving studies of soil-geomorphic relationships) was done by Morrison (1965) in the Gila River Basin area near Virden, New Mexico and Duncan, Arizona (Figure 8-1). The oldest piedmont gravels (Morrison's Unit 6) are locally more than 15 m (50 ft) thick. They cap a high-level erosion surface (pediment) cut on "Gila Formation" basin-fill north of Red Rock and grade to reconstructed basin-floor levels as much as 140 m (460 ft) above the present Gila River floodplain. Geomorphic position and relict soils with strong petrocalcic horizons (stage IV-V of Machette 1985) suggest an Early Pleistocene or Late Pliocene age for these Upper Gila deposits, which are here mapped as part of hydrostratigraphic unit (HSU) UGlc.

Extensive, but thin gravel and sand deposits (Morrison's Unit 5) cap basin-floor remnants, including Lordsburg and Pearson mesas south of Virden (Figure 8-1), which are from 110 m (360 ft) to more than 125 m (410 ft) above the present Gila River floodplain. Relict soils on stable parts of these tablelands also have well-developed petroclacic horizons. These ancient basin-floor surfaces and soils (map unit UGL, Plate 1) surround the Summit Hills area (Chapter 7) and overlie the zone of underflow-discharge from the Lower Animas Subbasin aquifer system.

Morrison (1965) subdivided the central-basin facies of his Unit 5 into (1) "a low-gradient alluvial fan delta of the ancestral Gila River that extended over most of Lordsburg and Pearson Mesas", and (2) a "high-shore" gravel of the first deep Quaternary lake in his "Duncan Basin." Both subfacies contain abundant, rounded gravel derived from upriver sources in the Datil-Mogollon section (see previous discussion of Cliff Subbasin area). At Nicolas Canyon, Yellowstone-derived volcanic ash tentatively identified as (~0.66 Ma) Lava Creek B by Izett and Wilcox (1982) locally occurs at the base of fluvial gravels in a channel cut into older (pre-Gila Group) volcanic and sedimentary rocks (T. Finnell, written communications, 1986). This ancestrial Gila Valley fill is inset as much as 60 m (200 ft) below mesa capping gravels of Morrison's Unit 5 "high shore" facies.

Morrison (1965) also mapped a stepped-series of "pediment-terrace" gravels that are associated with valley-border surfaces, respectively, about 65-70 m, 40-45 m, 25 m, and <14 m (215-230, 130-150, 80, <46 ft) above the Gila floodplain. Morrison (1965) suggested that parts of the two higher valley-border surfaces are capped with lake gravels (units 4 and 3), and he further inferred that his older "lake-gravel" (sequence 5 to 3) was of Early to Middle Pleistocene age. Morrison's (1965) lower two terrace fills (Units 1 and 2) were mapped as river gravels of Late Pleistocene age.

Gila River and tributary arroyo deposits below the modern Virden-Duncan and Safford Valley floors are as much as 34 m (110 ft) thick. Valley-fill thickness is about 23 - 24 m (75 - 78 ft) beneath broader floodplain areas according to Fair (1961) and Morrison (1965). Fair (1961, p. 128) suggests that a shift from river downcutting to valley aggradation may have occurred about 11,000 years ago in response to a "world-wide shift toward a drier climate." *Note that the coarse-grained fluvial-channel fills in the Cliff to Safford reach of the Gila River Valley (HSU: RG; facies a1 and 2) are the major aquifer units of this part of the study area.*

Morrison (1985, p. 136-137), suggested that both the Virden-Duncan and Safford basins were internally drained through "Early-Middle Pleistocene" time and that very large and deep lakes inundated basin floors to present elevations as high as 1,200 to 1,340 m (3,940 to 4,400 ft) in the Virden-Duncan Basin and 1,130 to 1,300 m (3,700 to 4,265 ft) in the Safford Basin. According to Morrison, "in both basins, the highest strand line varies considerably in altitude from place to place because of subsequent [tectonic] deformation..." He further suggests that "establishment of the Gila River and exterior drainage from these basins likely came about as a result of overflow of the lake in each basin, instead of by headward erosion and basin capture." Except for timing, this general concept fits reasonably well with previously discussed interpretations of lake-basin aggradation and initial valley incision in the upstream Cliff Subbasin area (Leopoldt 1981). The possibility of lake discharge from the Cliff and Mangas subbasins (Mangas structural basin) has also been discussed by Kottlowski and others (1965).

