

ADWR Open-File Report 12

**Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin**

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Arizona Department of Water Resources

Hydrology Division

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BACKGROUND

This memo evaluates available scientific evidence to determine whether it is possible to delineate a separate groundwater sub-basin in the Bowie area from the San Simon Valley sub-basin of the Safford groundwater basin (Griffin, 2012). In order to make this determination numerous existing reports and data were analyzed. Attempts were also made to contact and interview some local residents concerning their opinions about this question. Unfortunately, ADWR was unsuccessful in making those contacts.

DEFINITIONS

The Arizona revised statutes, A.R.S. 45-402, define the following terms:

- “Groundwater basin” means an area which, as nearly as known facts permit as determined by the director pursuant to this chapter, may be designated so as to enclose a relatively hydrologically distinct body or related bodies of groundwater, which shall be described horizontally by surface description.
- “Subbasin” means an area which, as nearly as known facts permit as determined by the director pursuant to this chapter, may be designated so as to enclose a relatively hydrologically distinct body of groundwater within a groundwater basin, which shall be described horizontally by surface description.

EXISTING GROUNDWATER BASIN AND SUB-BASIN DESIGNATIONS

The determination of whether or not a separate “Bowie” sub-basin may exist is dependent on both scientific evidence and how the phrase “... so as to enclose a relatively hydrologically distinct body of groundwater within a groundwater basin” is interpreted. Information on the original delineation of Arizona’s groundwater basins and sub-basins is presented in ADWR’s 1982 “Groundwater Basin and Sub-basin Designations” report. The 1982 groundwater basin and sub-basin designations identified 39 individual groundwater basins that had no sub-basins, and 13 additional groundwater basins that had a combined total of 42 sub-basins (Table 1).

The average size of basins and sub-basins is 1,654 and 1,111 square miles (sq. mi.), respectively (Figure 1). The median size of basins and sub-basins is 740 and 947 square miles, respectively. The largest basin is the Little Colorado River Plateau Basin (26,513 sq. miles), and the smallest basin is the Tiger Wash Basin (74 sq. mi.). The largest sub-basin is the Welton-Mohawk sub-basin (6,189 sq. mi.), and the smallest sub-basin is the Camp Grant Wash sub-basin (125 sq. mi.).

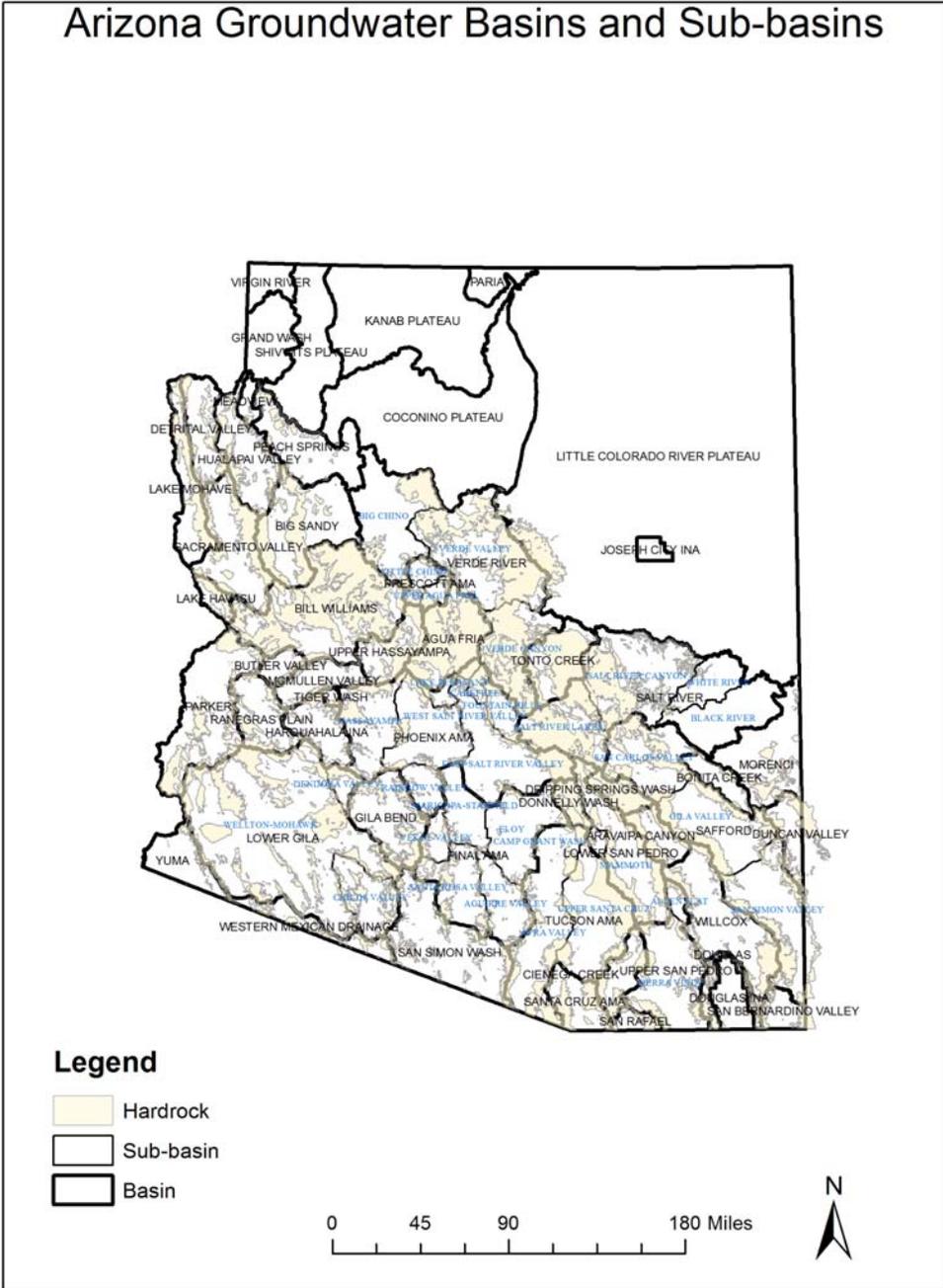


Figure 1 Arizona Groundwater Basins and Sub-basins

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

BASIN_NAME	SUBBASIN_NAME	Area Sq. Miles	Area Basins (Sq. Mi.)	Area Sub-basins (Sq. Mi.)
AGUA FRIA		1,262	1,262	
ARAVAIPA CANYON		517	517	
BIG SANDY	FORT ROCK	859		859
BIG SANDY	WIKIEUP	1,127		1,127
BILL WILLIAMS	ALAMO RESERVOIR	947		947
BILL WILLIAMS	BURRO CREEK	694		694
BILL WILLIAMS	CLARA PEAK	519		519
BILL WILLIAMS	SANTA MARIA	879		879
BILL WILLIAMS	SKULL VALLEY	309		309
BONITA CREEK		456	456	
BUTLER VALLEY		287	287	
CIENEGA CREEK		614	614	
COCONINO PLATEAU		5,809	5,809	
DETRITAL VALLEY		892	892	
DONNELLY WASH		293	293	
DOUGLAS		394	394	
DOUGLAS INA		554	554	
DRIPPING SPRINGS WASH		378	378	
DUNCAN VALLEY		550	550	
GILA BEND		1,283	1,283	
GRAND WASH		958	958	
HARQUAHALA INA		765	765	
HUALAPAI VALLEY		1,212	1,212	
JOSEPH CITY INA		181	181	
KANAB PLATEAU		4,245	4,245	
LAKE HAVASU		252	252	
LAKE MOHAVE		979	979	
LITTLE COLORADO RIVER PLATEAU		26,513	26,513	
LOWER GILA	CHILDS VALLEY	884		884
LOWER GILA	DENDORA VALLEY	233		233
LOWER GILA	WELLTON-MOHAWK	6,189		6,189
LOWER SAN PEDRO	CAMP GRANT WASH	125		125
LOWER SAN PEDRO	MAMMOTH	1,498		1,498
MCMULLEN VALLEY		648	648	
MEADVIEW		190	190	
MORENCI		1,599	1,599	
PARIA		408	408	
PARKER	CIBOLA VALLEY	694		694
PARKER	COLORADO RIVER INDIAN RES.	363		363
PARKER	LA POSA PLAINS	1,171		1,171
PEACH SPRINGS		1,408	1,408	
PHOENIX AMA	CAREFREE	141		141
PHOENIX AMA	EAST SALT RIVER VALLEY	1,704		1,704
PHOENIX AMA	FOUNTAIN HILLS	357		357
PHOENIX AMA	HASSAYAMPA	1,197		1,197
PHOENIX AMA	LAKE PLEASANT	237		237
PHOENIX AMA	RAINBOW VALLEY	422		422

BASIN_NAME	SUBBASIN_NAME	Area Sq. Miles	Area Basins (Sq. Mi.)	Area Sub-basins (Sq. Mi.)
PINAL AMA	AGUIRRE VALLEY	794		794
PINAL AMA	ELOY	1260		1260
PINAL AMA	MARICOPA-STANFIELD	715		715
PINAL AMA	SANTA ROSA VALLEY	1022		1022
PINAL AMA	VEKOL VALLEY	302		302
PRESCOTT AMA	LITTLE CHINO	308		308
PRESCOTT AMA	UPPER AGUA FRIA	172		172
RANEGRAS PLAIN		911	911	
SACRAMENTO VALLEY		1586	1586	
SAFFORD	GILA VALLEY	1642		1642
SAFFORD	SAN CARLOS VALLEY	1402		1402
SAFFORD	SAN SIMON VALLEY	1701		1701
SALT RIVER	BLACK RIVER	1253		1253
SALT RIVER	SALT RIVER CANYON	2128		2128
SALT RIVER	SALT RIVER LAKES	1213		1213
SALT RIVER	WHITE RIVER	635		635
SAN BERNARDINO VALLEY		387	387	
SAN RAFAEL		229	229	
SAN SIMON WASH		2282	2282	
SANTA CRUZ AMA		715	715	
SHIVWITS PLATEAU		1820	1820	
TIGER WASH		74	74	
TONTO CREEK		955	955	
TUCSON AMA	AVRA VALLEY	2143		2143
TUCSON AMA	UPPER SANTA CRUZ	1723		1723
UPPER HASSAYAMPA		787	787	
UPPER SAN PEDRO	ALLEN FLAT	175		175
UPPER SAN PEDRO	SIERRA VISTA	1640		1640
VERDE RIVER	BIG CHINO	1847		1847
VERDE RIVER	VERDE CANYON	1311		1311
VERDE RIVER	VERDE VALLEY	2500		2500
VIRGIN RIVER		433	433	
WESTERN MEXICAN DRAINAGE		610	610	
WILLCOX		1910	1910	
YUMA		791	791	
TOTAL AREA PER CATEGORY		113906	66143	47763
MEAN AREA PER CATEGORY		1372	1654	1111
MEDIAN AREA PER CATEGORY		859	740	947

Table 1 Arizona Groundwater Basins and Sub-basins

Review of written findings (ADWR, 1982) reveals that original groundwater basin and sub-basin designations were generally based on one or more of the following criterion:

- groundwater bodies (aquifers) that are generally partially, or nearly completely enclosed by surrounding bedrock features (mountains, hills or outcrops)
- topographic divides separating surface watersheds or drainages (sometimes also approximating sub-surface groundwater divides)
- aquifer types (volcanic, alluvial/basin fill, sedimentary rock, etc.)
- lines connecting one locally or regionally prominent bedrock feature to another
- bedrock narrows, and geologic structures (such as, anticlines)
- discharge of groundwater to surface water that travels between sub-basins to watershed outlets
- independent water use groups/areas (for sub-basin designation)
- political boundaries (state boundary, county lines)
- dams, rivers, water bodies and river confluences
- roads & highways
- township/range or section boundaries
- other

Of particular importance to this analysis is one of the criteria by which sub-basins may be designated within a groundwater basin. In the case of the Little Colorado River Plateau basin (ADWR, 1982, pg. 19), the following preliminary finding was made:

“2. Sub-basins have been established in areas where there is no clear physical change in aquifer conditions or extent. The sub-basins have been employed to distinguish areas of separate major use groups. These areas have been found to be hydrologically distinct not on the basis of geologic or other physical conditions, but because of the effect of each major use group on the aquifer is localized and independent of any other group’s activities. The distance between the locations of groundwater withdrawal is sufficiently great that the aquifer impacts in terms of depth to water, rate of decline, decrease in artesian head, etc., do not extend from one area to the other and the aquifer system is relatively unaffected by the withdrawals taking place”.

It should be noted that the Little Colorado River Plateau basin was originally proposed as having 6 groundwater sub-basins. However, those sub-basins were not adopted in the final basin/sub-basin designations. Although the originally proposed sub-basin designations were not adopted for the Little Colorado River Plateau basin, the previous paragraph likely provides the rationale that was followed for designating other sub-basins on the basis of place use.

SAN SIMON VALLEY SUB-BASIN OF THE SAFFORD BASIN

The San Simon Valley sub-basin of the Safford Basin is located in southeastern Arizona and covers an area in Arizona of about 1,701 sq. mi. (Figure 2). The sub-basin extends into New Mexico and covers a total area of about 1,930 sq. mi. The sub-basin includes the Arizona towns of Bowie, San Simon, Portal and Apache. The town of Rodeo, New Mexico is also located in the sub-basin. Significant agricultural acreage is located near Bowie, San Simon and Rodeo.

San Simon Valley Sub-basin and Adjacent Areas

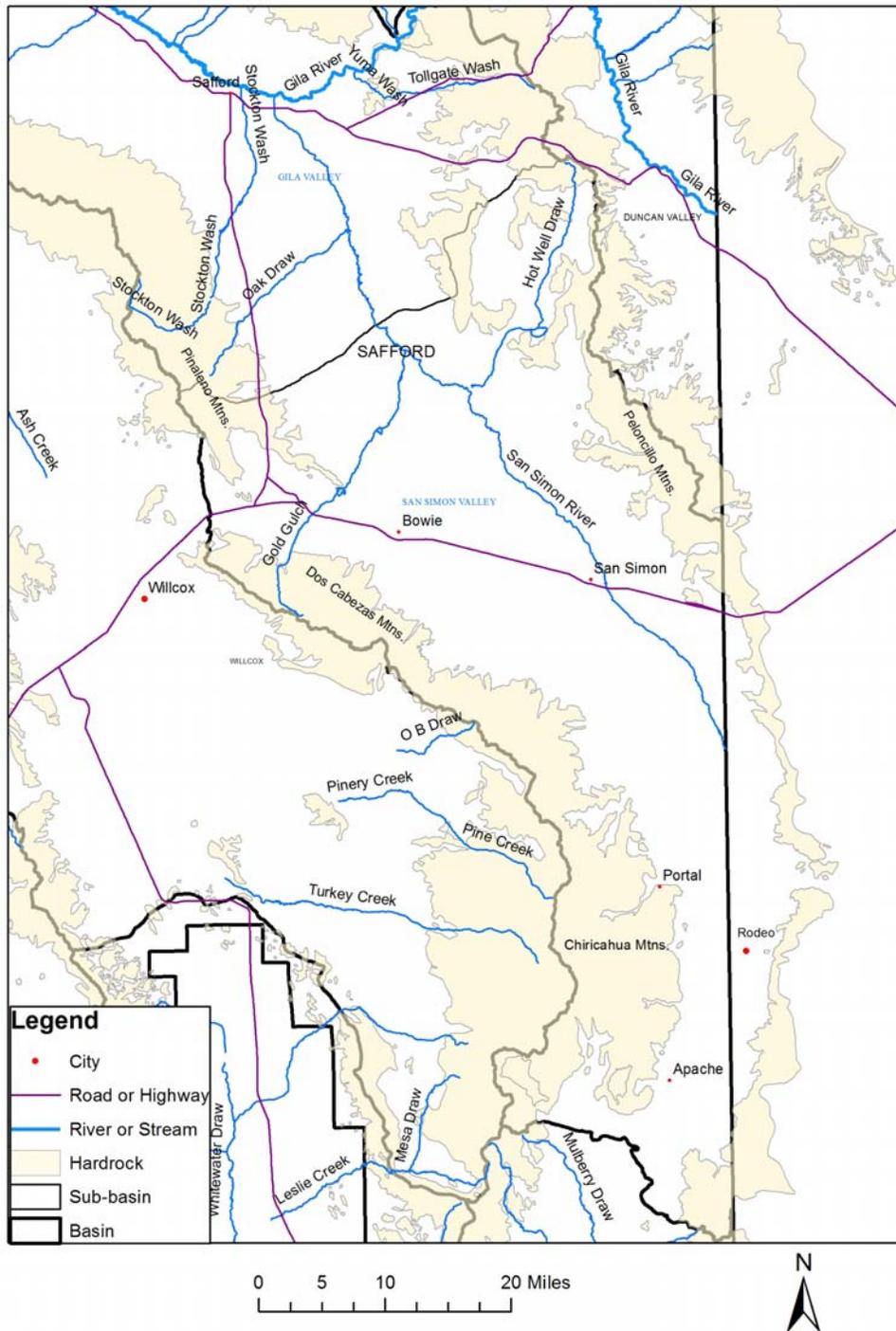


Figure 2 San Simon Valley Sub-basin and Adjacent Areas

The basis for the original delineation of the San Simon Valley sub-basin is described on page 24 of the 1982 ADWR report, "Groundwater Basins and Sub-Basin Designations". According to the findings of that report:

"2. The San Simon Valley Sub-Basin was originally proposed as a separate basin, however, review of the groundwater conditions in the area show a clear hydraulic connection of groundwater between the San Simon Valley area and the Gila Valley area, indicating that they lie in the same basin. There is however a distinct separation of the areas of use thereby showing a need for sub-basins."

Based on the description above, the original designation of the San Simon Valley as a separate sub-basin of the Safford Valley basin was based on a distinction between places of water use (the Gila Valley/Safford area versus the Bowie/San Simon area) rather than on any other type of hydrologic distinction. The Safford area, located along the Gila River, is about 38 miles north of Bowie and 48 miles northwest of San Simon. San Simon is located about 16 miles east-southeast of Bowie (Figure 2).

HYDROGEOLOGY, GROUNDWATER DEVELOPMENT AND AGRICULTURAL WATER USE IN THE SAN SIMON VALLEY SUB-BASIN

The San Simon Valley sub-basin is an intermontaine valley bounded on the west by the Pinaleno, Dos Cabezas and Chiracahua mountains, and bounded on the east by the Peloncillo mountains. The San Simon Valley is bounded on the south by the San Bernadino Valley basin and merges with the Gila Valley sub-basin to the north. The north-sloping, northwest-trending valley ranges from 6 to 25 miles wide, is 75 miles in length, and forms the southern end of a vast structural trough (Safford basin) typical of those found in the basin and Range Province (Barnes, 1991). The San Simon Valley is drained by the San Simon River, an intermittent watercourse that heads in a cienega area near the town of Rodeo, New Mexico and flows northwesterly along the valley axis, eventually joining the Gila River near the town of Safford (Barnes, 1991).

The San Simon Valley sub-basin is a large structural trough formed by the uplift of the mountain blocks relative to the blocks underlying the basin. The valley is filled with water-bearing older and younger alluvial fill materials derived from the erosion of the surrounding uplifted mountains. The older alluvial fill is composed of interfingering beds and lenses of clay, silt, sand and gravel. The older alluvial fill has been divided into lower, middle and upper units (DeCook, 1952) and may exceed 7000 feet in thickness in the basin center (Barnes, 1991). The older unit contains groundwater under both water table and artesian pressure and, in the early years of groundwater development in the Bowie-San Simon area, many flowing artesian wells were drilled (Barnes, 1991). The confining (artesian) conditions are created by the presence of a large "blue clay" unit (White, 1963) that was deposited in a lacustrine environment at a time when a large water body covered the valley (Barnes, 1991). The younger alluvial fill materials are composed of unconsolidated silt, sand and gravel deposited along the existing stream channels (Barnes, 1991).

The early history of groundwater development in the San Simon Valley sub-basin was described by Schwennesen (1917). According to Schwennesen, artesian water was discovered at San Simon in 1910, and continued prospecting for artesian water yielded numerous flowing wells that allowed irrigation to occur. By 1915, there were 127 flowing wells in and around San Simon (Schwennesen, 1917). Estimated potential continuous discharge from those wells was about 11,000 acre-feet per year (Schwennesen, 1917). Many farms in the area were abandoned after World War I, but many wells were not capped and much groundwater flowed to the surface without beneficial use, and artesian heads declined.

In 1946, there was a resurgence of agricultural activity and there were 140 artesian wells and 2 non-artesian wells in the area. As of 1991, only 10 flowing wells remained in the sub-basin (Barnes, 1991). Most of the groundwater pumped from the San Simon Valley sub-basin is for irrigation (USGS, 2012). Table 2 lists the estimated annual irrigation pumping for the sub-basin from 1915 to 2010 (USGS 1994, 2012).

Time Period or Year	Average Annual Pumping Per Time Period or Year (AF)	Time Period or Year	Annual Pumping (AF)
1915-1919	7,600	1997	47,500
1920-1929	4,600	1998	47,500
1930-1939	3,200	1999	49,000
1940-1949	4,700	2000	51,000
1950-1959	31,200	2001	48,500
1960-1969	70,700	2002	46,000
1970-1979	116,100	2003	50,500
1980-1989	65,450	2004	47,500
1990	47,000	2005	48,500
1991	46,000	2006	50,000
1992	41,500	2007	51,000
1993	47,500	2008	49,000
1994	48,000	2009	46,000
1995	46,000	2010	49,500
1996	46,500		

Table 2 Irrigation Pumping in the San Simon Valley Sub-Basin 1915-2010

In 1965, the extent of irrigated lands in the Bowie-San Simon area was approximately 28,000 acres (Figure 3) and about 6,500 acres (Figure 4) in the Rodeo-Apache area (Arizona Crop and Livestock Reporting Service, 1974). The maximum extent of irrigated acreage in the Bowie-San Simon area probably occurred in the 1970s (based on pumping data, Table 2). By 1989, estimated cropped acreage in the San Simon Valley sub-basin was about 18,000 acres (including about 500 acres in the New Mexico portion of the sub-basin (ADWR, 1991). By 2012, about 15,400 acres of irrigated agriculture was estimated in the Arizona portion of the sub-basin,

mainly in the Bowie and San Simon areas (USGS, 2012). Figure 5 is a May, 2011 satellite photo of the area downloaded from Google Earth™ that shows the extent of agriculture in the Bowie-San Simon portion of the sub-basin at that time.

