Chapter 9

Paleozoic Aquifers of the Llano Uplift

Richard Smith[1]

Introduction

The Paleozoic aquifers in Central Texas have a major impact on the towns and communities that depend on these sources of water. The purpose of this paper is to update and re-evaluate earlier studies of the minor aquifers adjacent to and, in some cases, surrounding the Llano uplift region of Central Texas. These aquifers, from oldest to youngest, are the Hickory Sandstone, the Ellenburger-San Saba and the Marble Falls. These aquifers are overlain in part and recharged by the Trinity aquifer to the south and west.

Location and Extent

The location of the area under investigation is shown in Figure 9-1. The counties considered are the core counties of Blanco, Burnet, Gillespie, Llano, Mason, McCulloch, and San Saba. In addition, outlying counties included in the re-assessment are Concho, Kendall, Kerr, Kimble, Lampasas, Menard, and Travis. The core counties use the vast majority of the total groundwater pumped from the different formations, but the outlying counties provide downdip information necessary for a more complete understanding of the quantity, quality, and aerial extent of the different aquifers.

Prior publications have concentrated on delineating the aquifers in the area and deriving estimates of the amount of water available from them. With this in mind, the author selected the same wells used in the most recent publications covering this area. These reports include TWDB Report 339, "Evaluation of the Ground-Water Resources of the Paleozoic and Cretaceous Aquifers in the Hill Country of Central Texas," by Bluntzer (1992) and TWDB Report 346, "The Paleozoic and Related Aquifers of Central Texas," by Preston and others (1996). By using the same data points from both publications, a continuity of the records is maintained to analyze trends in water levels.