The "large, deep Middle Pleistocene lake" model of Morrison (1965, 1985, 1991) definitely needs re-evaluation, however. First, an early deep lake in the Virden-Duncan Subbasin requires a large amount of tectonic deformation during Early to Middle Pleistocene time (locally more than 100 m; 330 ft) in order to account for basin closure and the very irregular (present) altitude of Morrison's (1965) highest shoreline deposits (his unit 5). Second, repeated closure of the Virden-Duncan Subbasin following overflow of preexisting lakes would be required to form shoreline deposits at the levels of his (lake-gravel) units 3 and 4. Presumably, this would also involve complex Basin and Range structural deformation of major proportions in Middle Pleistocene time (130 - 770 ka). Current work on neotectonic features of the area (Machette et al. 1986, 1998), however, does not support the premise of major Early Pleistocene or younger tectonic deformation in the Virden-Duncan area. The conceptual model of Gila River Valley evolution favored in this report requires reinterpretation of most, if not all of Morrison's (1965) "lake gravels" (Units 3-5) as fluvial to fluvial-deltaic deposits of the ancestral Gila River.

The existence of ancient lakes in the Virden-Duncan Subbasin (and also the Cliff Subbasin) prior to development of an integrated ancestral Gila River system is not questioned here. Such lakes, however, were probably of Pliocene and Late Miocene age, and they may not have been nearly as deep or extensive as suggested by Morrison (1965, 1985, 1991). Shallow lacustrine and cienega complexes, and low-gradient fluvial fans and deltas appear to have been the major components of basin-floor depositional environments. Analogous deposits are already well-documented in southwestern New Mexico and include the very extensive relict and active fluvial fans and fan deltas of the lower Mimbres River and Animas Creek, described in Chapters 4 and 7. The Upper Santa Fe Group (Camp Rice-Fort Hancock Fm) fluvial-deltaic environment of deposition described in the Mesilla and Hueco Bolson area by Hawley (1975), Gile and others (1981), and Mack and others (1998) is probably the most appropriate model for late-stage basin filling in the Virden-Duncan Subbasin.

GROUNDWATER FLOW SYSTEM

The groundwater flow system (Figure 8-3) closely parallels the direction of the surface water drainage, generally flowing toward and along the stream systems. Most subbasins are hydraulically interconnected with groundwater moving from higher to lower altitude. Groundwater occurs in a wide variety of igneous, metamorphic, and sedimentary bedrock units of Precambrian, Cretaceous, and Early to Middle Tertiary age. However, Neogene and Quaternary basin and valley fills are the major aquifer units, and they include local zones of interbedded basaltic volcanics (Figure 8-2 and Plate 1). The occurrence of groundwater in basin and valley fill is primarily controlled by rates of recharge and groundwater flow, and the method of deposition and character of the sediments. The water-bearing characteristics of the igneous, intrusive, metamorphic, and volcanic rocks are dependent on localized joint fractures and weathering characteristics, with well yields usually limited to a few gallons per minute. Well yields from basin and valley fills are significantly higher but are limited by recharge, which is derived primarily from mountain-front sources and valley-bottom infiltration (Robertson 1991). Groundwater discharge also occurs in various springs located in valley areas in the basin system.

Saturated valley-fill deposits of the inner Gila River Valley and the valleys of its major intermittent tributaries constitute the primary aquifer unit in most of the basin system. However, older piedmont and basin-floor alluvial deposits of the Upper and Middle Gila Group (HSUs: UGl, UG2, MGl), provide local sources of groundwater particularly in parts of the Mangas, Cliff, and Virden-Duncan subbasins. Primary groundwater use in these areas is for livestock and domestic consumption.