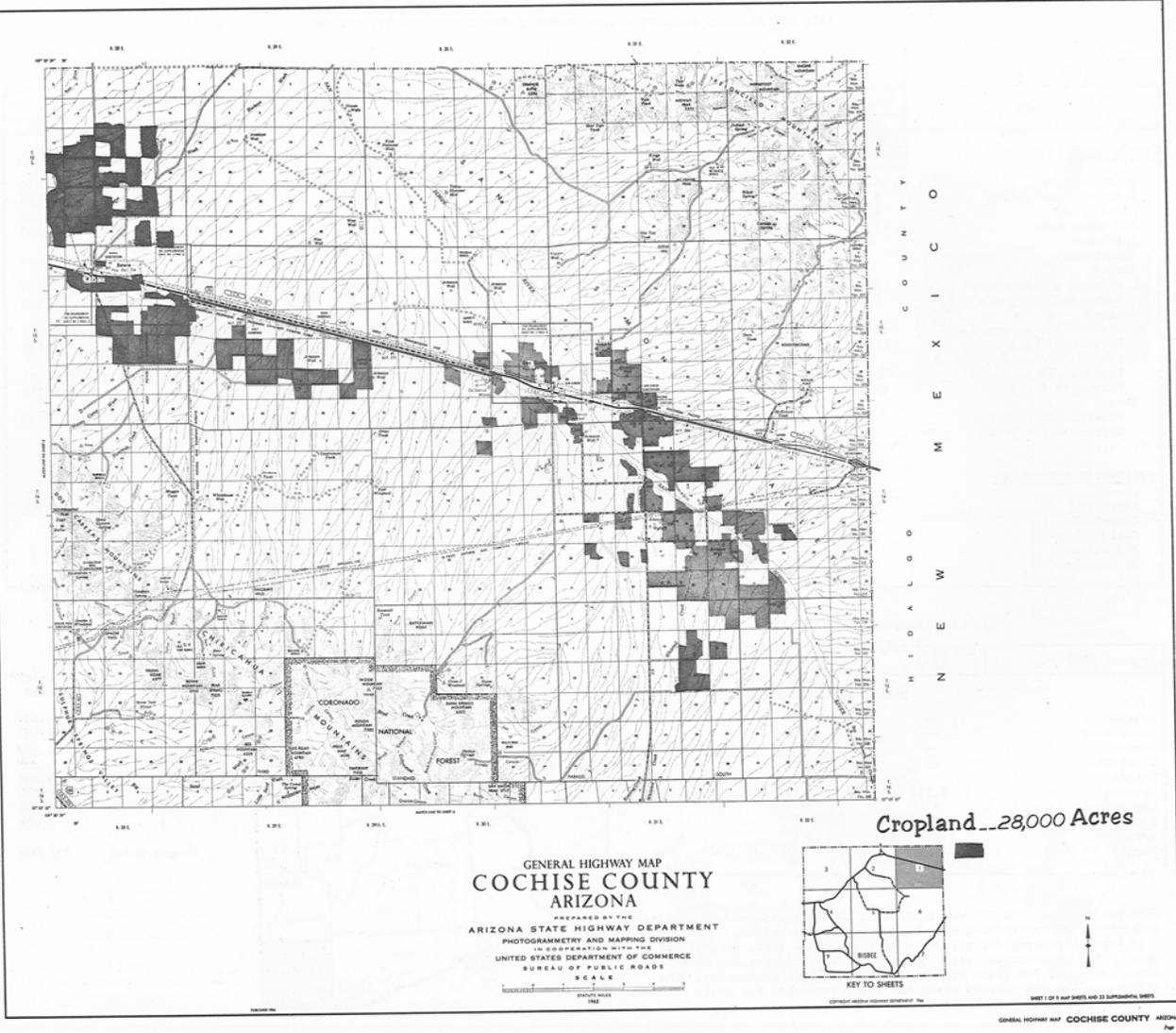


Figure 3 Agricultural Acreage in Bowie - San Simon Area Circa 1965

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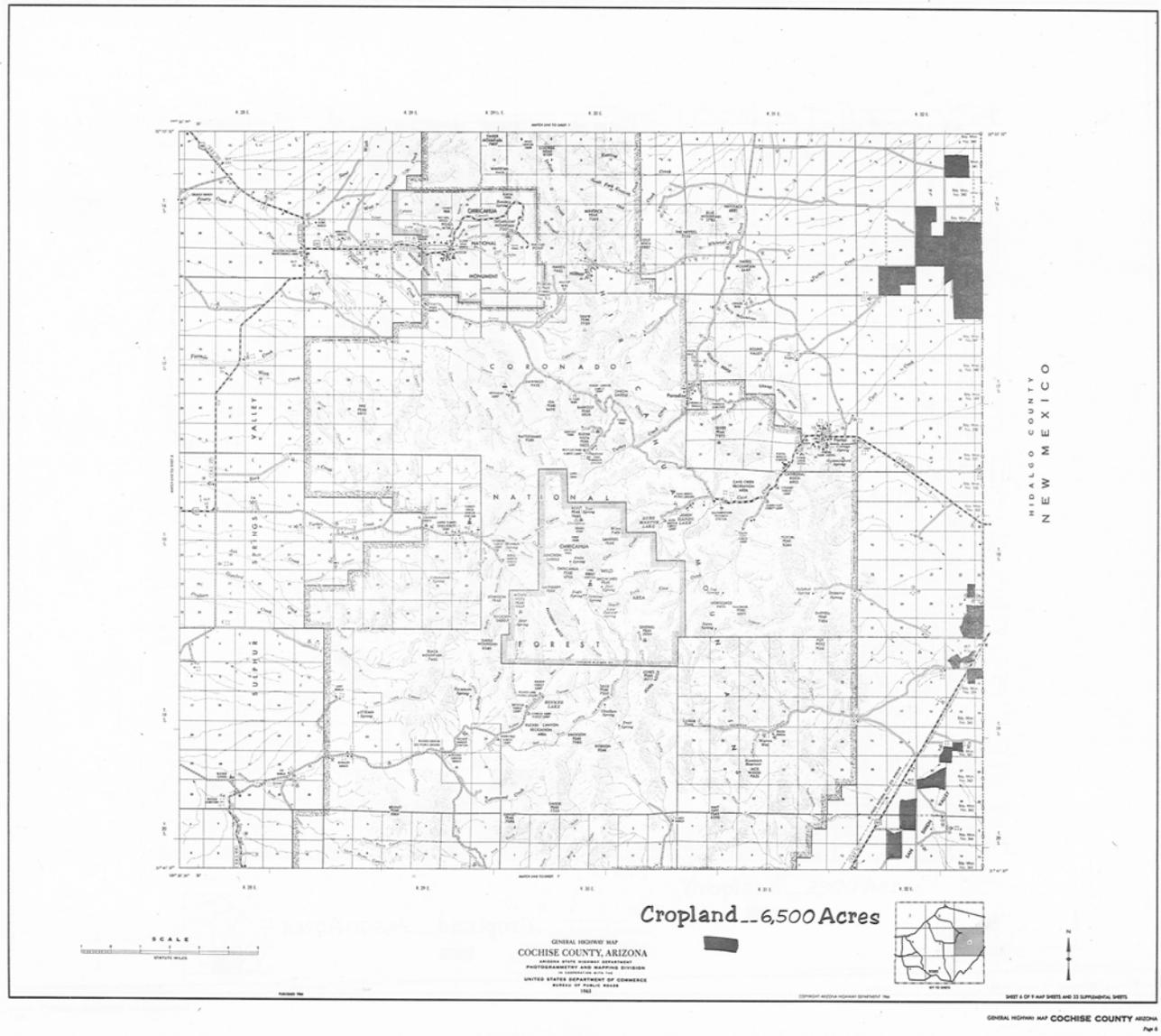


Figure 4 Agricultural Acreage in Rodeo - Apache area Circa 1965

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Figure 5 Extent of Agriculture in Bowie-San Simon area in 2011

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

EVALUATION OF AVAILABLE SCIENTIFIC DATA

The question that this report attempts to answer is:

Is there scientific evidence that supports the delineation of a Bowie sub-basin that is separate and distinct from the existing San Simon Valley sub-basin of the Safford groundwater basin?

ADWR performed tasks including the following to address this question:

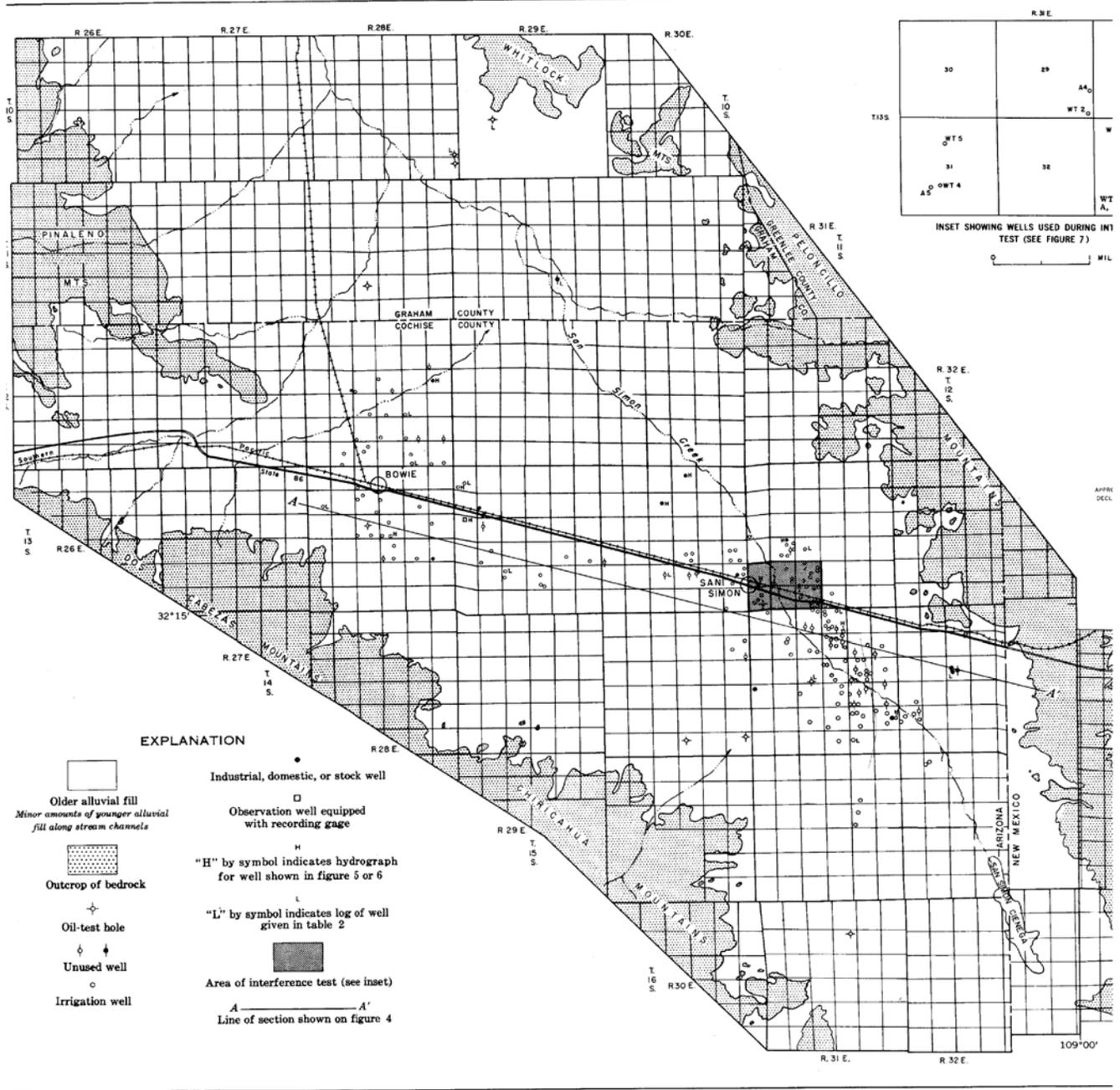
- compile, review and interpret several reports on the geology and hydrology of the area;
- review geophysical data and interpretations of groundwater basin structure;
- analysis of water level, water quality, land subsidence and earth fissure data and reports completed for the area

The following sections provide detail of these efforts.

Review of Reports

White, N.D., 1963. Analysis and Evaluation of Available Hydrologic Data for San Simon Basin, Cochise and Graham Counties, Arizona. Natalie D. White. United States Geological Survey Water-Supply Paper 1619-DD.

This report provided information on well locations, well log data, geologic unit thicknesses, geologic cross-sections and groundwater elevations and flow directions for 1915, 1919, 1952, 1960. An informative geologic cross-section was provided in this report (Figure 6) that is slightly south and approximately parallel to Interstate 10, between Bowie and San Simon (Figure 7).



Map from R. L. Cushman and J. Jones (1947). Modified by J. White, 1960

MAP OF THE SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA, SHOWING BEDROCK AREAS AND LOCATION OF WELLS

SCALE 1:250 000
2 0 2 4 6 8 MILES

668687 O - 6

Figure 6 Well and Cross-Section Location Map (from USGS WSP 1619-DD, Plate 1)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

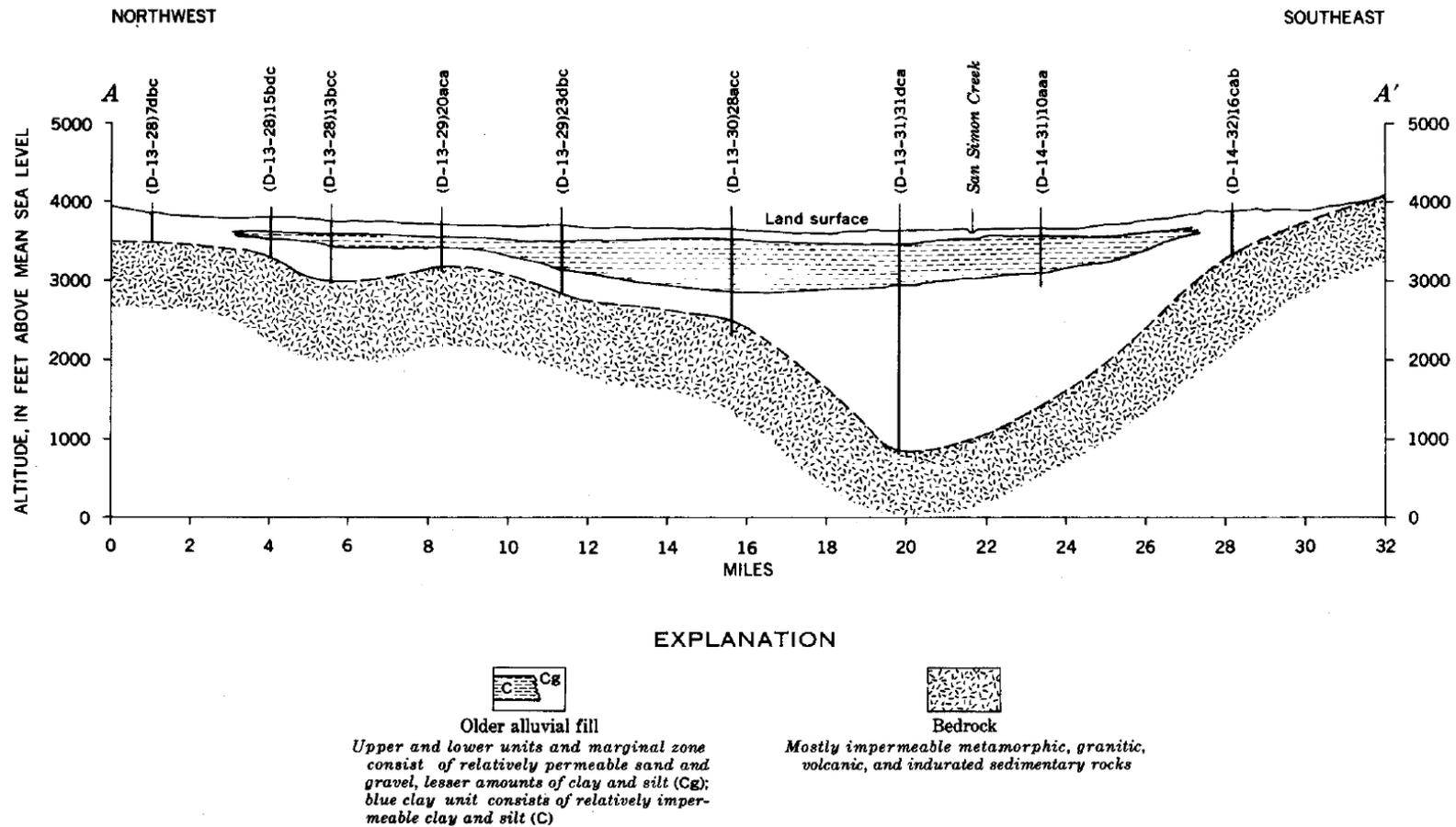


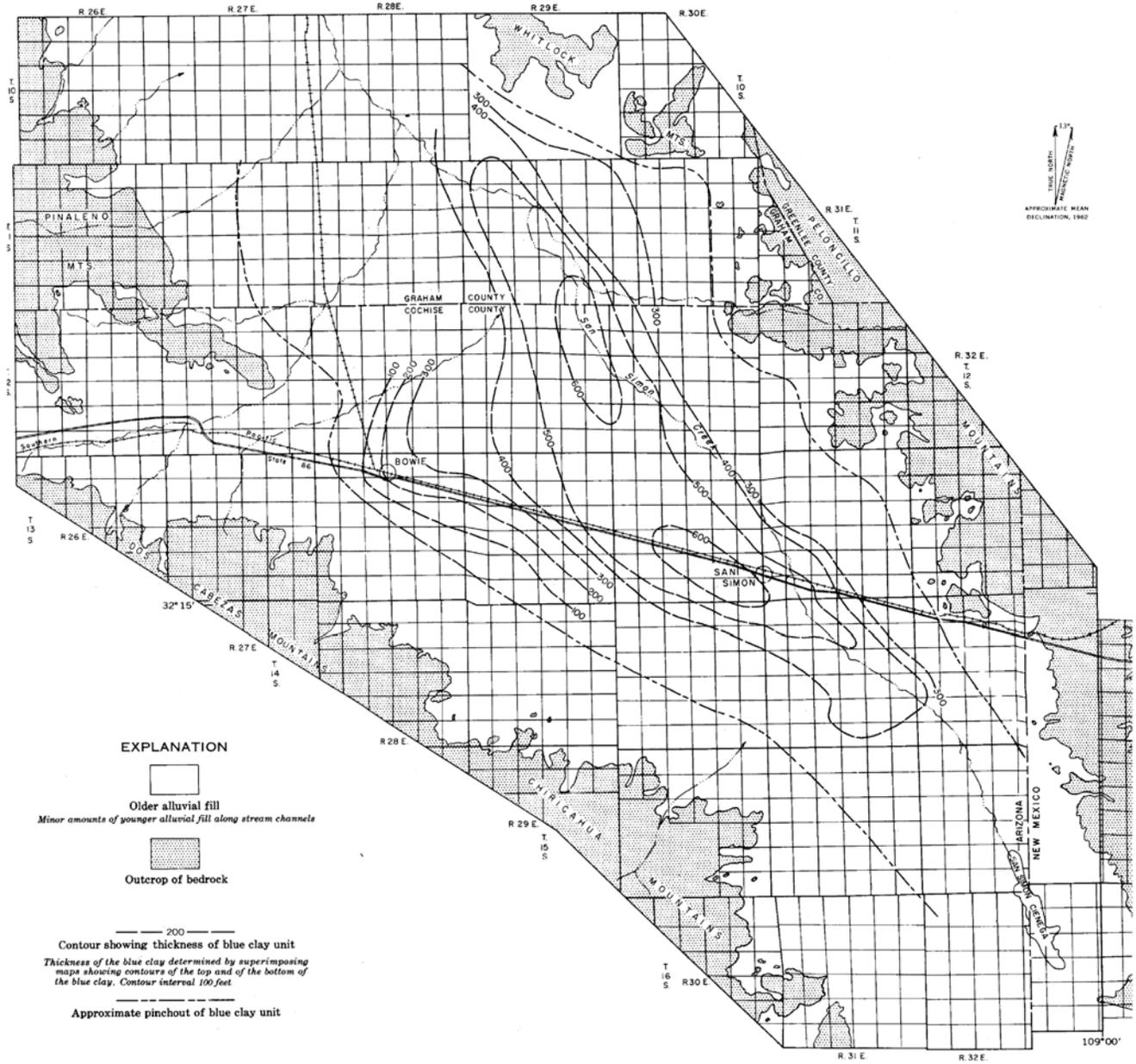
FIGURE 4.—Generalized geologic section along line A-A' shown in plate 1, San Simon basin, Cochise and Graham Counties, Ariz.

Figure 7 Geologic Section In Bowie-San Simon area (from USGS WSP 1619-DD)

Evaluation of Available Scientific Data Related to the
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The cross-section, based on well log data, demonstrates greater aquifer thickness in the San Simon area, and the presence of an areally extensive blue clay unit that thins to the northwest near Bowie and thickens to the southeast near San Simon. The blue clay unit (Figure 8) is an aquitard that creates confining conditions in the lower/older basin fill aquifer that historically, when penetrated by wells, provided flowing artesian wells Figure 9. The cross-section indicates hydraulic continuity of the lower/older basin fill aquifer between the Bowie and San Simon areas. Hydraulic continuity in the aquifer system is also indicated by maps showing the altitude of the artesian-pressure surface in 1915 and 1960 (Figures 9 and 10).

The change in the artesian-pressure surface (aka water level change map) from 1915 to 1960 is shown in Figure 11. The contours shown in Figure 11 reveal that decreases in artesian pressure were centered around the major agricultural pumping centers in Bowie and San Simon, and the groundwater depressions being created by each pumping center were spreading laterally toward one another. However, by 1960 the available data indicate little to no measurable impact from one pumping center to the other, as indicated by the area between groundwater depressions showing approximately zero change in artesian-pressure surface (Figure 11). For the purposes of this discussion, the term artesian-pressure surface and water level surface are used interchangeably. While not used herein, the commonly applied hydrologic term “potentiometric surface” could also be substituted in this context without changing the meaning or interpretation of this report.