The hydraulic properties of a typical river-valley-fill deposit in the reach of the Gila River near the Grant-Hidalgo County line (near gaging station downstream from lower end of Blue Creek, Figure 8-1) are described by Trauger (1972, p 84). The aquifer here comprises very coarse-grained deposits of the Late Quaternary Gila River channel complex (HSU: RG; facies a1 and 2) that are about 30 m

(100 ft) thick and 70 m (230 ft) wide. The hydraulic gradient is 0.0028 (15 ft/mi), and the estimated horizontal hydraulic conductivity of the gravel and sand aquifer is about 90 m/d (300 ft/d). Calculated underflow discharge across this valley-fill section, which is bounded by low-permeability rock units, (area of 2,100 m^2, 23,000 ft^2) is about 530 m^3/d (19,000 ft^3/d, 0.43 ac-ft/d) or about 1.95 x 10^5 m^3/yr (160 ac-ft/yr). Note that the hydraulic conductivity and gradient values for river valley fills are much higher than hydraulic characteristics of basin-fill hydrostratigraphic units. For example, hydraulic conductivities in Upper Gila Group fluvial facies (HSUs: UG2; lithofacies assemblages 1 and 2) (Table 3-5) rarely are more than 30 m/d (100 ft/d) and are commonly less than 10 m/d (30 ft/d), and basin-floor hydraulic gradients may be less than 0.001 (~ 5 ft/mi). Comparable very high conductivity and gradient values are only recorded in the Upper Mimbres River and Upper Animas Creek valleys (HSUs: Rmr and RAc).

SUMMARY

The Gila River Basin system has no trans-international boundary component. The lower reach (Virden-Duncan) of the river valley in New Mexico, however, does serve as the ultimate sink for groundwater flow from the Animas Basin system, and perhaps also for a very small amount of (predevelopment) underflow leakage from the Lower Playas Subbasin. The New Mexico portion of the Gila River drainage basin, excluding the San Francisco River watershed, has an area of about 9,300 km^2 (3,590 mi^2).

The headwaters of the Gila River are in the Datil-Mogollon section of the Transition Zone physiographic province and have an area of about 7,780 km^2 (2,645 mi^2). This drainage basin is bounded on the south, east and north by the Continental Divide, and on the northwest by its boundary with the San Francisco River watershed. High plateaus and deep canyons of the Mogollon-Datil volcanic field dominate the entire Upper-Gila, and northern parts of the Cliff, Redrock and Virden-Duncan subbasins. Elevation of the Datil-Mogollon section ranges from 3,320m (10,892 ft) at Whitewater Baldy in the Mogollon Mountains to 1,463m (4,800 ft) at Redrock in the Gila River Valley.

The Mexican Highland section of the Basin and Range province, with an area of about 1,520 km^2 (945 mi^2) in New Mexico, forms the lower part of the basin system. It comprises the entire Mangas Subbasin, which is structurally connected with the San Vicente Subbasin (Mimbres Basin system), and the southern parts of the Cliff, Redrock and Virden-Duncan subbasins. Bear Mountain and Burro Peak (elev. 2,449 m; 8,036 and 8,035 ft) in the Silver City and Big Burro Mountain area are the highest points in the Mexican Highland section. The elevation of the Gila River Valley floor at Virden, near the New Mexico-Arizona border, is about 1,152m (3,780 ft), which is only 20m (65 ft) higher than the San Bernadino Basin floor (Chapter 9) at the International Boundary.

The two major land use/landcover categories in the Gila River Basin system are extensive forest areas at higher elevations, primarily in the Upper Gila and southern Cliff subbasins, and the Big Burro Mountains, and rangeland in most of the rest of the basin. Small urban and agricultural communities are present in only two places along the river valley, in the Gila-Cliff area and at Virden. Most cropland is located in the Virden (Duncan) Valley and near Buckhorn and Cliff. Some groundwater is also used for mineral processing activities in the southern Mangas Subbasin (Tyrone area).

Climate of the Gila River Basin system ranges from arid to subhumid. Average annual precipitation ranges from 23.1cm (9.1 in) at the Virden Station to 51cm (20 in) at the Pinos Altos station (elev. 2,134 m; 7,000 ft) on the Continental Divide. The recorded average air temperature at Redrock is (elev. 1,483 m; 4,900 ft) 15.1°C (59.1°F), and it is 11.6° C (52.9° F) at Gila Hot Springs (elev. 1,707 m; 5,600 ft).

Upper Cenozoic basin fill of the Gila Group and local basaltic volcanics comprise the most extensive aquifer system in the Gila River Basin of New Mexico. An important, but areally limited aquifer unit is the inner valley fill of the Gila River Valley and its major perennial to intermittent tributaries. Hydrostratigraphic units RG and AA are the major aquifers in narrow valley and canyon reaches of the Gila River system, while Lower to Middle Gila Group sandstone, mudstone, and conglomerate (HSU's LG, MG, MLG) form a marginally productive groundwater zone. Underlying fractured volcanic rocks, mostly silicic tuffs and flows, are also significant aquifers in a few areas. Poorly consolidated to partly indurated Upper and Middle Gila Hydrostartigraphic Units (HSUs: UG1-2, MG1-2) are significant aquifers only where they fill the deepest parts of the Cliff, Mangas, Redrock and Virden-Duncan structural basins below the level of present river valley system.

The Gila River Basin system is the only part of the study area where basin aggradation has not been the major geomorphic process in Pliocene and Quaternary time. Basin filling in most of the Datil-Mogollon section was completed by the Middle Pliocene (about 2.5 - 3.5 m.y. ago), and widespread aggradation of basin floors in the Mexican Highland section appears to have terminated in Late Pliocene to Earliest Pleistocene time (1.5 - 2.5 m.y. ago). In the central parts of the Mangas, Cliff, Redrock and Virden-Duncan subbasins, deposits of extensive but shallow lakes, and bordering fluvial-deltaic plains and alluvial flats that mark the final stages of basin filling are now deeply dissected by the valleys and canyons of the upper Gila River and its tributaries.

Progressive integration of a previously segmented series of *closed* structural basins to form in the present through-flowing river system in the Upper Gila Basin of southeastern Arizona and southwestern New Mexico appears to have been completed by the Early Pleistocene at least one million years ago and perhaps earlier. While tectonism has had some influence on rates of valley incision (and clearly controls valley and canyon position), climatic shifts of the past 2.5 million years have played the major geomorphic role in valley formation. Extended intervals of accelerated valley deepening and widening appear to be associated with Late Pliocene and Pleistocene glacial-pluvial stages when the upper Gila drainage basin contributed much more sustained discharge, than during interglacial (interpluvial) stages such as the Holocene (past 10,000 yrs) when the Gila Valley tends to aggrade. The last cycle of valley entrenchment and partial backfilling has produced the 20 to 30 m (65 to 100 ft) of inner valley fill (HSU: RG) that constitutes the shallow aquifer system and major groundwater resource downstream from the Upper Gila Subbasin.

The hydraulic properties of Gila River deposits in the valley segment downstream from Redrock are representative of inner-valley-fill aquifers in the Cliff, Redrock and Virden-Duncan subbasins. The aquifer comprises very coarse-grained deposits of the Late Quaternary river-channel complex (HSU: RG; facies a 1 and 2) that are about 30 m (100 ft) thick and 70 m (230 ft) wide. The hydraulic gradient is 0.0028 (15 ft/mi), and the estimated horizontal hydraulic conductivity of the gravel and sand aquifer is about 90 m/d (300 ft/d). Calculated underflow discharge across this valley-fill section, which is bounded by low-permeability rock units, is about 530m^3/d (19 x 10^3 ft^3/d) or 1.95 x $10^5$$m^3$/yr (160 ac-ft/yr). Hydraulic conductivity and gradient value for river-valley fills are much higher than for any Gila Group Hydrostratigraphic Unit in this or any adjacent basin system. Comparable conductivity and gradient values are only recorded in the valleys of the Upper Mimbres River and Animas Creek.