Map from R. L. Cushman and
Jones (1947). Modified by
White, 1960

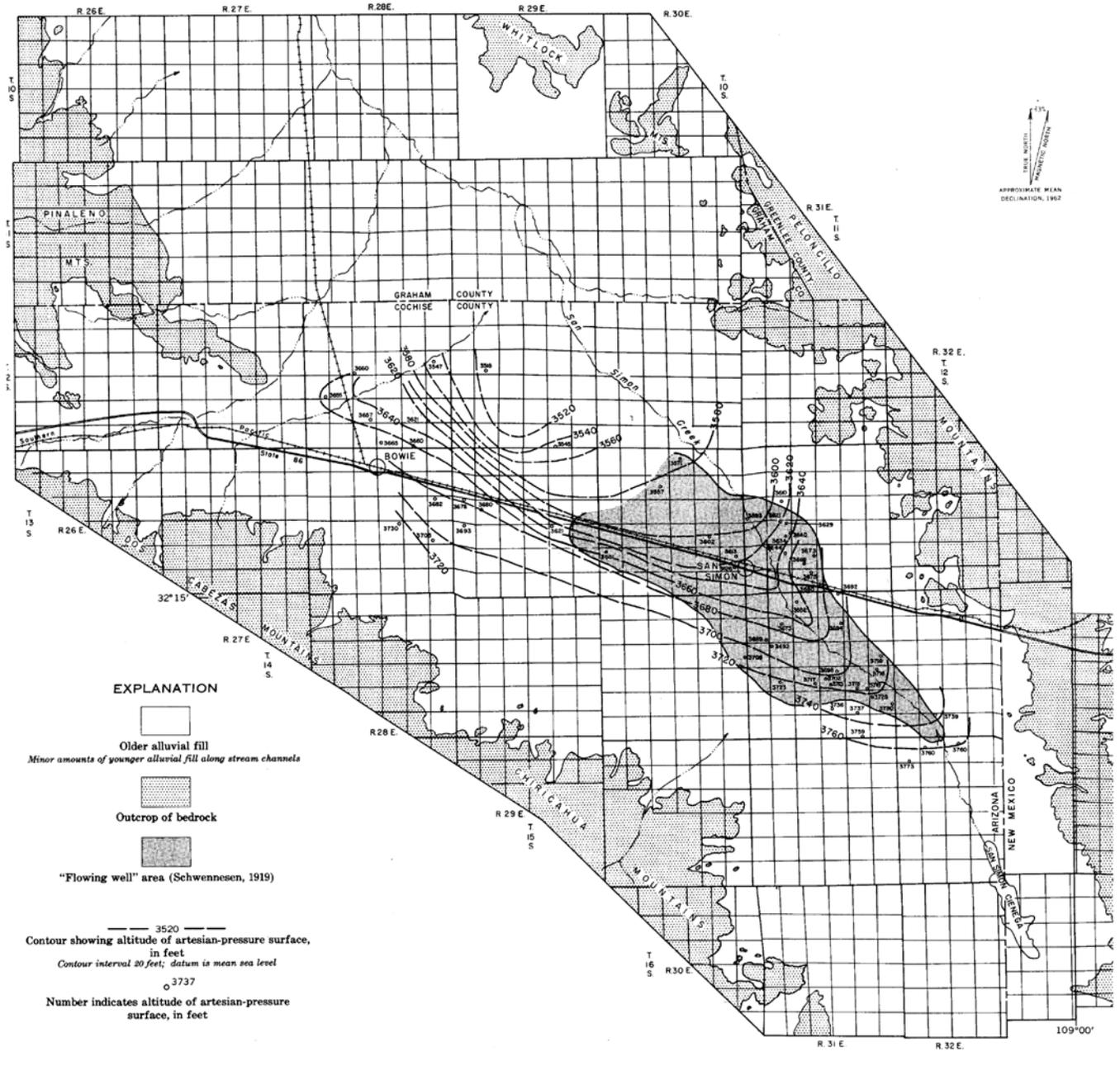
Pinchout of blue clay unit delin

**MAP OF THE SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA, SHOWING CONTOUR
OF THE THICKNESS OF THE BLUE CLAY UNIT**

SCALE 1:250 000
2 0 2 4 6 8 MILES

Figure 8 Thickness of the Blue Clay Unit (from USGS WSP 1619-DD, Plate 2)

68887 O -



map from R. L. Cushman and Jones (1947). Modified by White, 1960

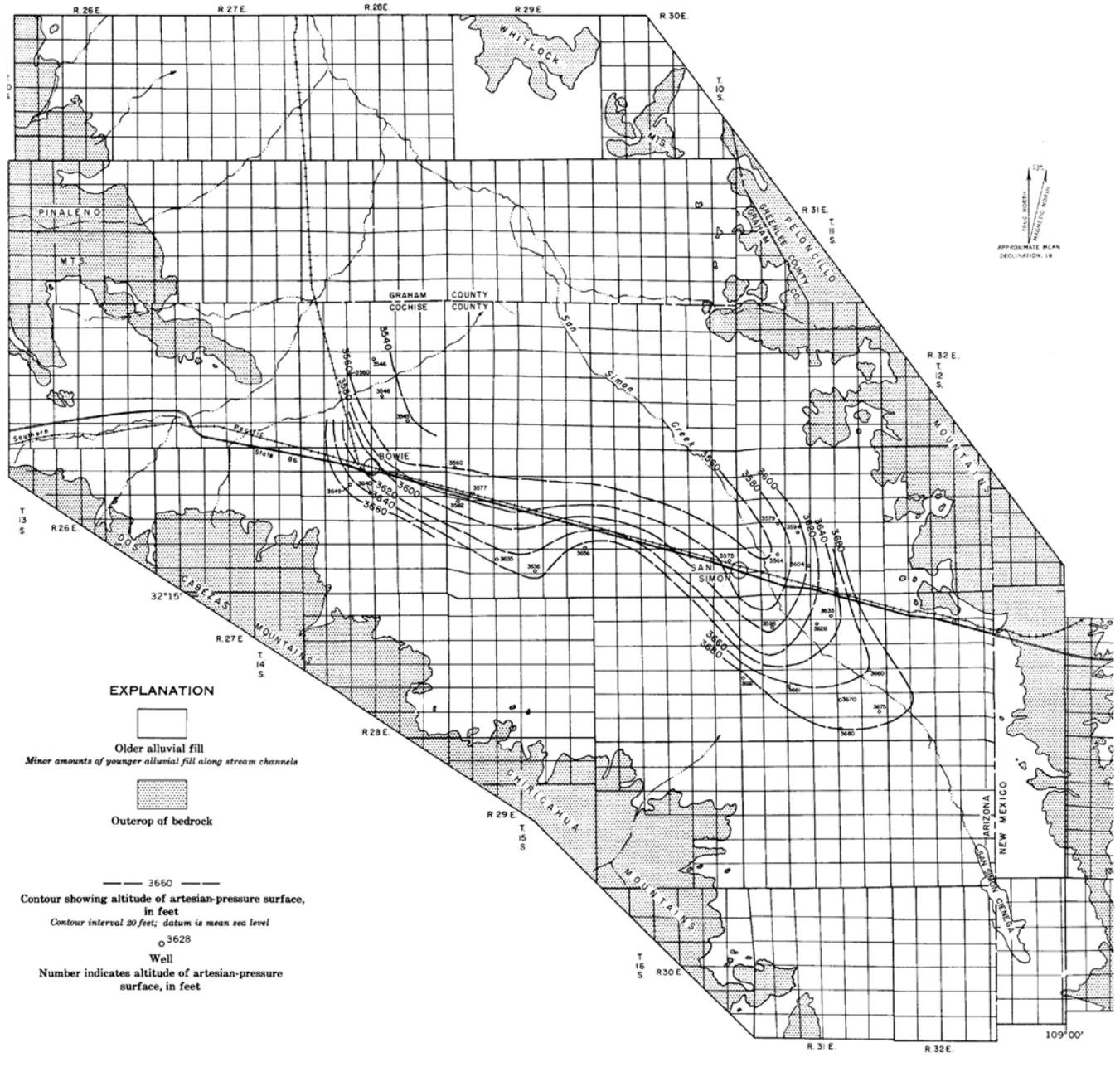
MAP OF THE SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA, SHOWING CONTOUR OF THE ALTITUDE OF THE ARTESIAN-PRESSURE SURFACE, 1915

SCALE 1:250 000
2 0 2 4 6 8 MILES

668687 O -

Figure 9 Altitude of Artesian-Pressure Surface, 1915 (from USGS WSP 1619-DD, Plate 3)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Map from R. L. Cushman and
 others (1947). Modified by
 White, 1960

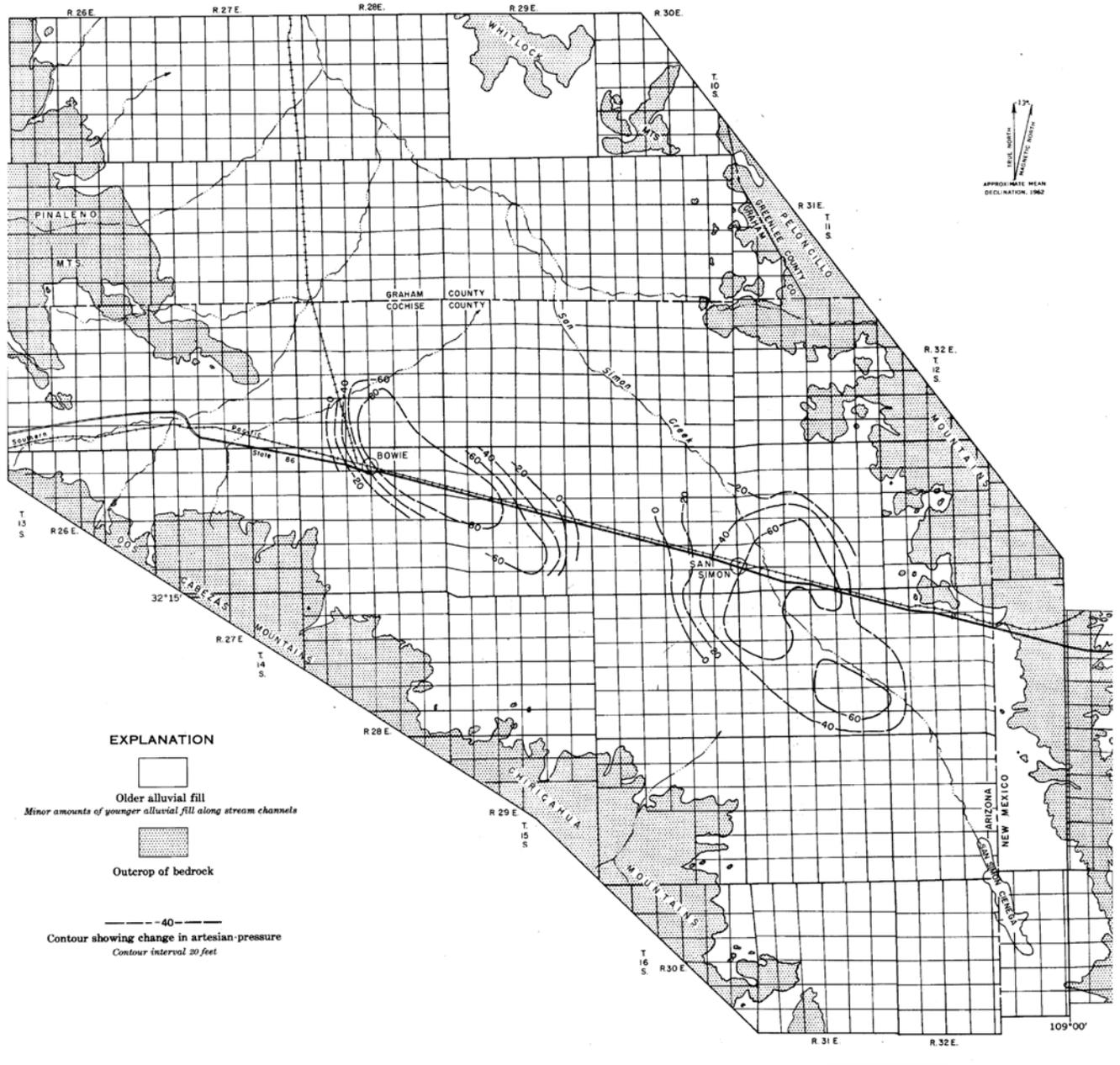
MAP OF THE SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA, SHOWING CONTOURS
 OF THE ALTITUDE OF THE ARTESIAN-PRESSURE SURFACE, SPRING 1960

SCALE 1:250 000
 2 0 2 4 6 8 MILES

668687 O - 63

Figure 10 Altitude of Artesian-Pressure Surface, 1960 (from USGS WSP 1619-DD, Plate 4)

Evaluation of Available Scientific Data Related to the
 Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Map from R. L. Cushman and others (1947). Modified by White, 1960

MAP OF THE SAN SIMON BASIN, COCHISE AND GRAHAM COUNTIES, ARIZONA, SHOWING CONTOURS OF THE CHANGE IN ARTESIAN PRESSURE, 1915-60

SCALE 1:250 000
 2 0 2 4 6 8 MILES

668687 O - 5

Figure 11 Change in Artesian-Pressure Surface 1915-1960 (from USGS WSP 1619-DD, Plate 7)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

White, N.D., and Smith C.R., 1965. Basic Hydrologic Data for San Simon Basin, Cochise and Graham Counties Arizona, and Hidalgo County, New Mexico. Arizona State Land Department, Water-Resources Report Number Twenty-One. Prepared by the United States Geological Survey.

This report was a compilation of water level, well log and pumping data that served as a basis for later groundwater studies and groundwater modeling of the area. Interpretation of water level data shown for 1964 indicate hydraulic connection between groundwater in the Bowie and San Simon areas (Figure 12).

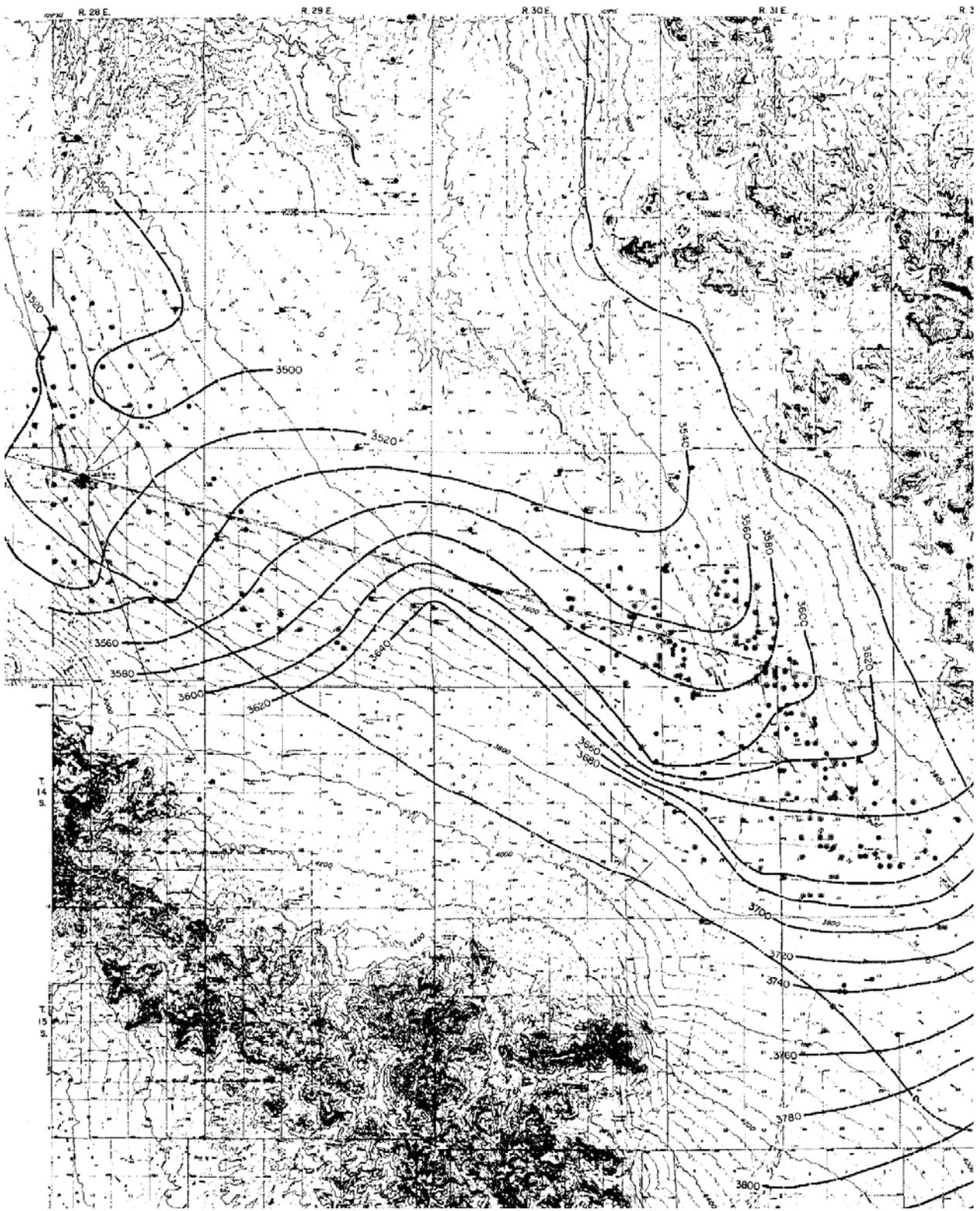


Figure 12 Map of San Simon basin, Showing Well Locations and Water Level Contours in Spring 1964 (from Az. State Land Department, #21, Figure 3)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

White, N.D., and Hardt, W.F., 1965. Electrical-Analog Analysis of Hydrologic Data for San Simon Basin, Cochise and Graham Counties, Arizona. United States Geological Survey Water-Supply Paper 1809-R.

This report presents analysis of hydrologic data and the construction of an electrical-analog model of the San Simon Basin constructed to analyze the effects of ground water withdrawals. While the electrical-analog method of groundwater modeling has long been replaced by numerical computer models, the modeling results are none-the-less informative and also demonstrate the hydraulic connection between groundwater bodies in the Bowie-San Simon areas. The model was constructed based on hydraulic data from the well logs and specific capacity data listed in Table 1 of White and Hardt (1965). Estimated transmissivities averaged about 20,000 to 23,000 gallons per day per foot (gpd/ft) in the Bowie and San Simon areas, respectively. Estimated specific yield averaged from 13 to 11 percent for those areas. Lateral continuity in the artesian aquifer was simulated by the electrical analog model.

The electrical-analog model of the San Simon Basin simulated historical groundwater conditions from 1915 to 1963, as shown in Figures 13 and 14. The electric-analog model simulated change in water levels from 1915 to 1960 is shown Figure 15.

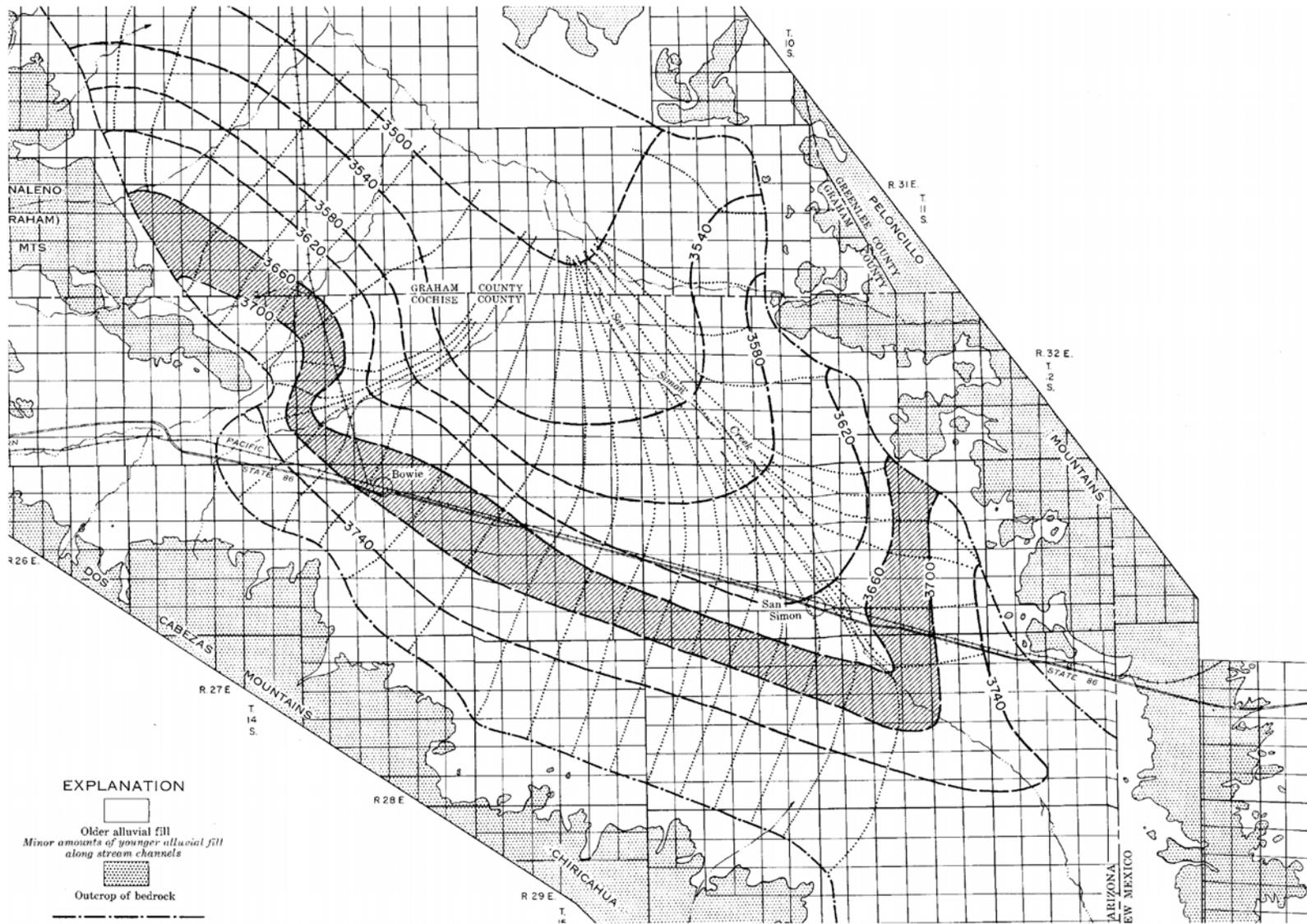


Figure 13 Generalized Flow Net based on 1915 WL Contours (from WSP 1809-R, Plate1A)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Figure 14 Generalized Flow Net based on 1963 WL Contours (from WSP 1809-R, Plate 1B)

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Figure 15 Simulated Change in Water Level 1915-60 by Electric-Analog Model (from WSP 1809-R, Plate 1D)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

The results of the 1915 to 1960 model run (Figure 15) showed similar patterns and magnitudes of simulated water level change compared to measured data covering the same period (Figure 11). The results confirm that a laterally continuous groundwater system likely exists in the Bowie–San Simon area, and in the early decades of groundwater development separate groundwater depressions developed in each area that gradually expanded outward toward these adjacent pumping centers, and groundwater basin boundaries. The results also indicate that appreciable cross-impacts between each pumping center had not occurred by 1960 (Figure 15).

The USGS electric-analog model of the San Simon Basin was also used to project the affects of future groundwater withdrawals for the period from 1960 to 1980. The projected pumping rates simulated in the model over this period are shown in Figure 16 and totaled about 2,000,000 acre-feet. That total compares reasonably with the 1.86 million acre-feet estimated for that time period by the USGS (1994).

The model predicted water level altitude in 1980 and the predicted change in water level from 1960 to 1980 are shown in Figure 17 and 18, respectively. Both the predicted altitude of the water level in 1980 and the predicted pattern of water level change from 1960 to 1980 are similar to measured data for that time period (as discussed in later sections). It is important to note that by 1980, the model simulations show the overlap and collective impact of the separate Bowie and San Simon groundwater depressions on the area between the two pumping centers (Figure 18) and provides additional support for the hypothesis that groundwater in the two areas is hydraulically connected.

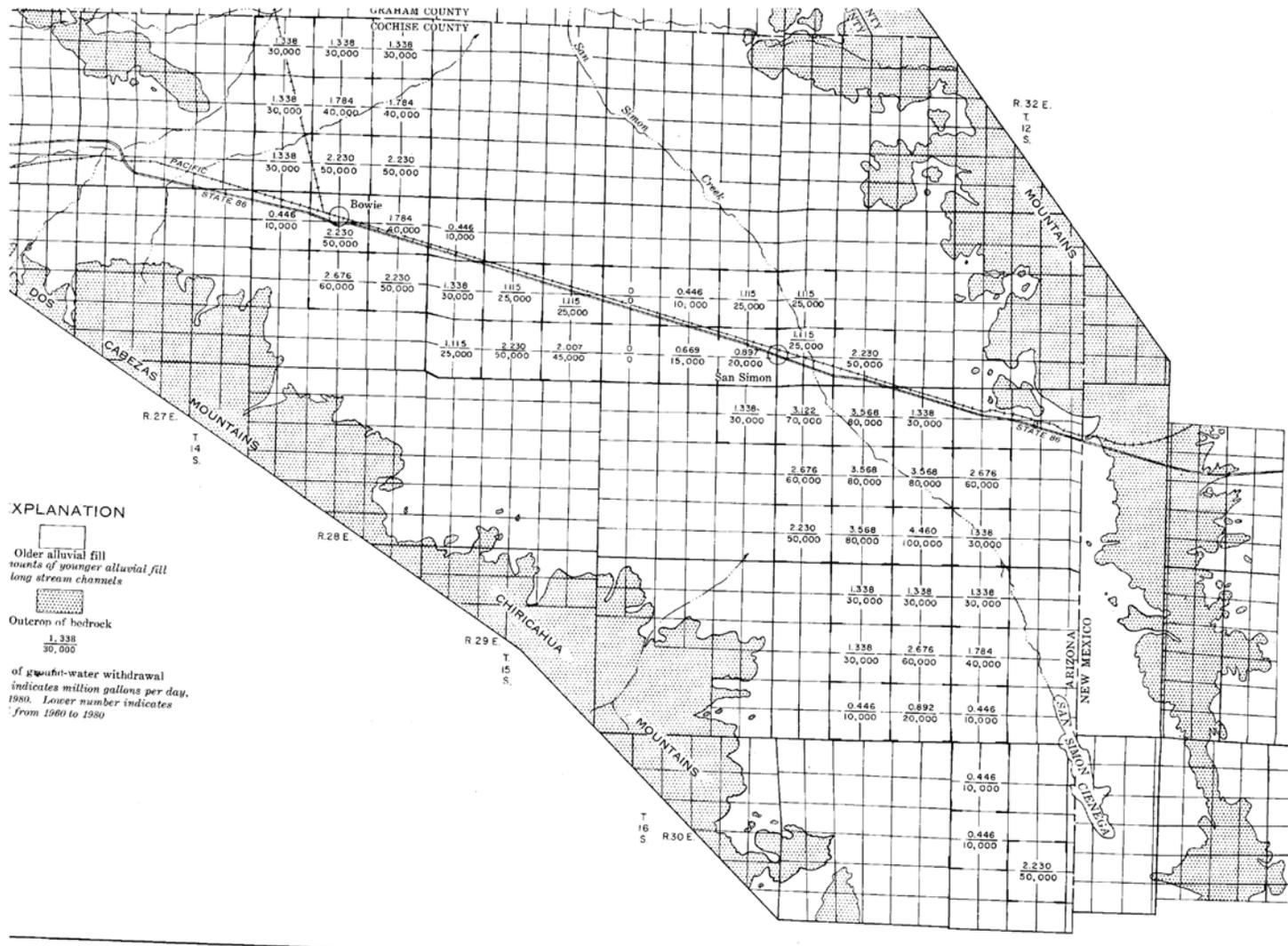


Figure 16 Hypothetical Pattern and Amount of Groundwater Withdrawal 1960-1980 as Simulated With USGS Electric-Analog Model (from WSP 1809-R, Plate 2A)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

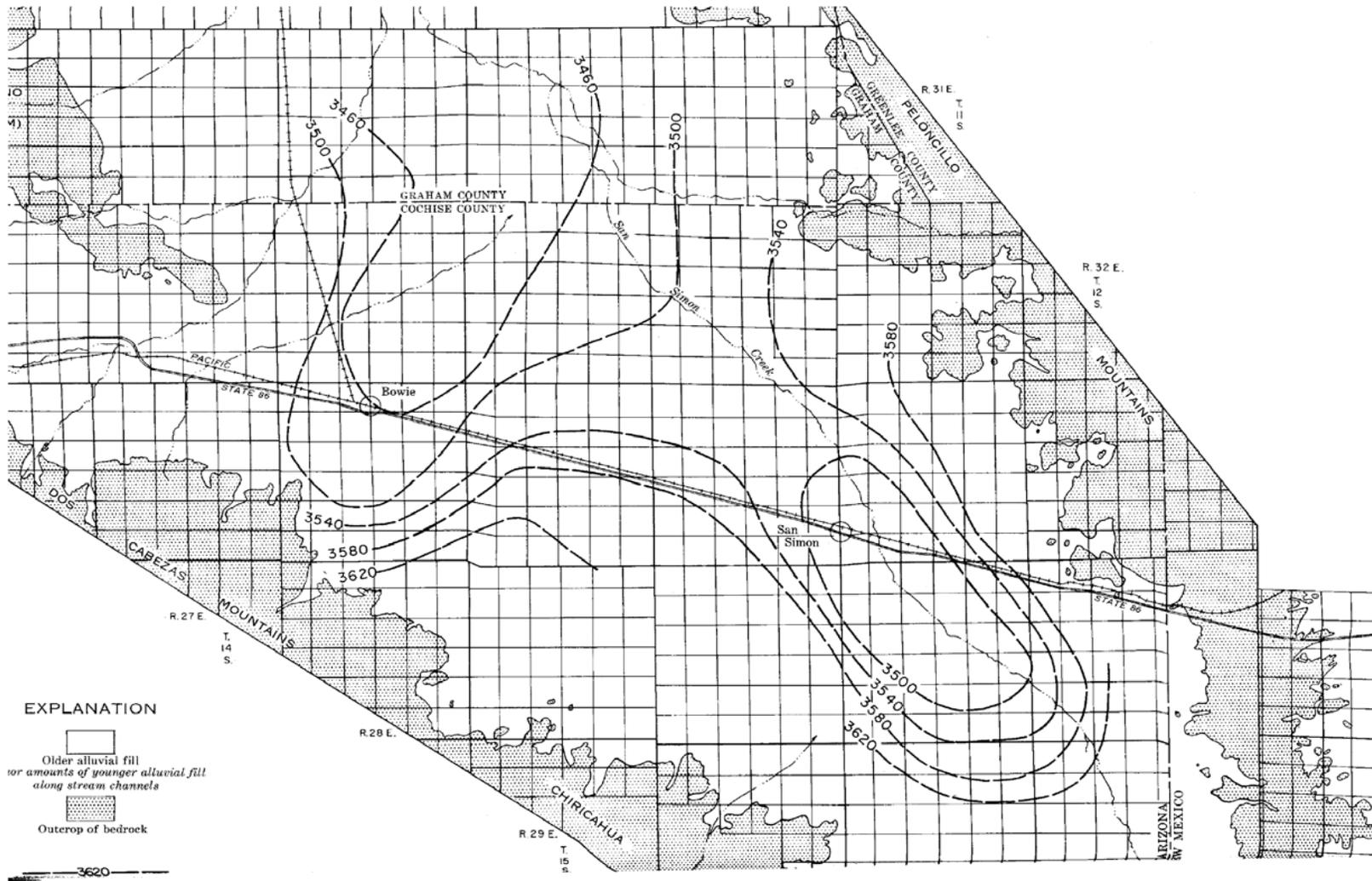


Figure 17 Electric-Analog Model Simulated Water Levels in 1980 (from WSP 1809-R, Plate 2C)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

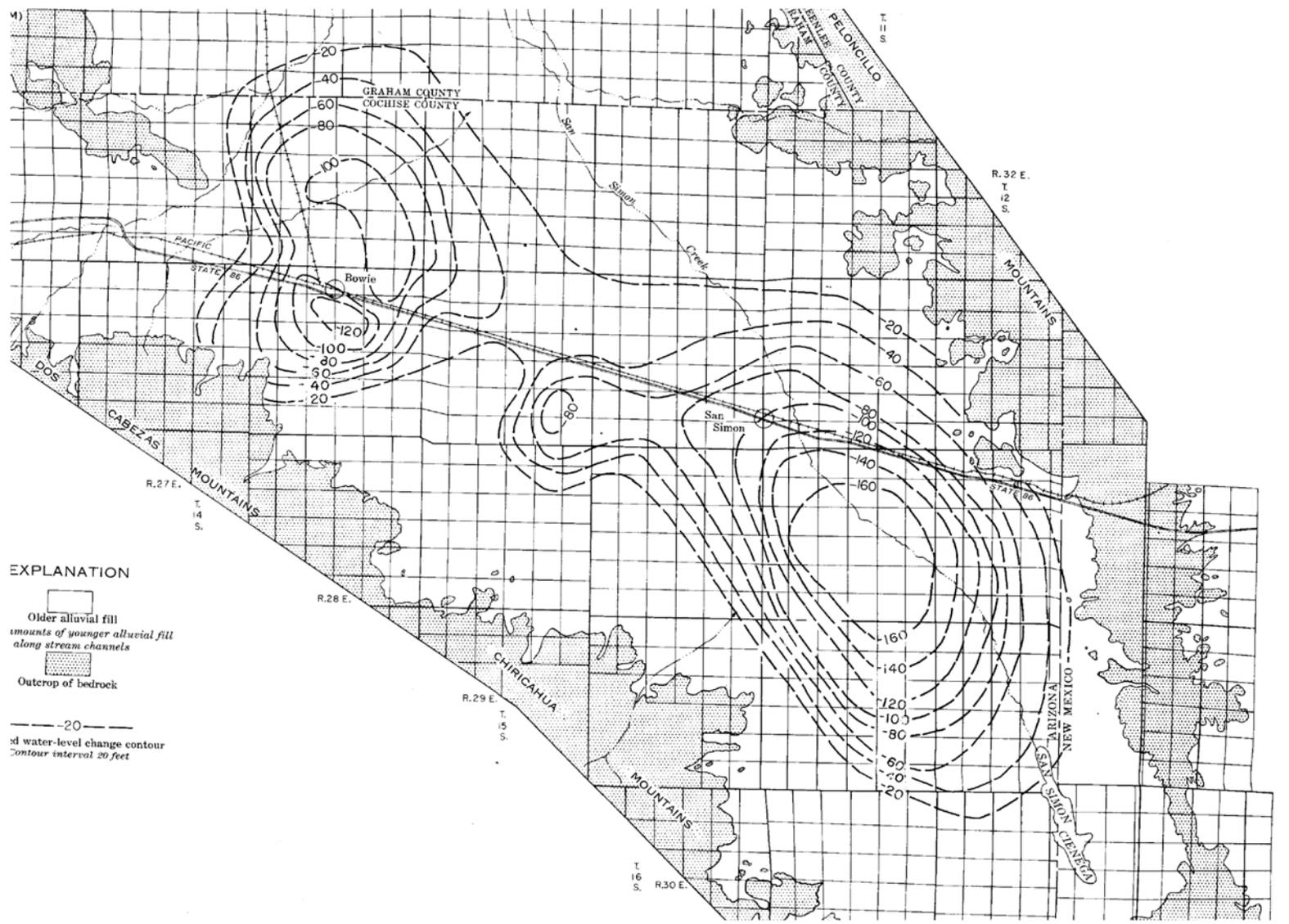


Figure 18 Electric-Analog Model Simulated Change in Water Levels 1960-1980 (from WSP 1809-R, Plate 2B)

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

Wilson, R.P., and White, N.D., 1976. Maps Showing Ground-water Conditions in the San Simon Area, Cochise and Graham Counties, Arizona, and in Hidalgo County, New Mexico-1975. United States Geological Survey Water-Resources Investigations 76-89 Open-File Report.

This report summarizes water level, pumping and groundwater quality data for the lower artesian aquifer system in the Bowie-San Simon area, and for other parts of the San Simon Valley. Depth to water, well depth and the altitude of the water level in 1975 are shown in Figure 19.

The 1975 water level data presented in this report show similar groundwater flow paths, hydraulic gradients and water level elevations compared to the electric-analog model projected groundwater flow system in 1980 (Figure 17). The water level contours show a general direction of groundwater flow from southeast to northwest, sub-parallel to the axis of the San Simon Valley with complex flow paths occurring near the groundwater depressions located in the vicinity of the San Simon and Bowie pumping centers. By 1975, the data indicate that groundwater withdrawals in the artesian aquifer in the Bowie area had altered earlier groundwater flow paths, and causing groundwater flow from San Simon to toward the Bowie area (Figure 19).

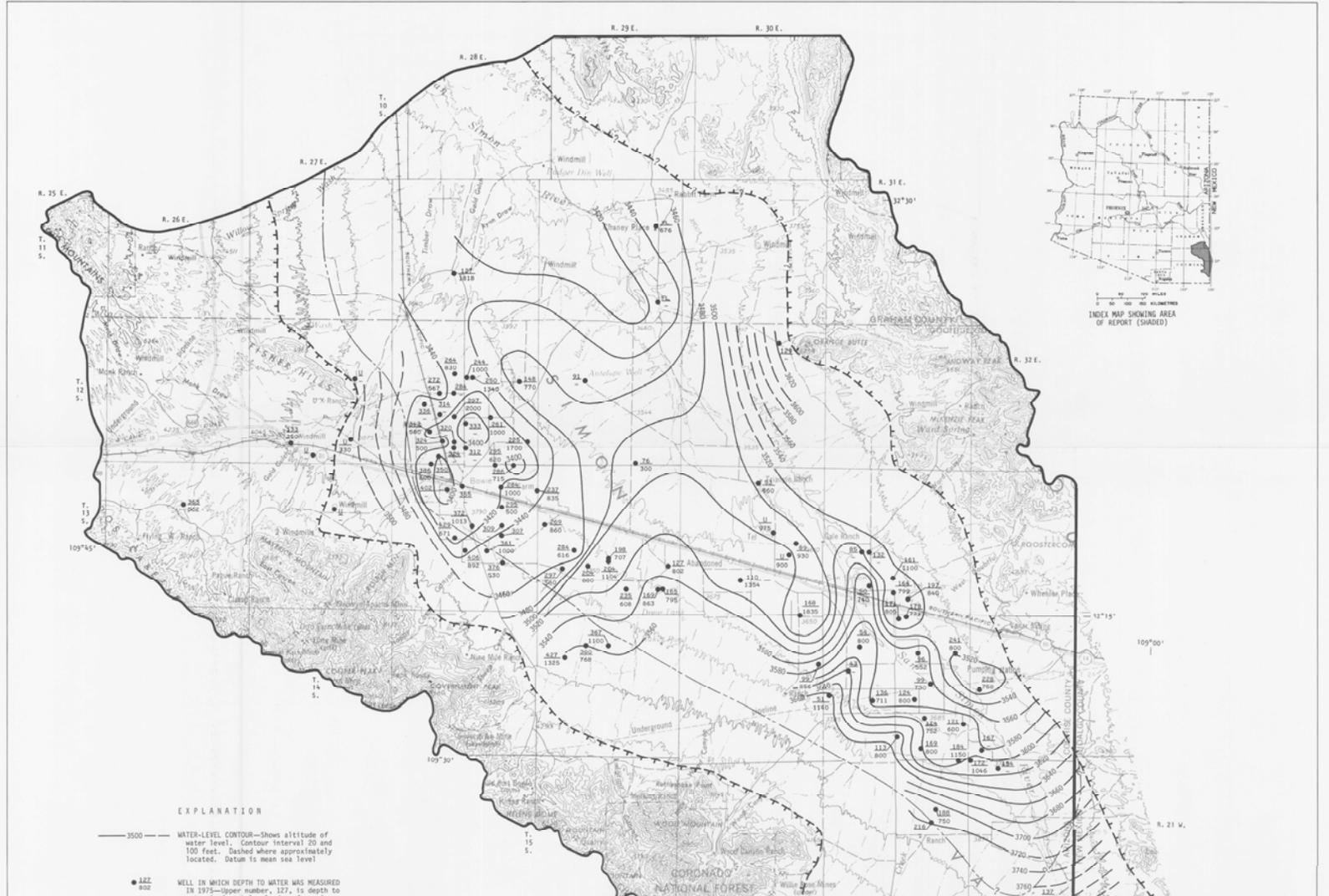


Figure 19 Depth to Water, Well Depth and Altitude of the Water Level in 1975 (from USGS WRI 76-89, Plate 1)

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

Witcher, J.C., 1981. *Geothermal Resource Potential of the Safford-San Simon Basin, Arizona. Arizona Geological Survey Open-File Report 81-26.*

This report presents data and interpretations related to geothermal potential in various areas in the Safford basin. The report presents separate analyses for both the San Simon and Bowie areas. In the discussion of the Bowie area, Witcher reports on the analysis of Eaton (1972) who postulated, on the basis of gravity data, the existence of a graben (a depression or basin-like structural feature in the bedrock likely caused by faulting) in the Bowie area (see Figure 20). According to Witcher (1981), "Gravity interpretation by Eaton (1972) shows a graben, which is about five miles wide and filled with up to 760 m of clastic sediment. Tertiary volcanic rock[s], 300 to 600 m thickness are modeled to underlie the basin-fill sediments". The location of the gravity profile is shown as profile line, A-A', on Figure 21.

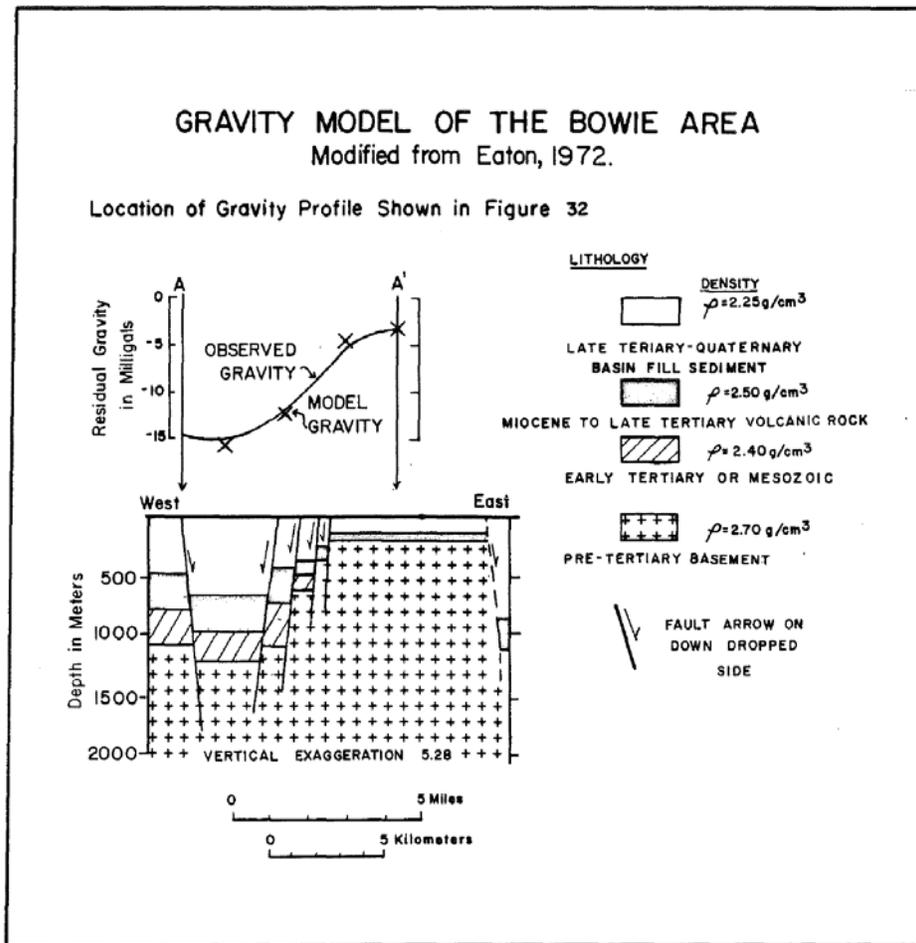


Figure 20 Gravity Model of Bowie Area based on Eaton (1972)(from AZGS OFR 81-26, Figure 31)

BOUGUER GRAVITY MAP OF BOWIE AREA WITH LOCATIONS OF GROUND-WATER FALLS AND PROFILE USED TO MODEL SUBSURFACE STRUCTURE

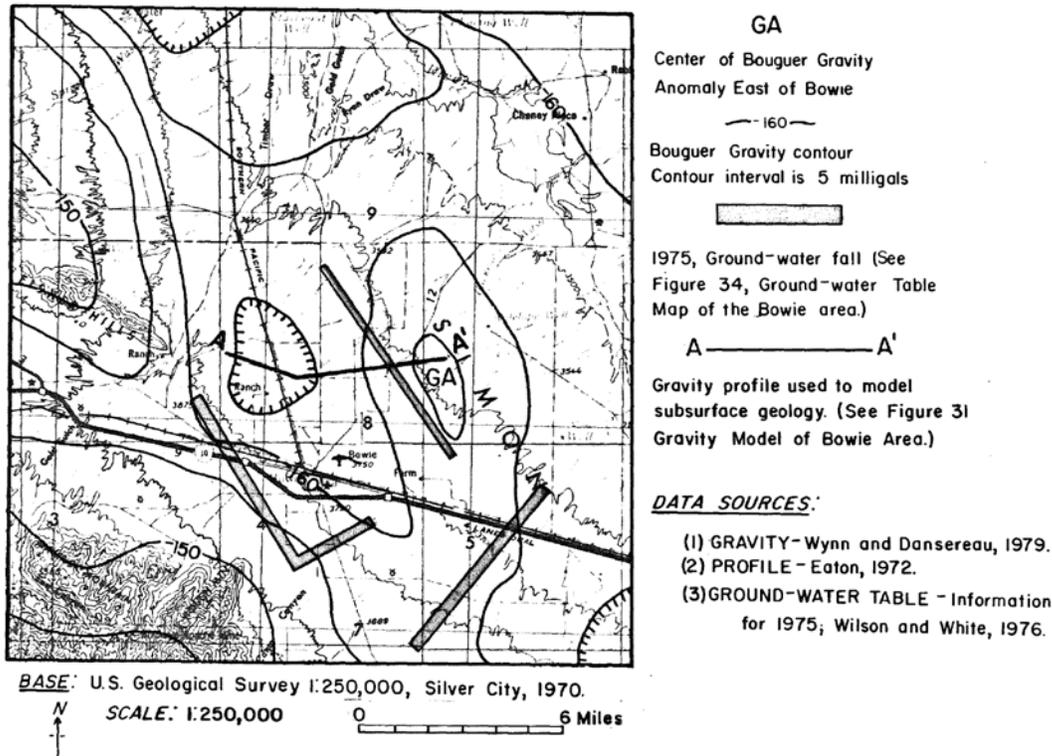


Figure 21 Bouguer Gravity Map of Bowie Area (from AZGS OFR 81-26, Figure 32)

Eaton's interpretation of gravity data indicates the existence of a graben located north of the Bowie area. Eaton's interpretation of the gravity data indicates that the graben is bounded to the east-northeast by up-faulted block of shallow bedrock (a horst) (Figures 20 and 21). Witcher discusses the presence of "groundwater falls" based on the interpretation of 1975 water level data (Figure 19) that are located to the southwest, southeast and northeast of the graben area (Figure 21). Witcher postulates that the groundwater falls may correspond to low permeability zones that are caused by faults that bound the graben area. However, whether low permeability or low transmissivity zones exist in those areas or not, the available water level data (Figure 19) indicate hydraulic connectivity between the Bowie and San Simon areas.

Wynn, J.C., 1981. Complete Bouguer Anomaly Map of the Silver City 1' x 2' Quadrangle, New Mexico-Arizona. United States Geological Survey Miscellaneous Investigations Series, MAP I-1310-A.

Figure 22 shows a gravity anomaly (low/high zones) located in the area north and northeast of Bowie that was interpreted by Eaton (1972) as a graben/horst feature (Figure 20). Factors that may affect the interpretation of gravity data in that general area are discussed beginning on Page 51, below.

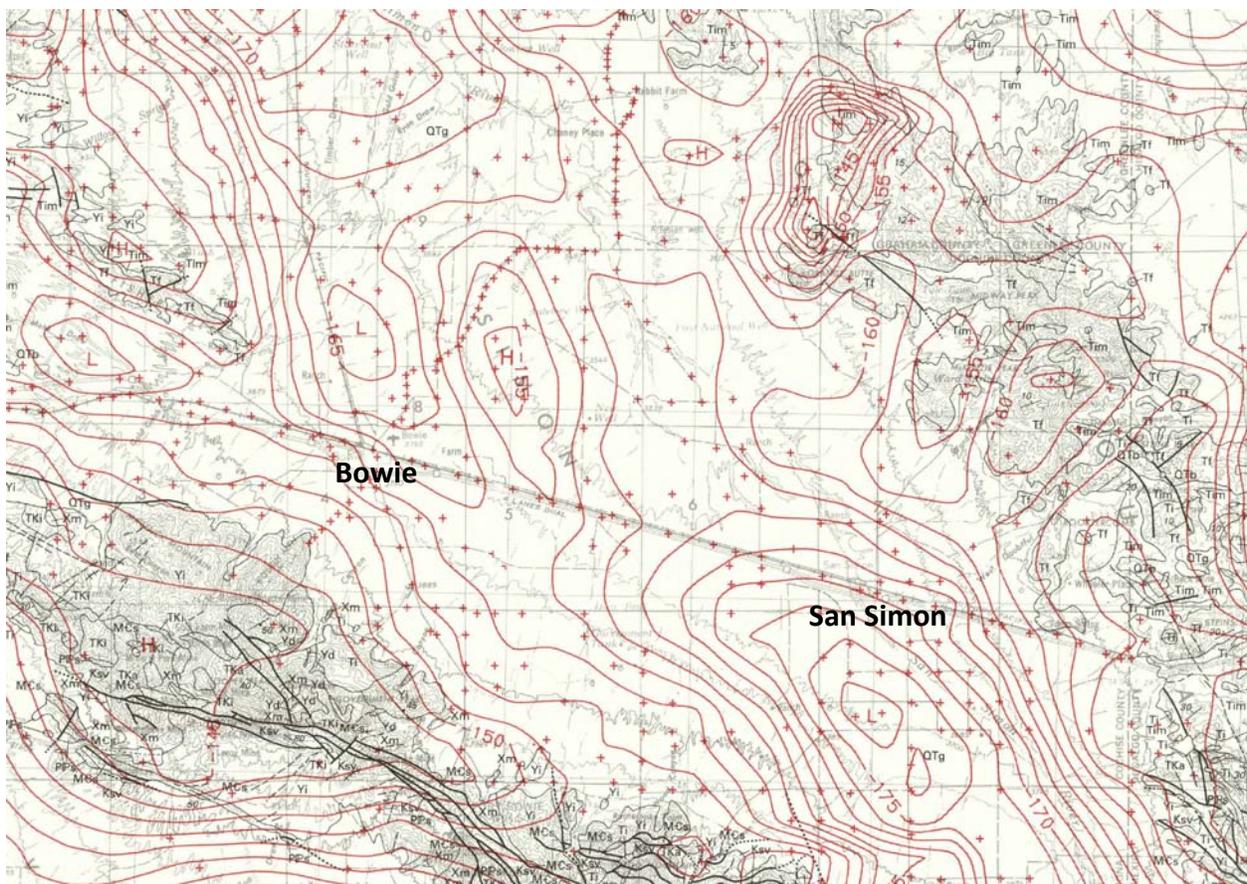
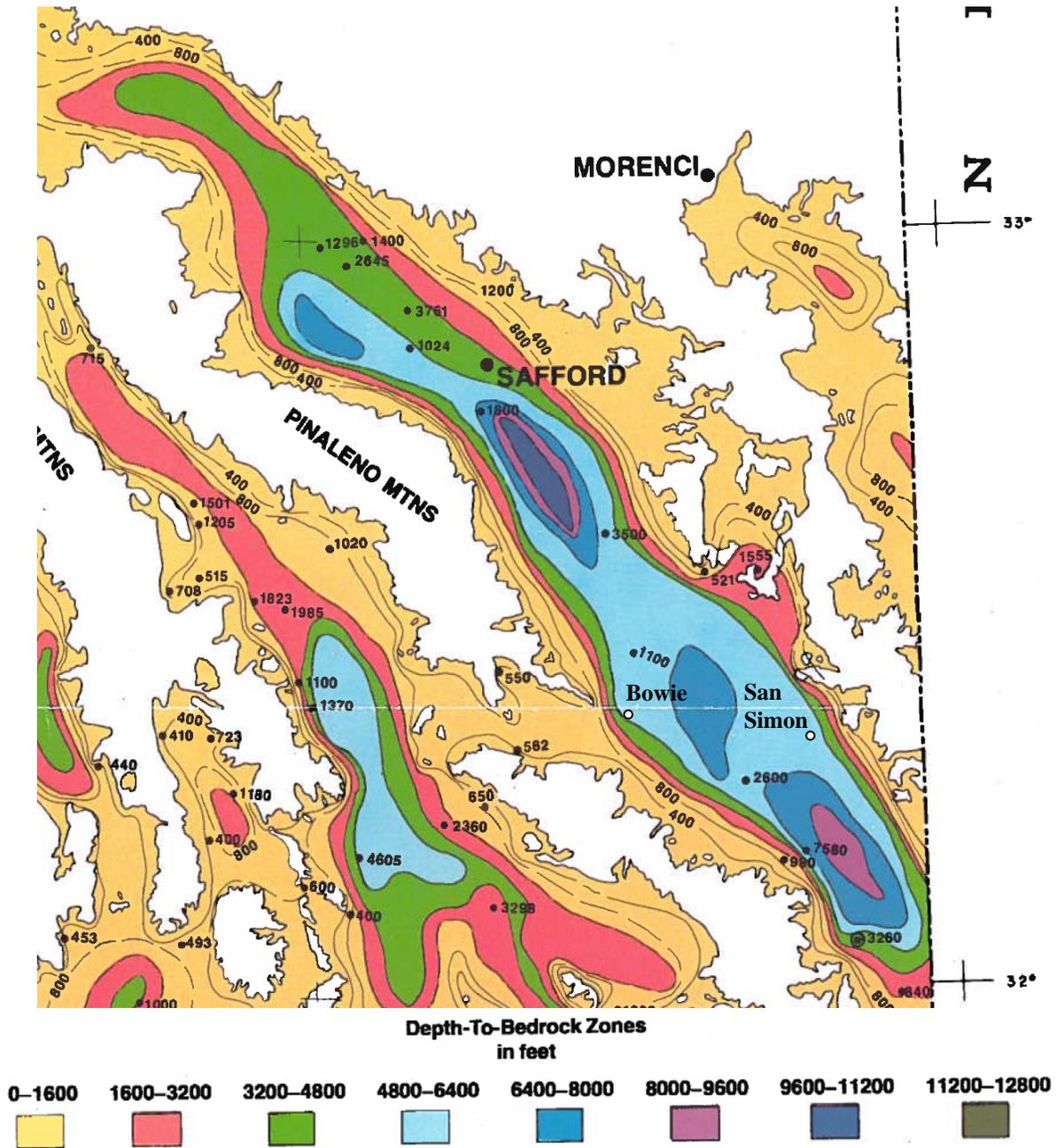


Figure 22 Complete Bouguer Anomaly Map of the Silver City 1' x 2' Quadrangle, New Mexico-Arizona. (from USGS MIS, MAP I-1310-A).

Oppenheimer, J.M. and Sumner, J.S., 1980. Depth-To-Bedrock Map, Basin and Range Province, Arizona. Laboratory of Geophysics, University of Arizona, Tucson, Arizona.

Figure 23 shows depth-to-bedrock contours based on the interpretation of gravity data and well log data. The graben feature postulated to exist in the Bowie area (Figures 20 and 21) is not indicated in this interpretation.

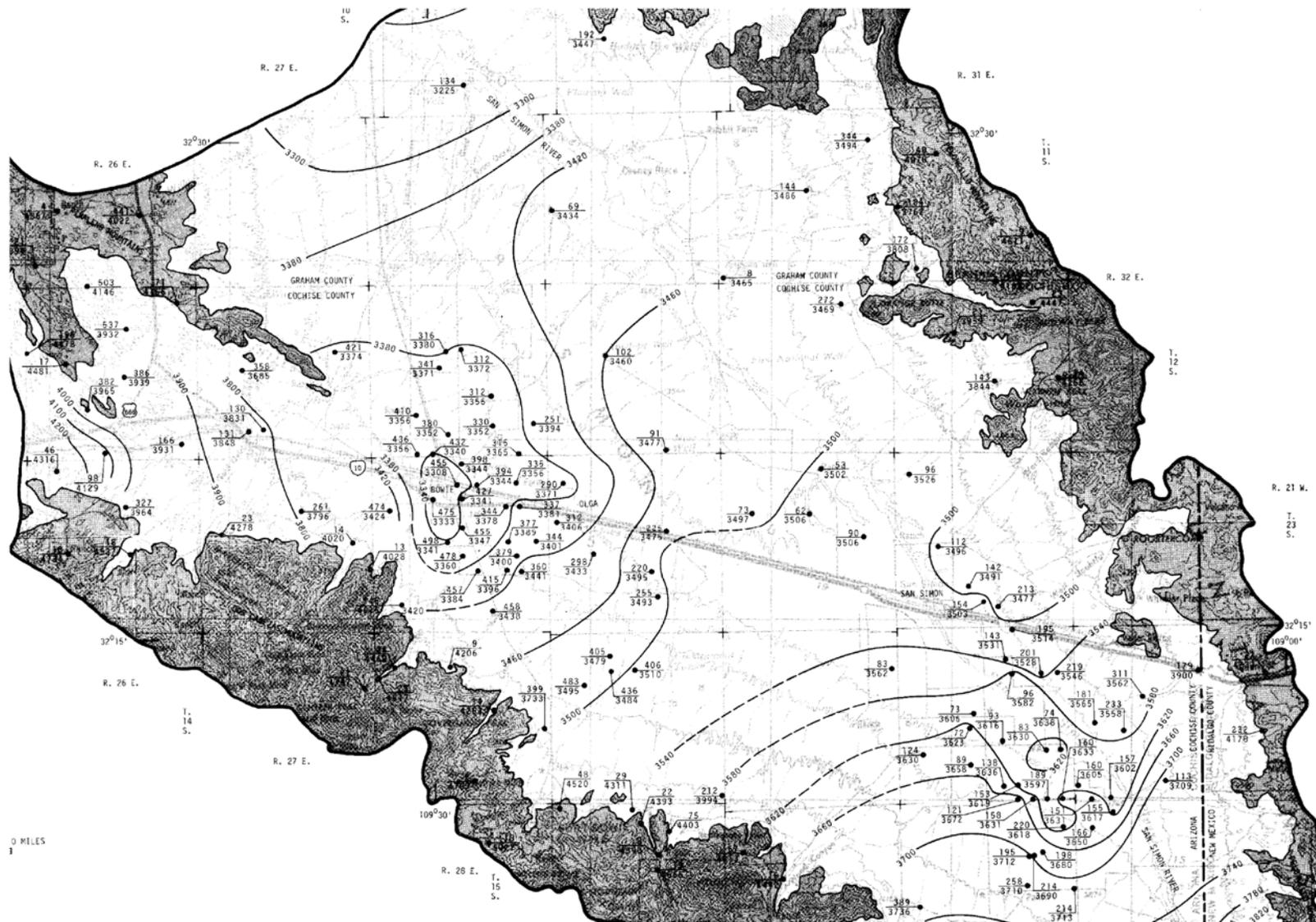


**Figure 23 Depth-to-Bedrock Map, Basin and Range Province, Arizona
(Approximate locations of Bowie and San Simon added)**

Barnes, R.L., 1991. Maps Showing Groundwater Conditions in the San Simon Sub-Basin of the Safford Basin Graham and Cochise Counties, Arizona Hidalgo County, New Mexico – 1987. Arizona Department of Water Resources Hydrologic Map Series Report Number 19.

This report presents water level, pumping, water quality and hydrogeologic data for the San Simon sub-basin. Figure 24 is a 1987 water level elevation map of the lower (artesian) aquifer in the Bowie-San Simon area. The contoured data clearly indicate groundwater flow from San Simon to the Bowie area in the lower aquifer.

Figure 25 is a 1987 water level elevation map for the upper (water table) aquifer in the Bowie-San Simon area. Figure 26 is a water quality map for the upper and lower aquifers in the Bowie-San Simon area. The data indicate around Bowie all samples from the lower aquifer were below the secondary water quality standard for total dissolved solids (TDS) <500 milligrams\liter (mg/l). However, in the San Simon area, about half the lower aquifer wells sampled showed TDS levels in excess of 500 mg/l (Barnes, 1991). Higher TDS was generally found in water samples from wells that tap the upper aquifer in both the Bowie and San Simon areas where dissolved solids tend to accumulate from the deep percolation of agricultural recharge.



**Figure 24 1987 Depth-to-Water and Water Level Elevation Contours (Lower Aquifer)
Bowie and San Simon area (from Barnes, 1987 Plate 1)**

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

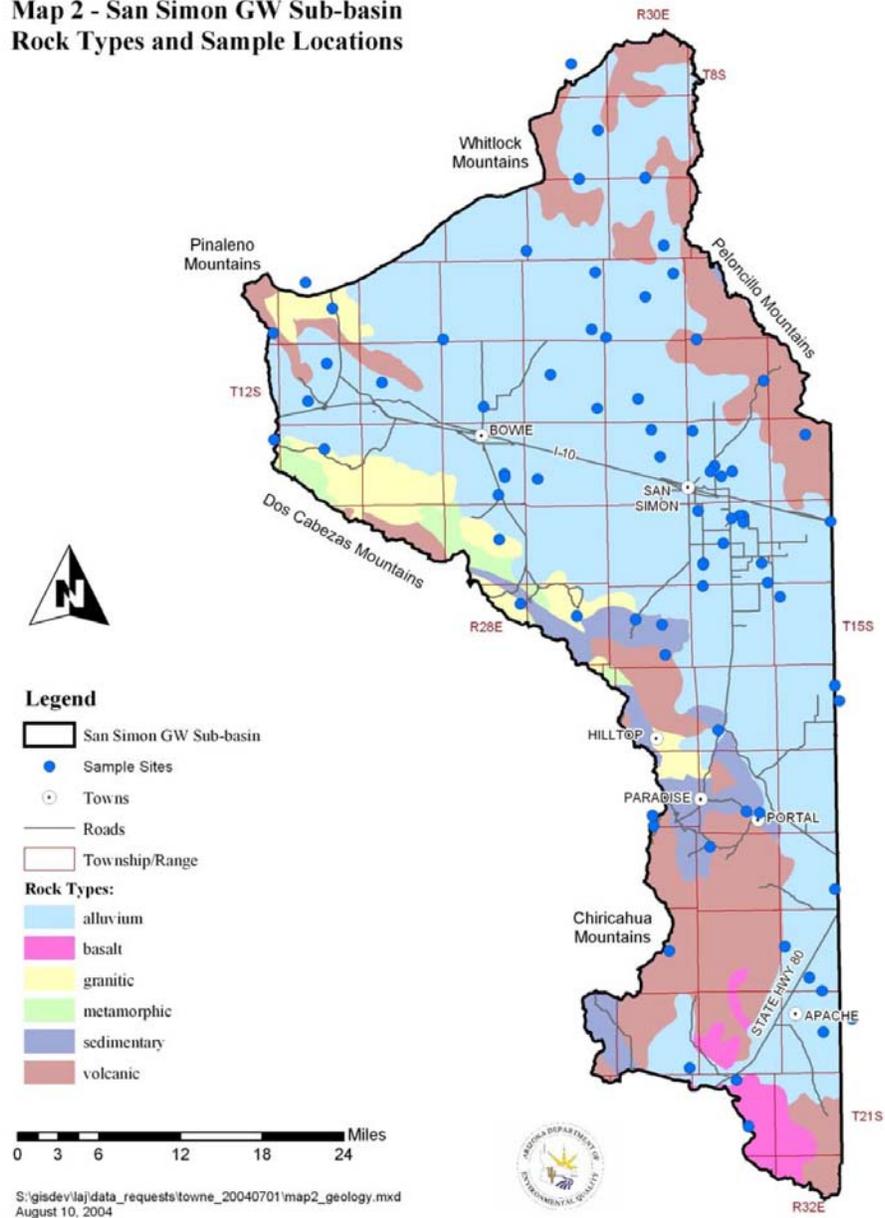
Towne, D.C., and Rowe, L. 2004. Ambient Groundwater Quality of the San Simon Sub-Basin of the Safford Basin: A 2002 Baseline Study. Arizona Department of Environmental Quality Open File Report 2004-02.

Towne and Rowe present an ambient water quality study of the San Simon Valley sub-basin based on 1997 and 2002 water quality samples. Figure 27 shows rock types and locations of wells and springs where groundwater samples were collected. Information presented in the report includes distributions of various cations, anions and general water chemistry in the basin (Figures 28, 29 and 30).

Many water quality patterns in the San Simon and Bowie areas can be explained by past and current agricultural activities that impact recharge to the upper aquifer. According to Towne and Rowe (2004) groundwater in the upper and lower aquifers in the of the San Simon sub-basin north of Interstate 10 is commonly unsuitable for domestic and/or municipal use without additional water treatment. Sample sites near the town of Bowie generally met all health based water quality standards. The majority of sites around the town of San Simon and northwest along the San Simon River exceeded both health and aesthetics-based water quality standards. Northwest of the town of San Simon along the San Simon River, most sites exceeded TDS standards with some slightly saline groundwater with concentrations over 1,000 mg/l (Towne and Rowe, 2004, pg.39).

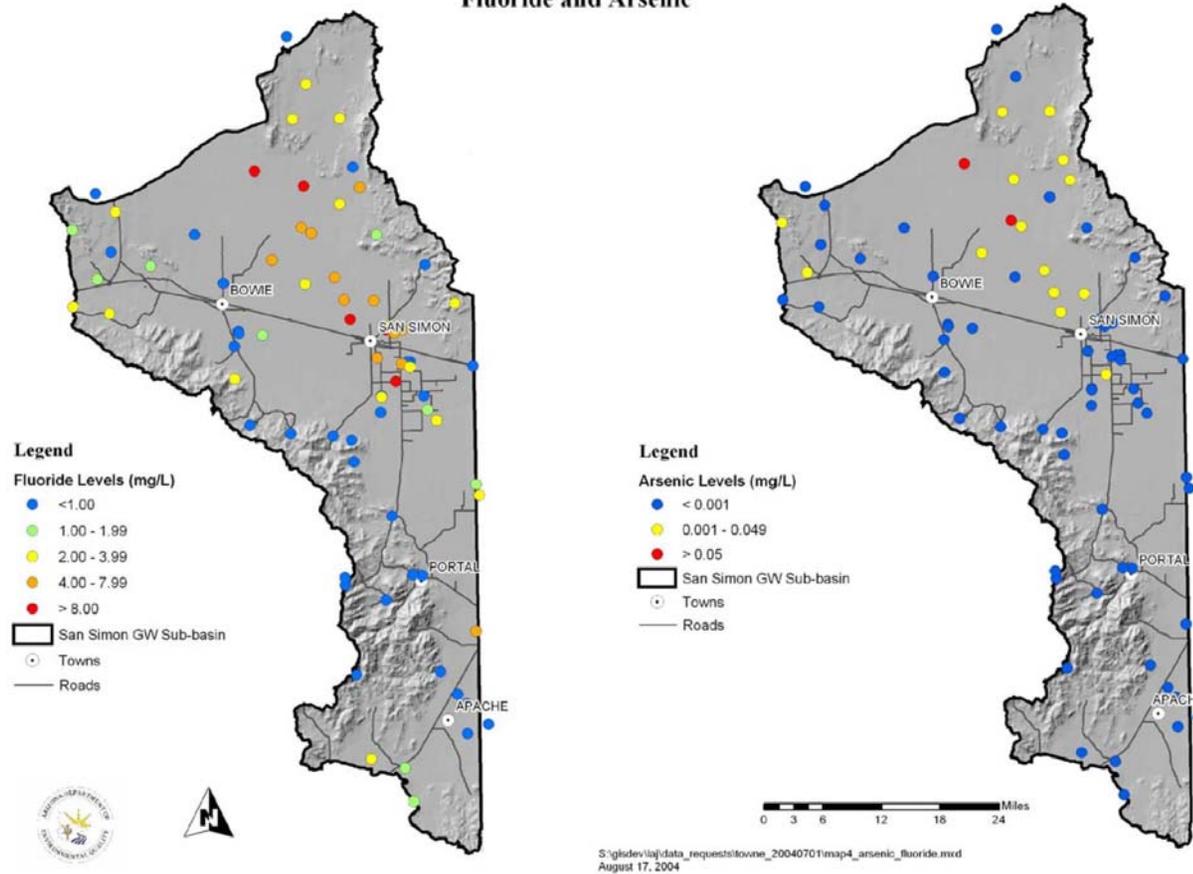
Typical groundwater chemistry for both the San Simon and Bowie areas is generally described as a sodium bicarbonate type (Figure 30). Although chemical constituents and concentrations display some degree of vertical and lateral variability within the San Simon Valley, there is no geochemical evidence that suggests groundwater in the upper and lower aquifers in the Bowie and San Simon areas is hydraulically disconnected. Similar variations in water quality both spatially and between aquifer units within groundwater basins and sub-basins is exhibited throughout the State.

**Map 2 - San Simon GW Sub-basin
Rock Types and Sample Locations**



**Figure 27 Rock Types and Sample Locations in San Simon GW Sub-basin
(from Towne and Rowe, 2002, Map 2).**

**Map 4 - San Simon GW Sub-Basin
Fluoride and Arsenic**

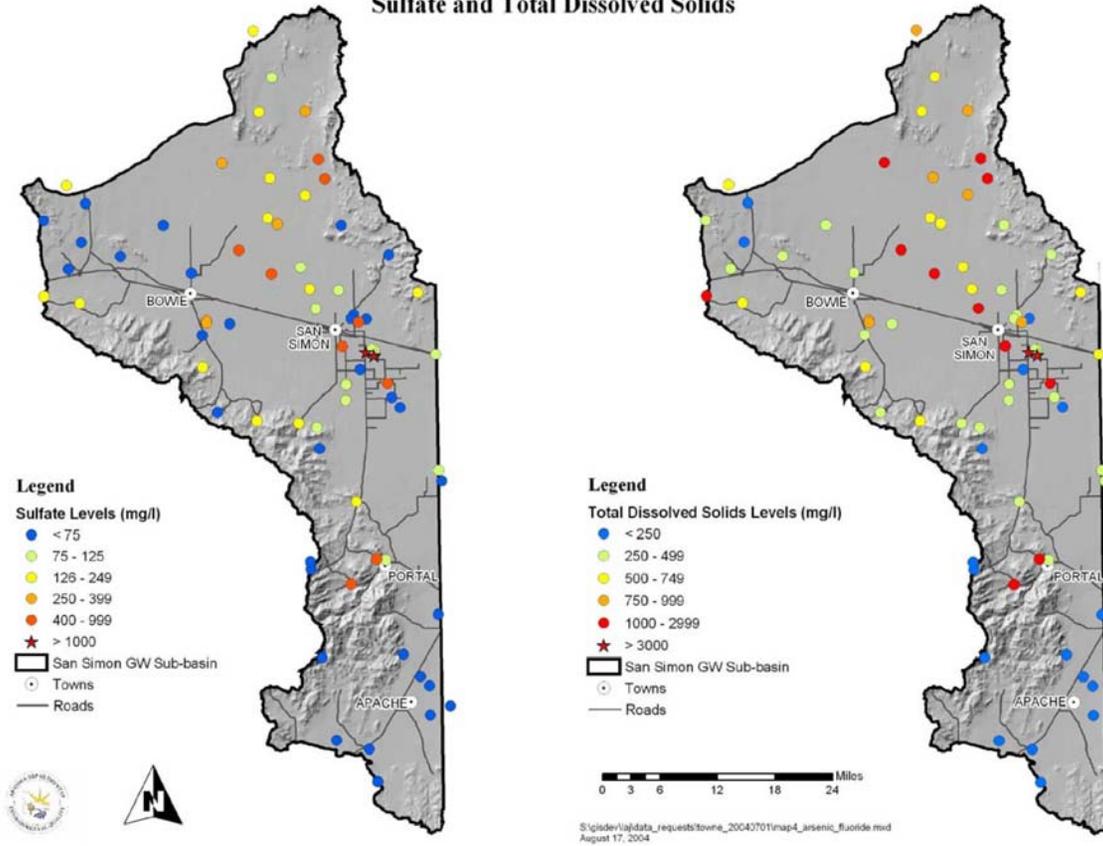


17

Figure 28 Map Showing Fluoride and Arsenic Concentrations (from Towne and Rowe, 2002, Map 4)

Evaluation of Available Scientific Data Related to the
 Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

**Map 6 - San Simon GW Sub-Basin
Sulfate and Total Dissolved Solids**



20

Figure 29 Map Showing Sulfate and TDS Concentrations (from Towne and Rowe, 2002, Map 6)

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

**Map 7 - San Simon GW Sub-basin
Water Chemistry**

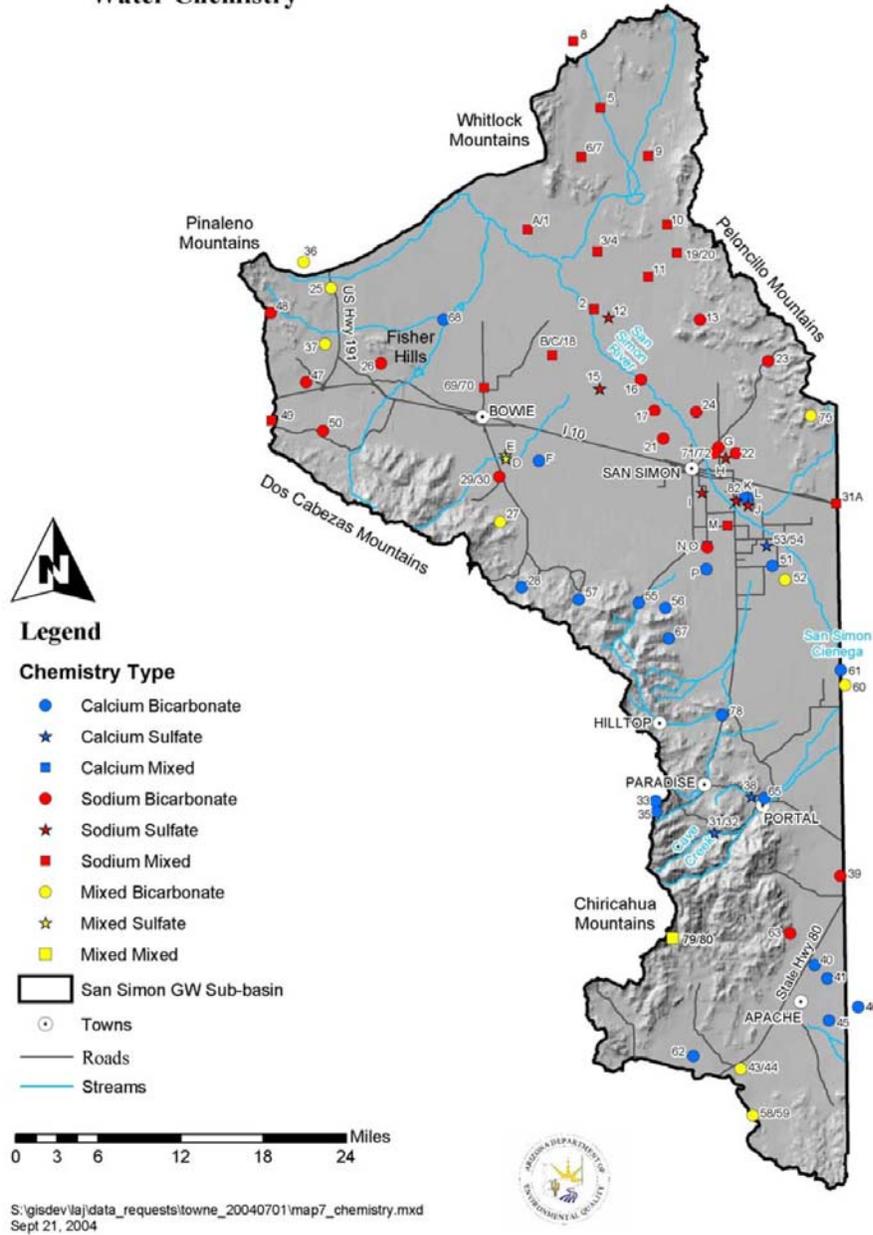


Figure 30 Map Showing Water Chemistry (from Towne and Rowe, 2002, Map 7)

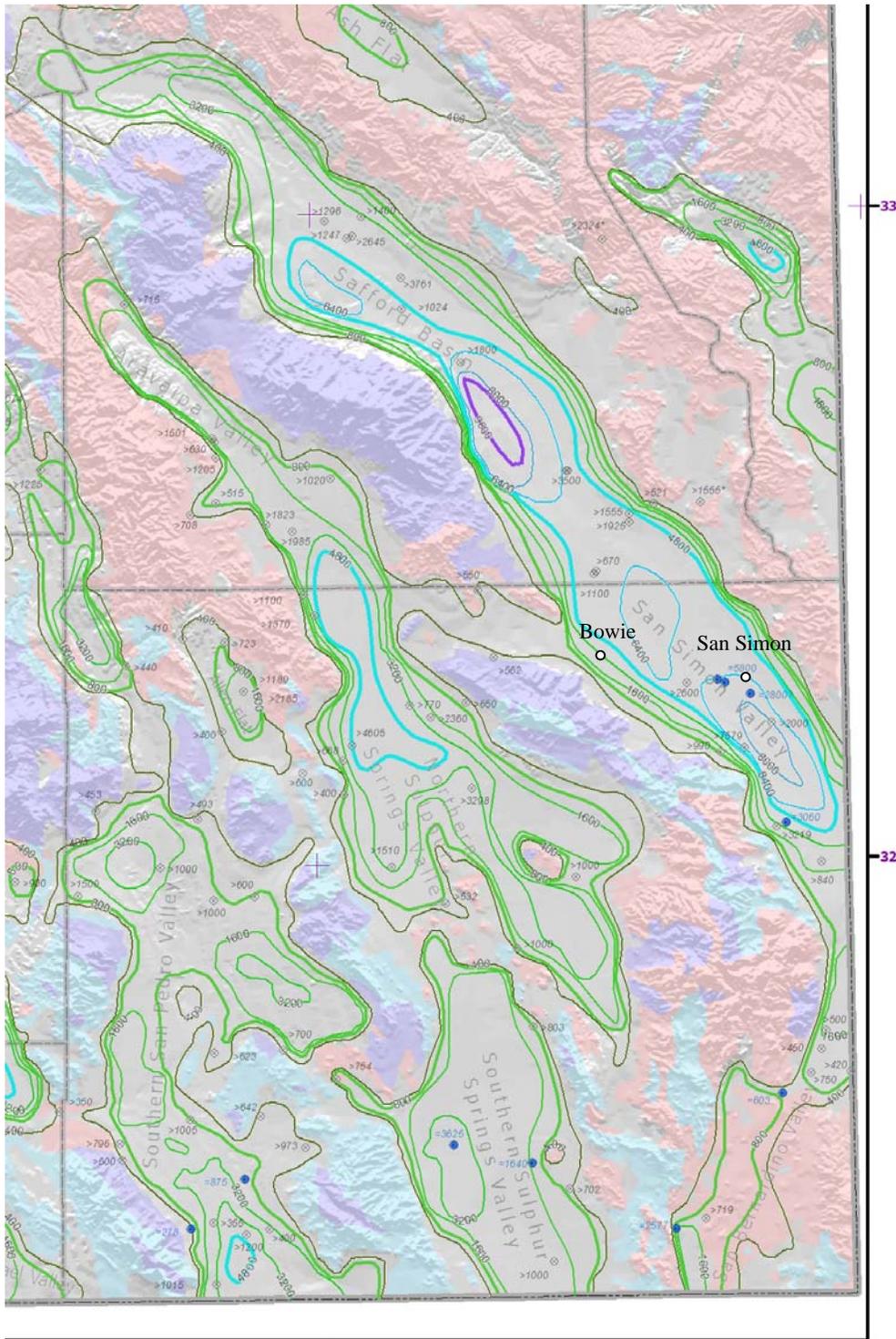
Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

AGS, 2007. Estimated Depth to Bedrock in Arizona. Arizona Geological Survey Digital Geologic Map Series, DGM-52 2007, Version 1.0.

This report updates the 1980 Oppenheimer and Sumner depth-to-bedrock map (Figure 23). A variety of additional sources were used to update the 1981 depth to bedrock contours including additional well control data from published and unpublished Arizona Oil and Gas Commission wells, ADWR Wells 55 and GWSI database wells, an Arizona well inventory by (Pierce and Scurlock, 1972) and from consultant's reports.

According to the report, "Contour lines from Oppenheimer and Sumner (1980) were revised or, in places, replaced with new interpretations based on all the available information using map overlays in an ESRI ArcMap project. The greatest changes are in the interpretation of basin geometry away from the gravity profiles constructed by Oppenheimer and Sumner (1980), where the Saltus and Jachens (1995) or other more recent basin studies were considered more accurate depictions of subsurface geometry. Where bedrock outcrops were intersected by contours showing significant basin depth, the contour lines have been adjusted to be consistent with the bedrock outcrop".

Review of this map compared to the Oppenheimer and Sumner (1980) reveals no significant reinterpretation in estimated depth-to-bedrock for Bowie – San Simon area (Figure 31). The graben/horst feature postulated by Eaton (1972) is not shown on in this map.



**Figure 31 Depth-to-Bedrock Map of Safford Basin Area
 (from AGS(2007), DGM-52, Version 1.0, Plate 1)
 (Approximate locations of Bowie and San Simon added)**

Ivanich, P., 2012. Memo from Paul Ivanich, ADWR Field Services Section, to Frank Corkhill concerning interpretation of Safford Basin gravity data .(unpublished)

Ivanich (2012) describes the existing gravity data in the Safford groundwater basin in southeastern Arizona and explains the two previous depth-to-bedrock studies done using gravity data in the area, Oppenheimer and Sumner (1980) and Gootee (2012).

A large number of gravity data points have been collected in the Safford Basin. The Pan-American Center for Earth & Environmental Studies (PACES, 2009) dataset contains over 4000 gravity points within the basin boundary (Figure 32). The data coverage is very good, with gravity data points collected roughly every one mile in much of the basin. The data contain Complete Bouguer Anomaly (CBA) values for each gravity point, which can be gridded to show the CBA in the basin (Figure 33).

The CBA is a representation of lateral density variations in the subsurface, which could be due to shallow or deep sources. Shallow sources of density variations include different thicknesses of alluvial basins, the presence of different rock types, or the presence of evaporites or ore bodies. Deep sources can include variations in crustal thickness, of which the general dip of the CBA to the northeast in the Safford basin is an example.

An apparent gravity high (a relative high in the CBA) exists to the east and northeast of Bowie (Figure 33). It is relatively small compared to the entire basin. A gravity model reported in Witcher (1981) (modified from Eaton, 1972) suggests that the gravity high east of Bowie is evidence of a horst, and that a grabben exists to its west (Figures 20 and 21 [this report]). The model suggests a depth-to-bedrock at the horst of approximately 500 ft below land surface (Witcher, 1981, Figure 20 [this report]). This interpretation is contradicted by Oppenheimer and Sumner (1980) and Gootee (2012).

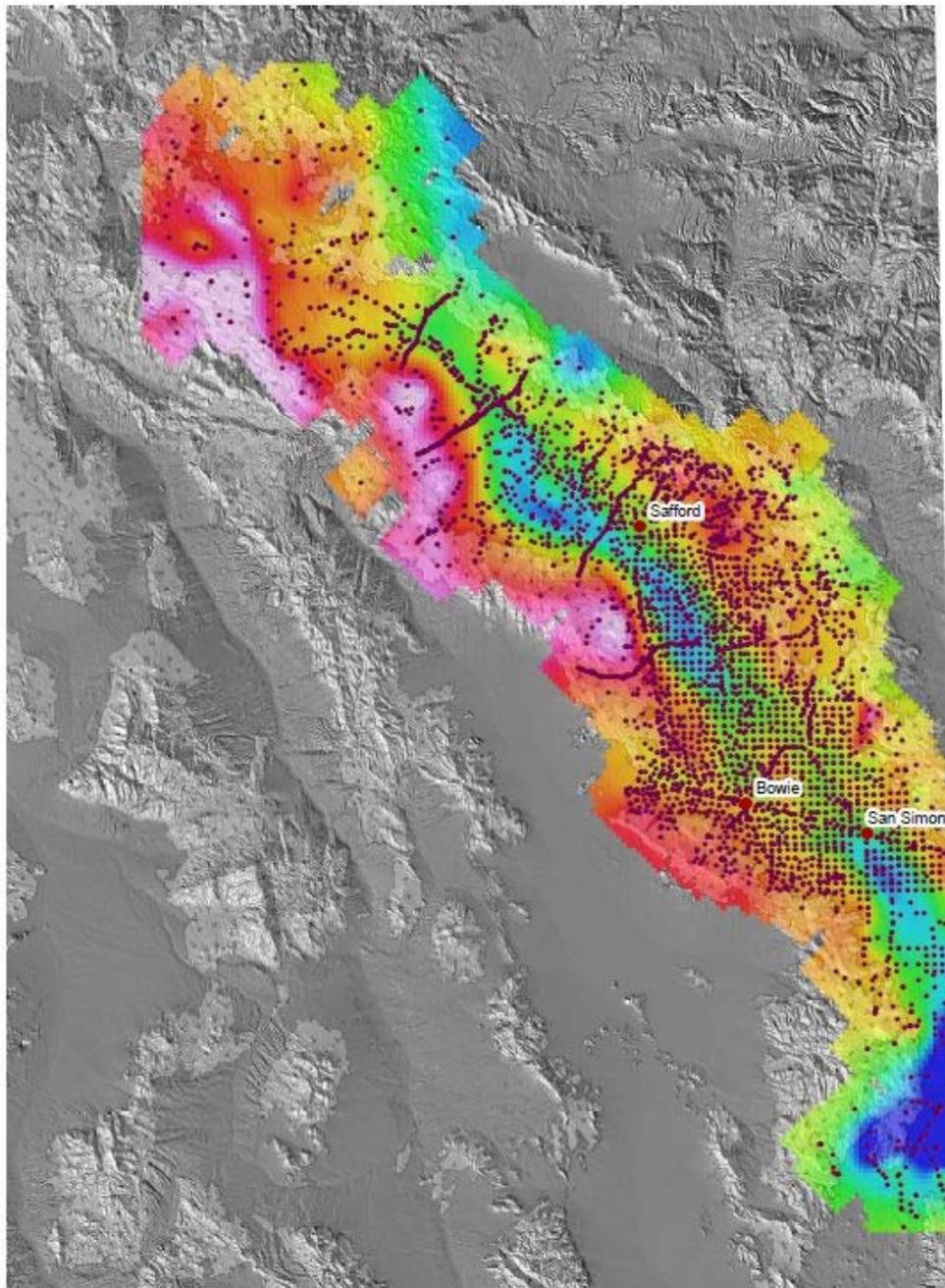
Oppenheimer and Sumner (1980) modeled 20 gravity profiles in the Safford basin for their depth-to-bedrock interpretation. They also included 19 wells for control, one of which penetrated bedrock (at a depth of 3260 ft). Three of their gravity profiles are in the vicinity of the gravity high east of Bowie. One of those intersects the gravity high, but is modeled as thick alluvium (>4800 ft depth-to-bedrock), indicating that they did not interpret the high in the CBA as a horst.

The reason Oppenheimer and Sumner's (1981) model shows this profile as deep (Figure 23 [this report]) is likely due to their methodology for constructing their residual gravity anomaly and the density model they used for the alluvium profile. Oppenheimer and Sumner (1980) assumed that densities in the middle of basins are greater than at the edges, so instead of having a vertical density profile (like a layer-cake), they have a horizontal density profile, where vertical prisms at the edges of basins have lower densities and prisms in the centers of basins have higher densities (see Oppenheimer and Sumner, 1981). Because this gravity high is in the center of the basin, their method would minimize or possibly eliminate an interpretation of a horst there.

One of Gootee's (2012) geological cross-sections through the Safford basin is just south of Bowie (profile G – G', Gootee (2012), Pg. 41). His cross-sections are based on available reports, borehole data and geologic maps. An oil and gas well located approximately 4 – 5 miles

southwest of the gravity high (number 204 in Gootee, 2012) penetrates 4,110 ft of unconsolidated sediments and consolidated sediments, but does not encounter granitic or metamorphic bedrock. The location of the oil and gas well reported in Gootee (2012), in conjunction with the gradient in the CBA between this well and the gravity high (approximately 5 – 10 mGal), does not support an interpretation of a shallow horst east of Bowie. It is possible that a horst/graben structure exists, but that the top of the horst is deep. This could explain both the observed gravity high and the lack of data indicating a hydrologic barrier.

A gravity model is not a unique solution to an observed gravity field. There are many combinations of geologic conditions that can produce similar gravity responses, such as different combinations of geologic unit thicknesses and densities. Choosing a representative density contrast for the units being modeled is an important step in gravity modeling. Because of the non-uniqueness of gravity modeling, it is important to take the known geologic conditions into account. This can include getting good estimates of geologic unit densities and extents in an area, and incorporation of well data.



Complete Bouguer Anomaly (CBA) with Gravity Points
 gridded from PACES Gravity Data (Downloaded 07/28/2009)

CBA (mGal)
Value
 High : -124
 Low : -200

0 10 20 40 Miles

N
 W E
 S

Figure 32 Locations of Gravity Stations in the Safford Basin

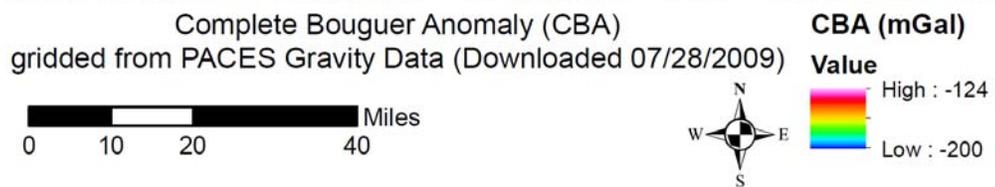
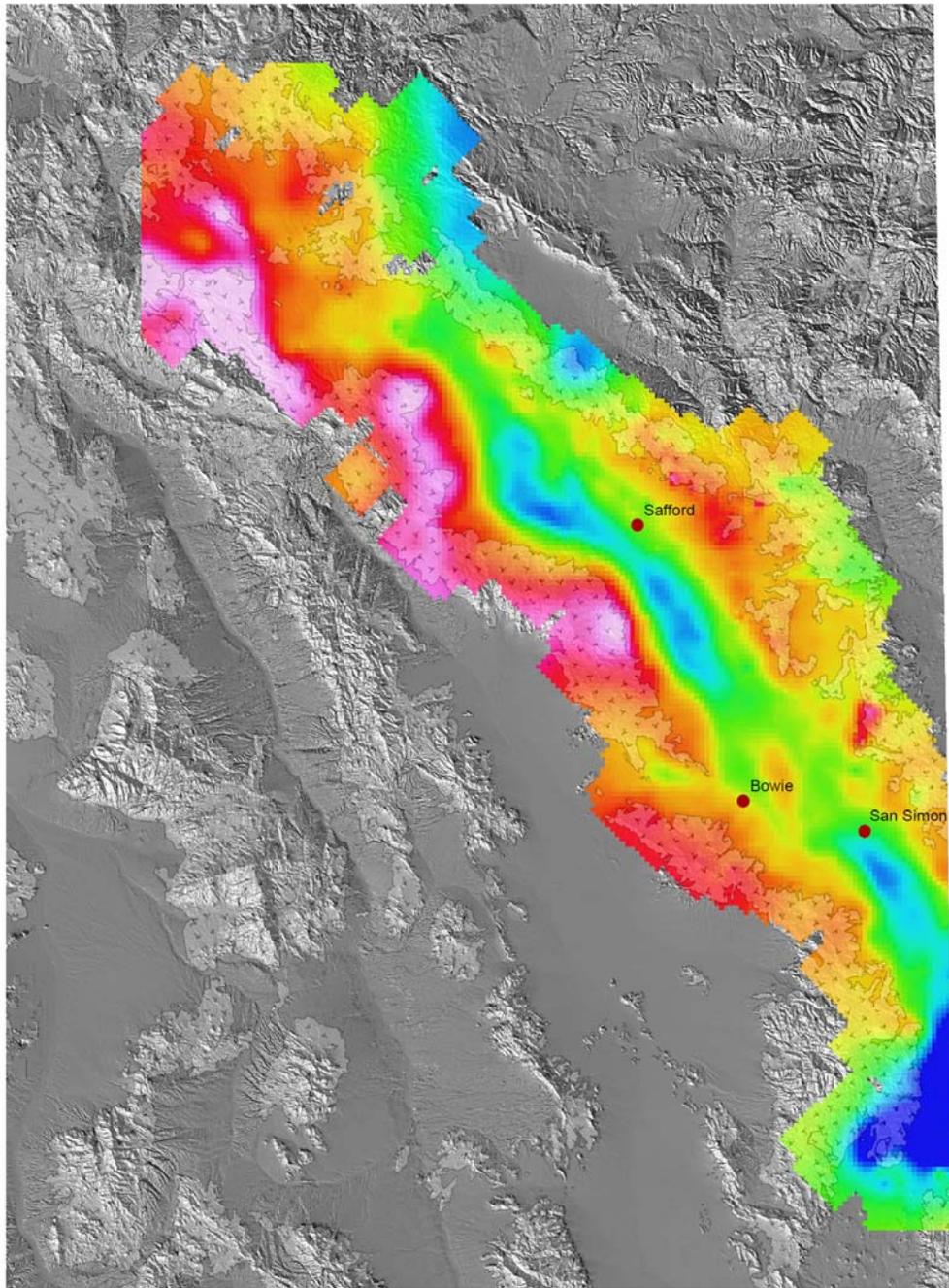


Figure 33 Complete Bouguer Anomaly in the Safford Basin

ADWR GWSI Water Level Data (2007)

ADWR Groundwater Site Inventory (GWSI) water level data have been compiled for 2007, the last year when a significant water level sweep was conducted in the sub-basin (Figure 34). Regional groundwater flow patterns interpreted from water level data are similar to earlier years (see Figures 19 and 24) with regional groundwater flow from southeast to northwest in the sub-basin. However, the groundwater depressions caused by pumping in the San Simon and Bowie areas have deepened and capture substantial local flow from most directions (Figure 34). Groundwater flow from the San Simon to Bowie area is indicated by the water level data.

Water Level Change From 1987-2007 and Hydrographs of GWSI Index Wells

Water level change data from 1987-2007 for the San Simon Valley sub-basin are shown in Figure 35. Significant water level declines, mainly caused by agricultural groundwater withdrawals were noted in most wells in the Bowie and San Simon areas (Figure 35 and Table 2). However, a few wells located west and northwest of San Simon demonstrated water level recovery over that time period (Figure 35). The trends in these wells may be related to reduced or shifted pumping in the general area. The overall trends and patterns of water level change in the Bowie – San Simon area are consistent with an area with two semi-local pumping centers, but reflects no indication of hydrologic isolation between the two centers. The mean water level change in the San Simon Valley sub-basin for the period from 1987 to 2007 was about -16 feet (Corkhill, 2012). Locations of GWSI Index wells in the Bowie – San Simon area are shown on Figure 36. Hydrographs of the wells are shown in the following pages.

2007 Water Level Elevation Map (San Simon Valley Sub-basin)

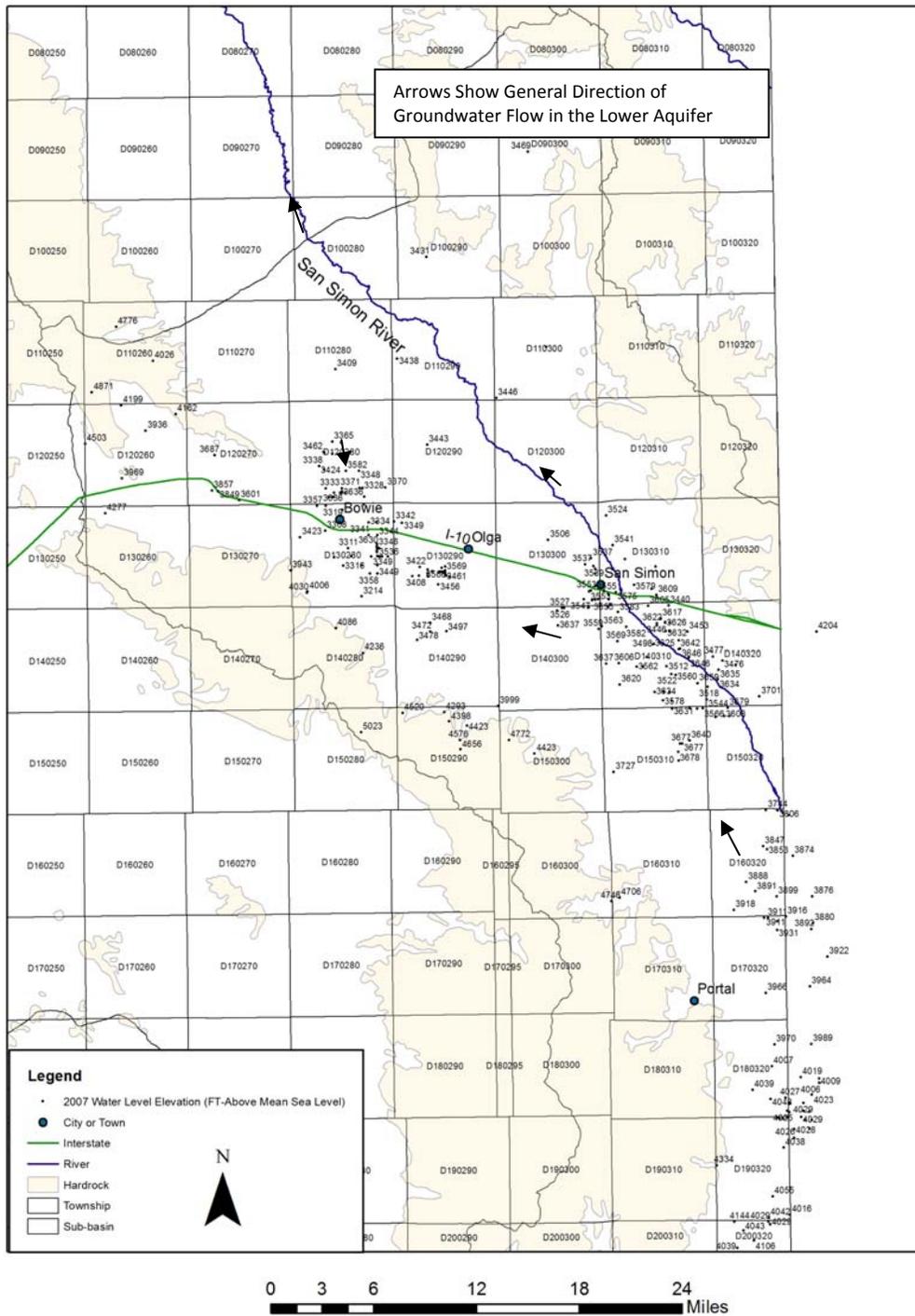


Figure 34 2007 GWSI Water Level Elevations (Bowie-San Simon area)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

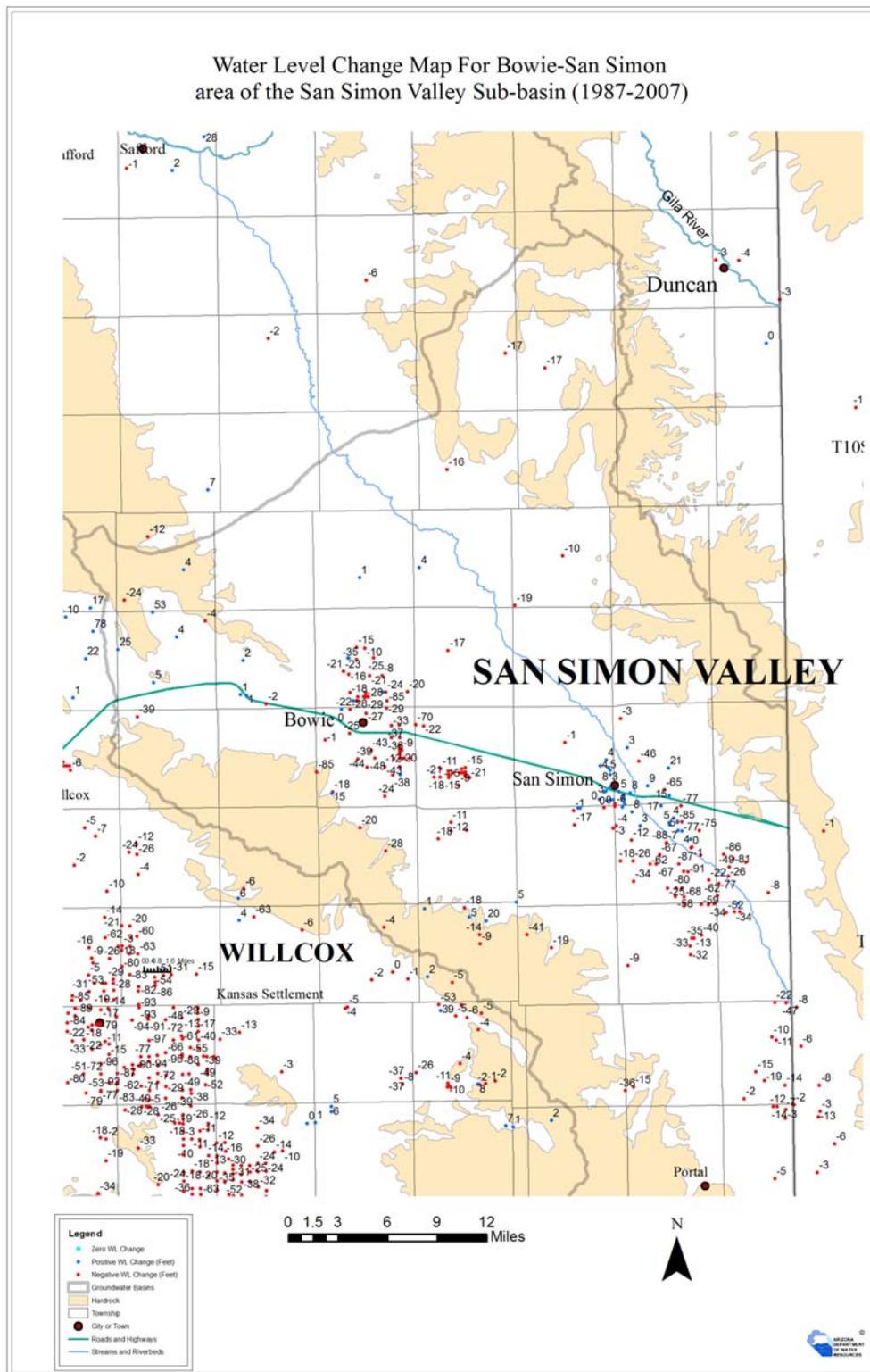


Figure 35 Water Level Change in the Bowie-San Simon Area (1987 – 2007)

Evaluation of Available Scientific Data Related to the
Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

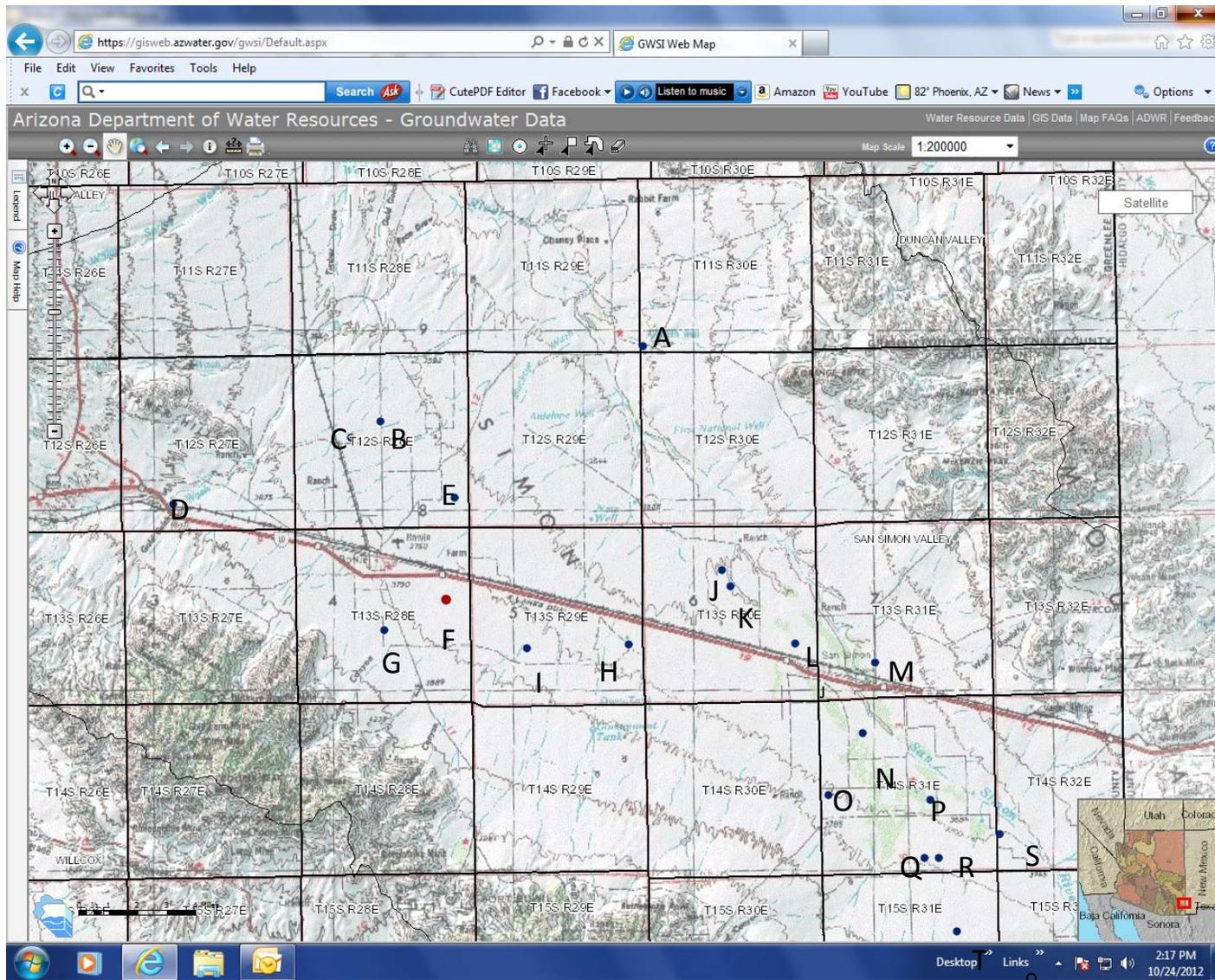
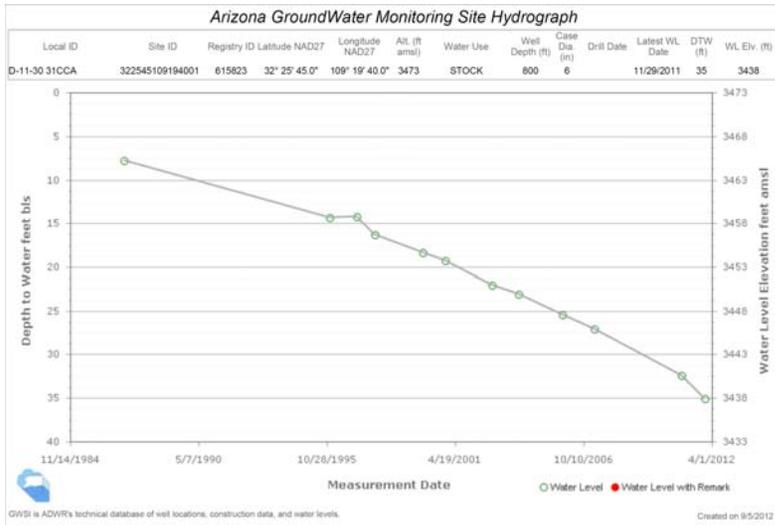
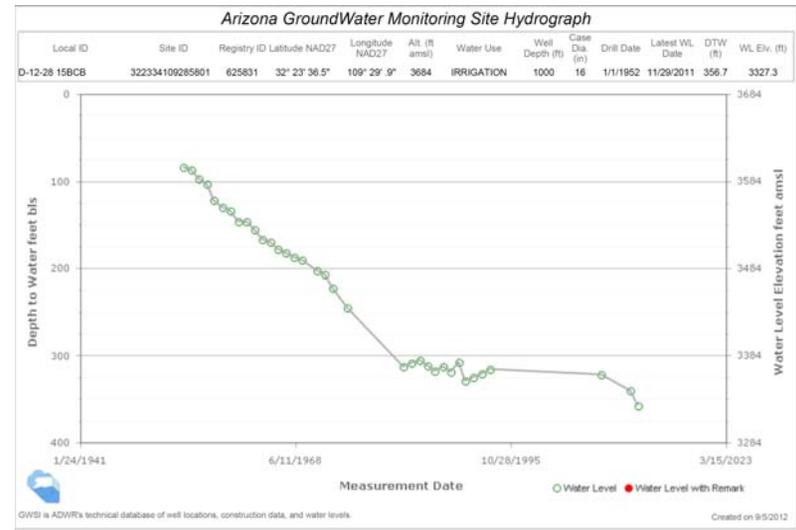


Figure 36 Location of GWSI Index Well With Hydrographs in the Bowie – San Simon Area

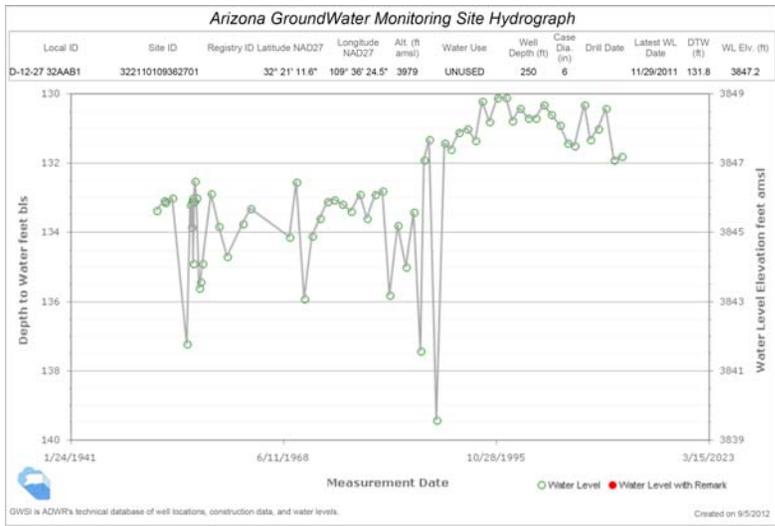
Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



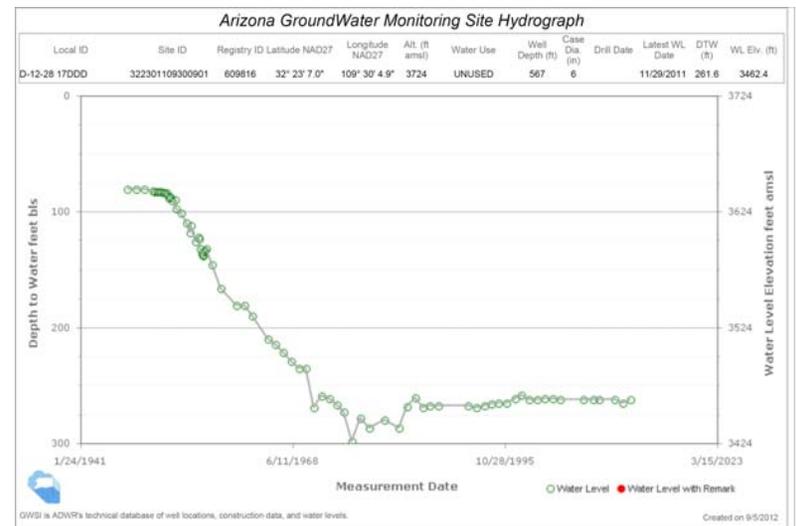
Well A. D-11-30 31CCA (Lower Aquifer)



Well C. D-12-28 15BCB (Lower Aquifer)

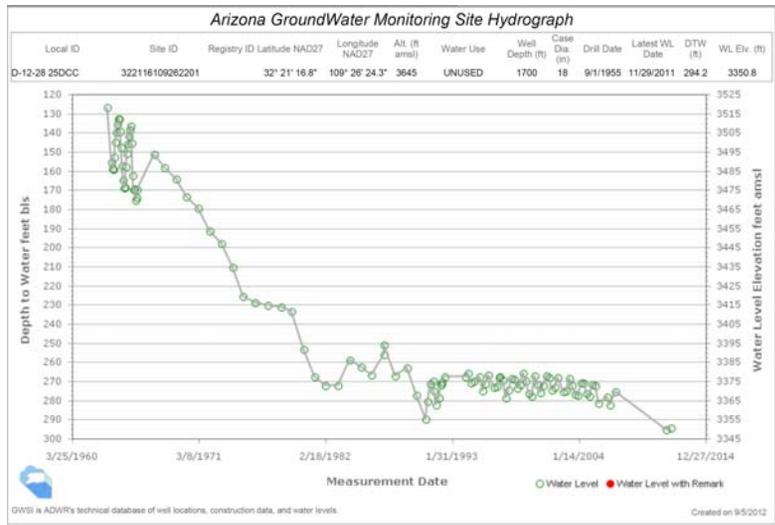


Well B. D-12-27 32AAB1 (Lower Aquifer)

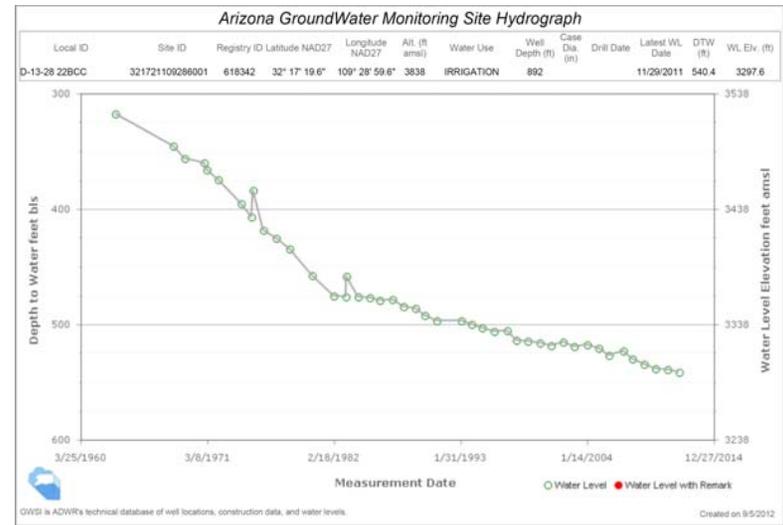


Well D. D-12-28 17DDD (Upper/Lower Aquifer)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



Well E. D-12-28 25DCC (Lower Aquifer)



Well G. D-13-28 22BCC (Lower Aquifer)

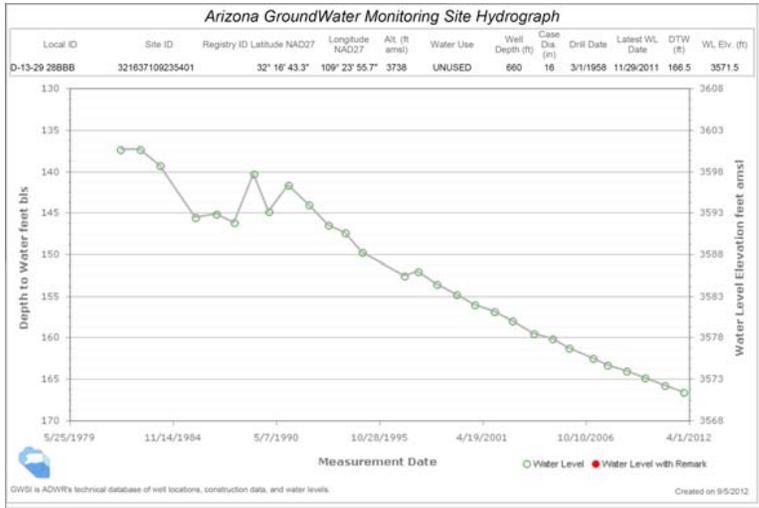


Well F. D-13-28 13BCD (Upper Aquifer)

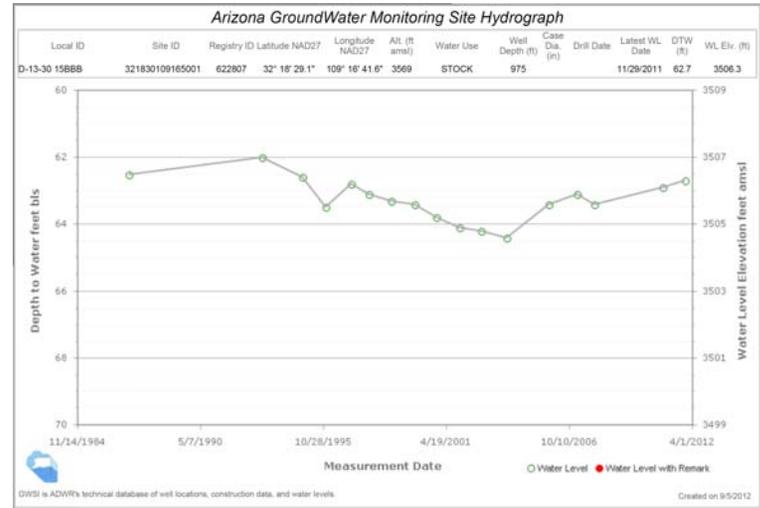


Well H. D-13-29 24DCC2 (Upper Aquifer)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



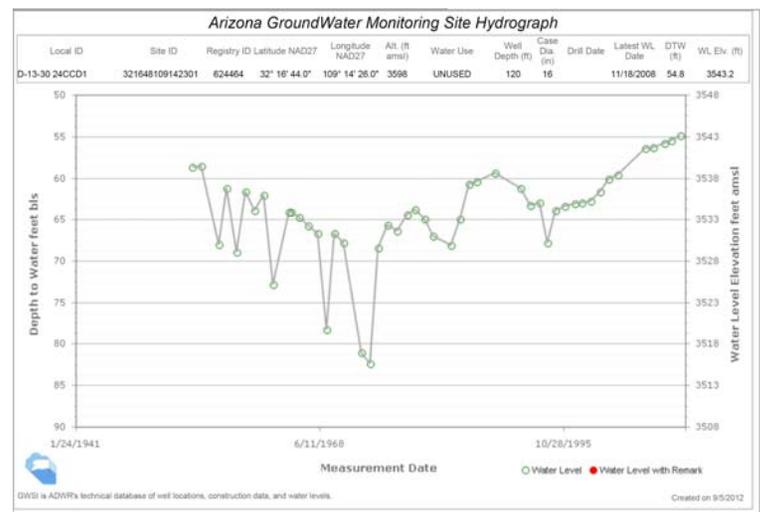
Well I. D-13-29 28BBB (Upper Aquifer)



Well K. D-13-30 15BBB (Lower Aquifer)

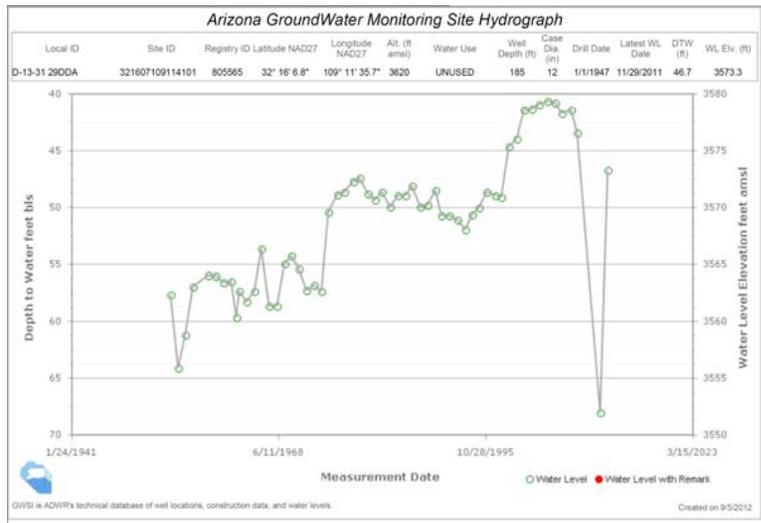


Well J. D-13-30 09ACD2 (Upper Aquifer)



Well L. D-13-30 24CCD1 (Upper Aquifer)

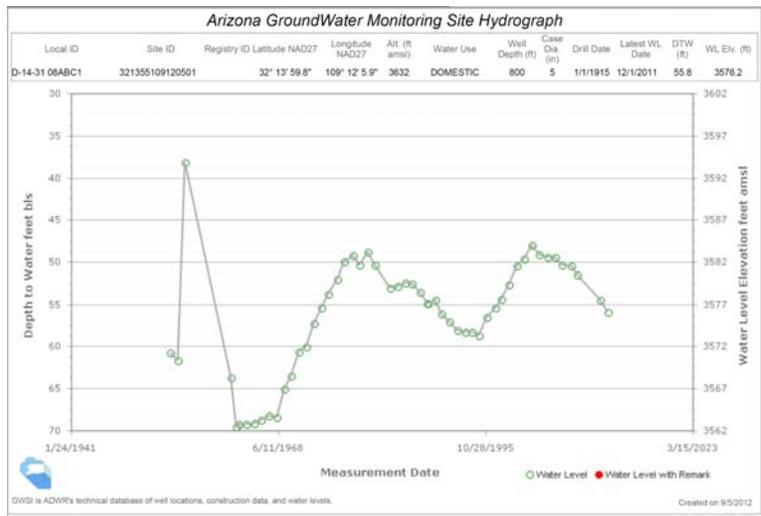
Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



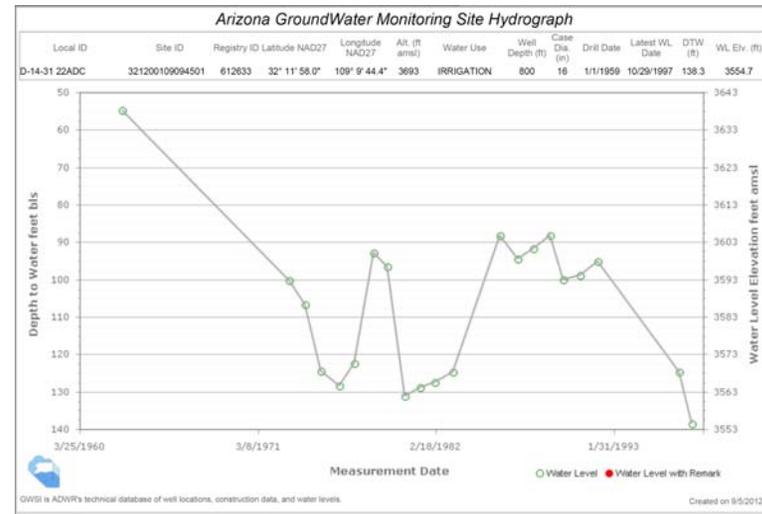
Well M. D-13-31 29DDA (Upper Aquifer)



Well O. D-14-31 19BAC (Lower Aquifer)

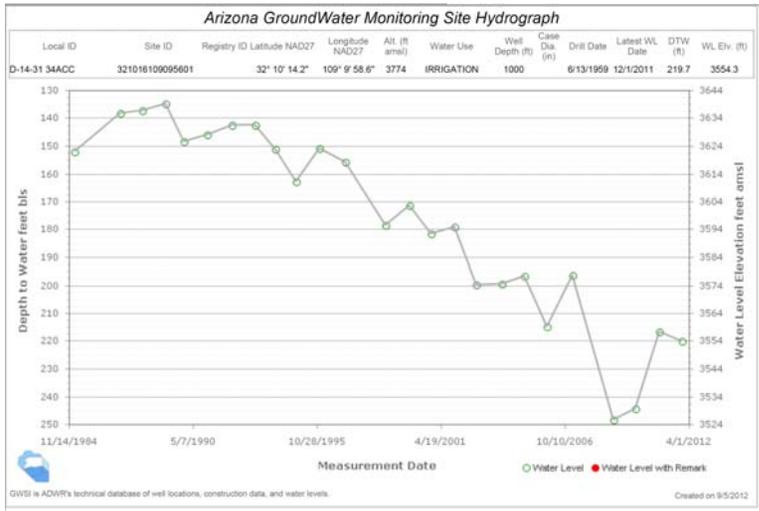


Well N. D-14-31 08ABC1 (Upper/Lower Aquifer)

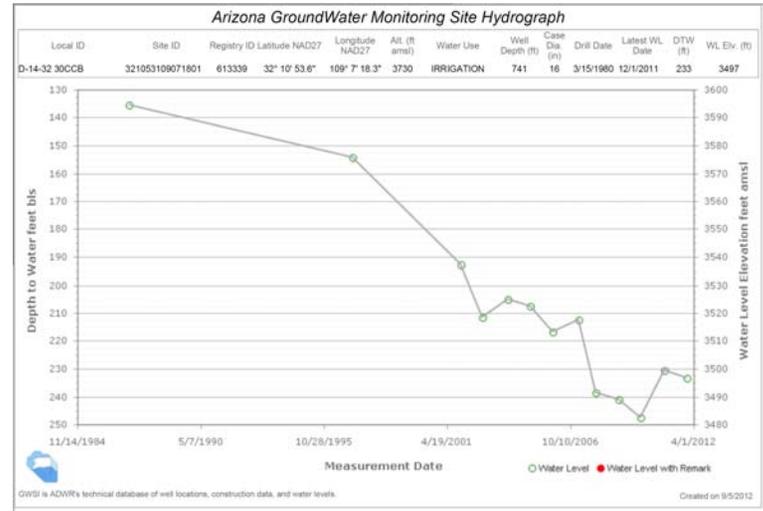


Well P. D-14-31 22ADC (Lower Aquifer)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin



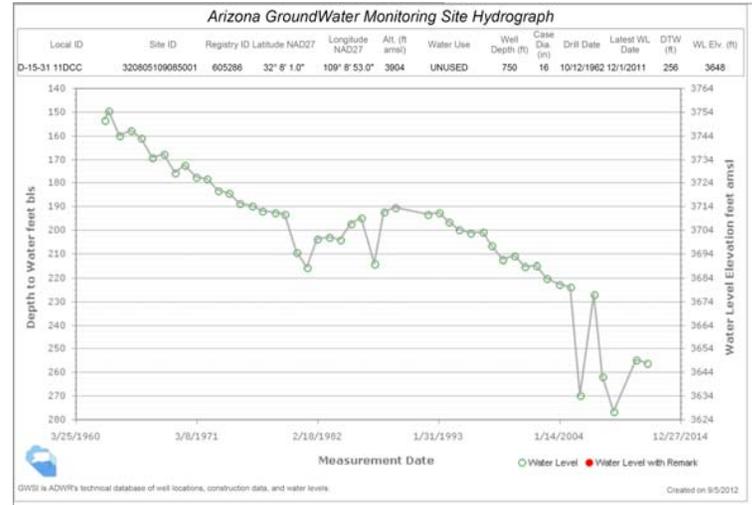
Well Q. D-14-31 34ACC (Lower Aquifer)



Well S. D-14-32 30CCB (Lower Aquifer)



Well R. D-14-31 35BCC (Lower Aquifer)



Well T. D-15-31 34ACC (Lower Aquifer)

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

Land Subsidence Data

Land subsidence and earth fissuring, a consequence of groundwater withdrawals, have been occurring in the Bowie – San Simon areas for several decades. Maps showing current subsidence areas and rates are shown in Figures 37 and 38 (ADWR, 2012). The maps show evidence land subsidence in and around the major agricultural pumping centers at Bowie and San Simon. The zone of subsidence extends between the two pumping areas. This observation is consistent with historic water level declines between the pumping centers, again reflecting some degree of hydraulic connection between the two areas.

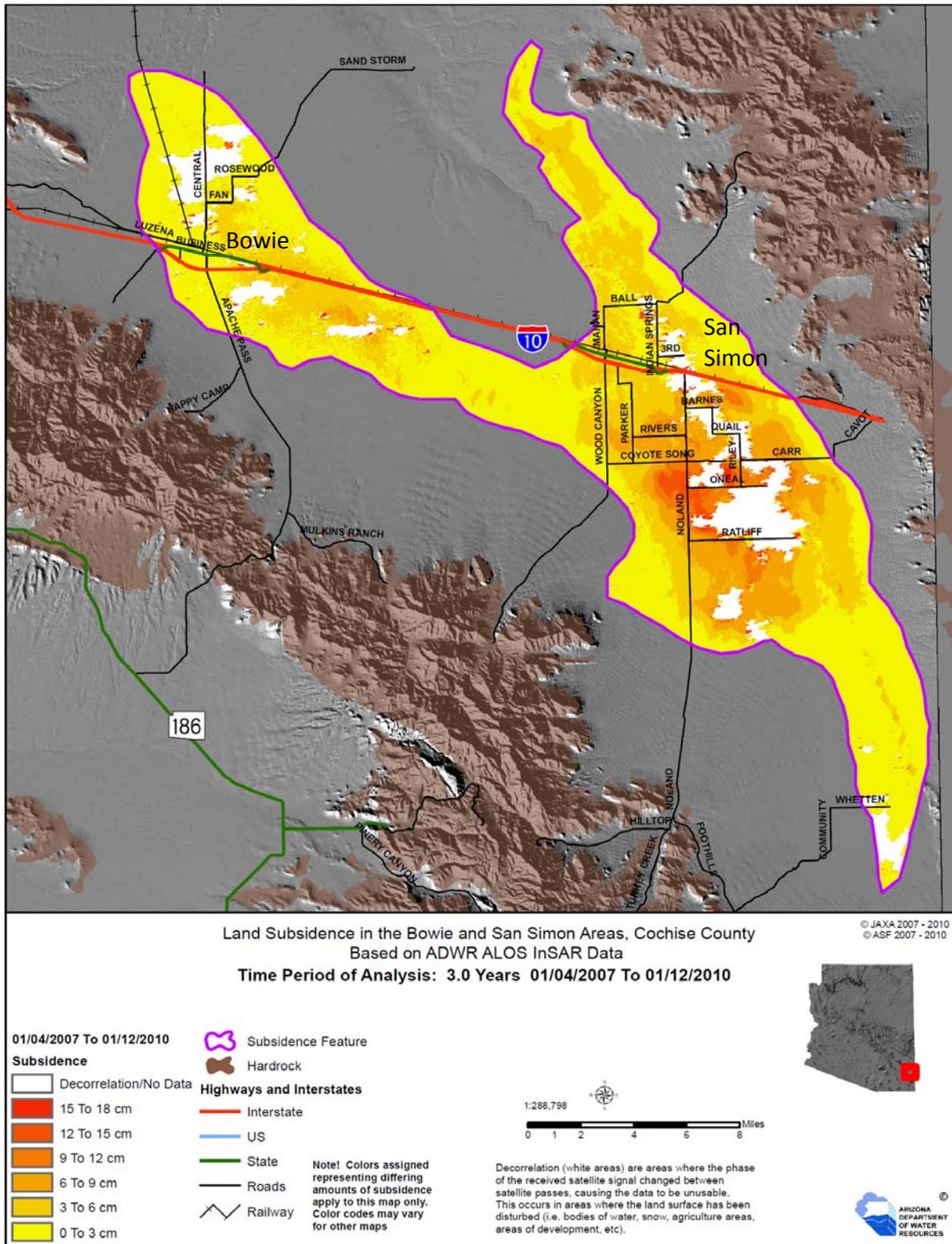


Figure 37 Land Subsidence in the Bowie – San Simon area 01/2007 to 01/2010

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

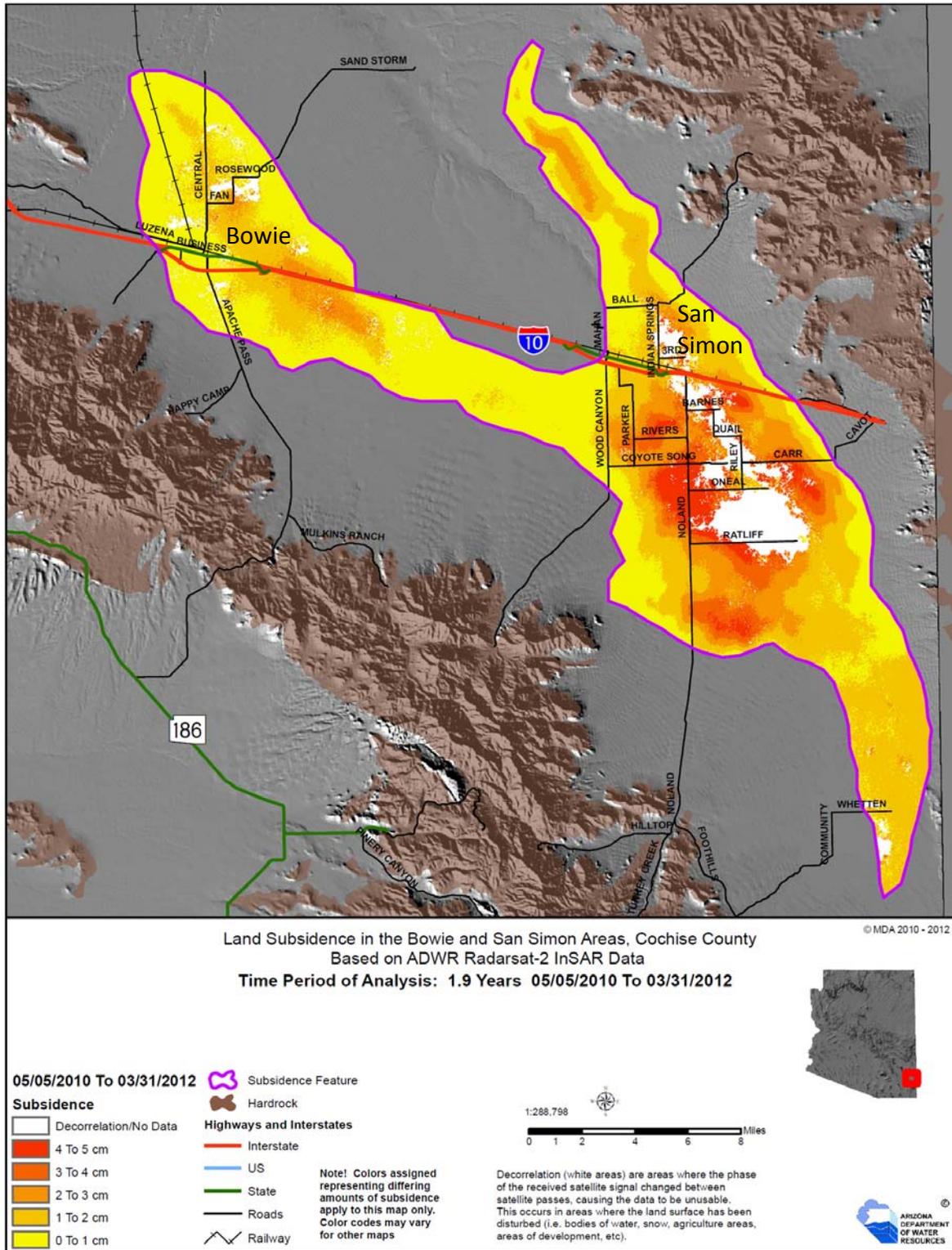


Figure 38 Land Subsidence in the Bowie – San Simon area 05/2010 to 03/2012

Evaluation of Available Scientific Data Related to the Possible Delineation of a Bowie Sub-Basin of the Safford Groundwater Basin

CONCLUSIONS

ADWR conducted a review of available hydrologic data to determine whether a hydrologically distinct groundwater sub-basin (as defined by Arizona law) exists in the San Simon Valley sub-basin of the Safford basin. Historic water level data and technical reports have been reviewed. In all cases, the data indicate a hydrologic connection in both the shallow and deep aquifer systems between the Bowie and San Simon areas.

Gravity data and depth to bedrock maps have been reviewed. Some gravity data indicate a gravity low/high anomaly exists in the general Bowie area. However, the interpretation that the anomaly indicates the presence of a graben/horst feature in that area may be erroneous due to potential mis-estimation of geologic material densities and thicknesses. Regardless, all recent depth-to-bedrock maps of the area do not identify the graben/horst feature. Additionally, if such a feature actually exists, there are no data available that indicate that it serves as a hydrologic barrier isolating groundwater in the Bowie area from other parts of the San Simon Valley sub-basin.

Water sample data reviewed indicate agricultural recharge has degraded groundwater quality in both the Bowie and the San Simon areas, consistent with other agricultural areas in the State. However, no available data indicate significantly different water types that would suggest hydrologic or geochemical isolation between the two areas.

Land subsidence patterns and rates are consistent with historic patterns of water level decline and also with known distributions of fine grained sediments. Subsidence is observed to occur continuously between the two pumping centers.

In conclusion, no data that has been reviewed directly indicates or suggests hydrologic isolation between groundwater in the Bowie and San Simon areas. On the basis of this evidence, there is no basis to define or propose a separate Bowie sub-basin within the San Simon Valley sub-basin of the Safford groundwater basin.

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