[1] Texas Water Development Board

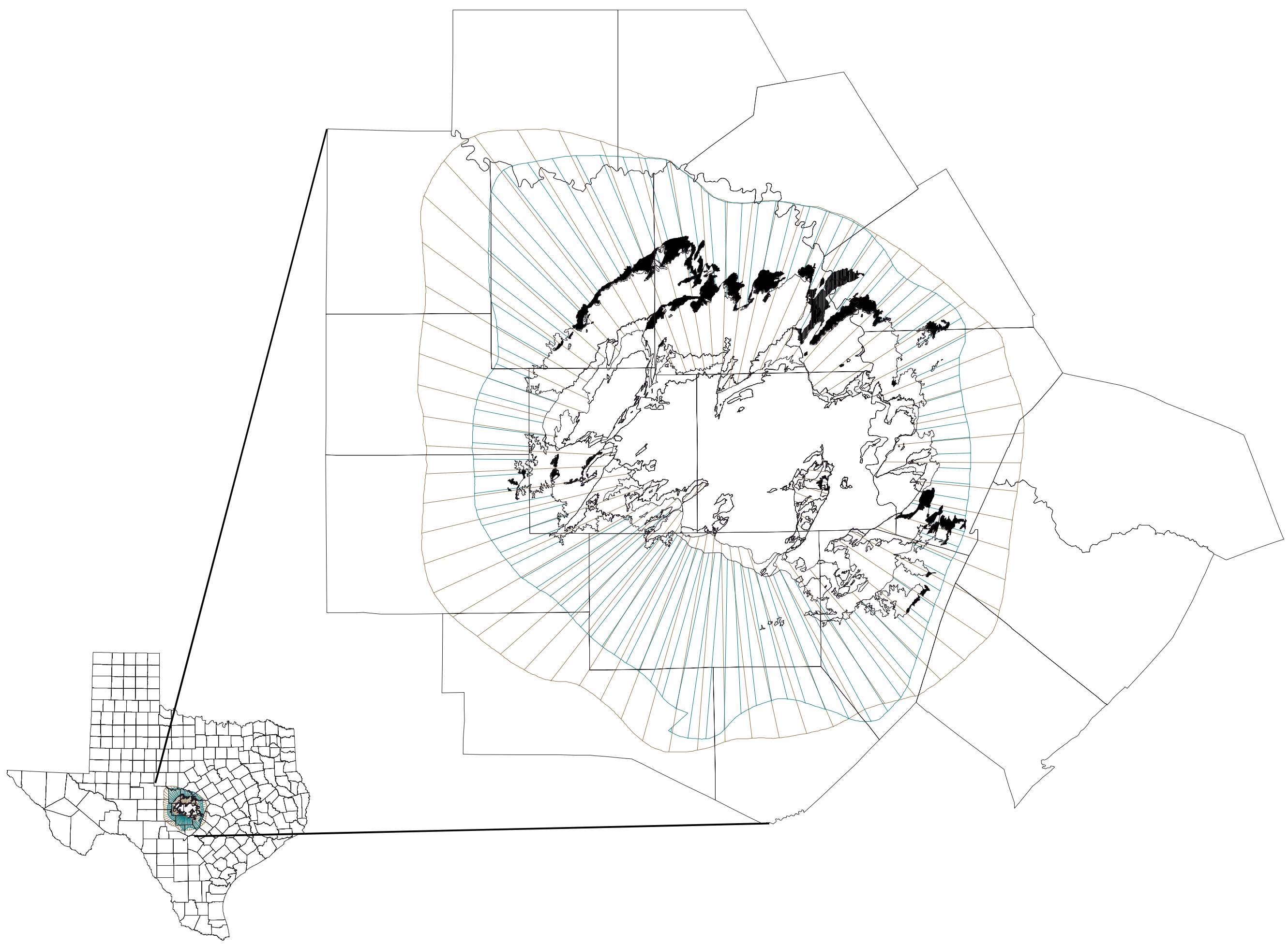

Figure 9-1: Location of area of interest with downdip limits of minor aquifers shown as hatched lines.

Climate and Geography

The climate of the area is subtropical to temperate, subhumid to semiarid (Bluntzer, 1992). Average annual rainfall ranges from under 26 to over 32 inches and generally decreases from east to west. Much of the rainfall occurs in a bimodal distribution with peaks in May and September (Figure 9-2). The average annual gross lake-surface evaporation is more than twice the average annual rainfall, ranging from less than 63 inches in the east to over 70 inches in the northwest. The annual mean temperature varies from 64˚ F in the north and west side of the area to 67 ˚F the southeast. The average January low temperature for the same period is 31 ˚F in the northwest and 34 ˚F in the southeast. The average July high is 96 to 97 ˚F throughout the area (Texas A&M TexasSet website at http://texaset.tamu.edu/rainfall.php).

Parts of both the Edwards Plateau and the central Texas Hill Country are included in the study area. The region is centered on a topographic basin created by an eroded domal structure known as the Llano Uplift. This core area is also referred to as the Llano Dome, the Llano Basin, and the Central Texas Mineral Region. Bounded on the south and west by the Edwards Plateau and on the east by the central Texas Hill Country, the area is drained by the Colorado River and its tributaries, including the Pedernales, Llano, and San Saba rivers, and numerous creeks, such as Brady, Baron, Cypress, Cherokee, Sandy, and Threadgill. The hills to the south, west, and east are capped by Cretaceous limestones underlain by sands and shales of Cretaceous age. North of the area are flat to rolling plains developed on Pennsylvanian and Permian shales, siltstones, sandstones, and limestones. The topography can be relatively rugged, especially along and near the major streams. The relatively flat inner portion of the basin is characterized by several granite domes, some of which rise several hundred feet above the surrounding surface. These include Enchanted Rock, Smoothingiron Mountain, and Granite Mountain (site of the Texas Pink Granite quarry near Marble Falls).

Geology and Hydrogeology

Structure

The Llano Uplift, a large granite batholith, is the major structural feature of the area. Dip in the rocks overlying the basal Precambrian granites and metamorphics of the central dome is in a radial pattern outward from the dome. Dip varies significantly. Cretaceous rocks dip at a few feet to about 100 feet per mile. Dip in Paleozoic rocks varies greatly from a few tens of feet per mile in parts of the area to several hundred feet per mile near buried Precambrian highs (Barnes and Bell, 1977). Other major structural features in the general area that affect groundwater include the San Marcos Arch, the Kerr Basin, the Concho Arch, and the Balcones Fault Zone. Considerable faulting has occurred in and around the uplift. There is a major system of faults associated with the Paleozoic rocks of the area that appears to have occurred in Pennsylvanian time (Barnes and Bell, 1977).

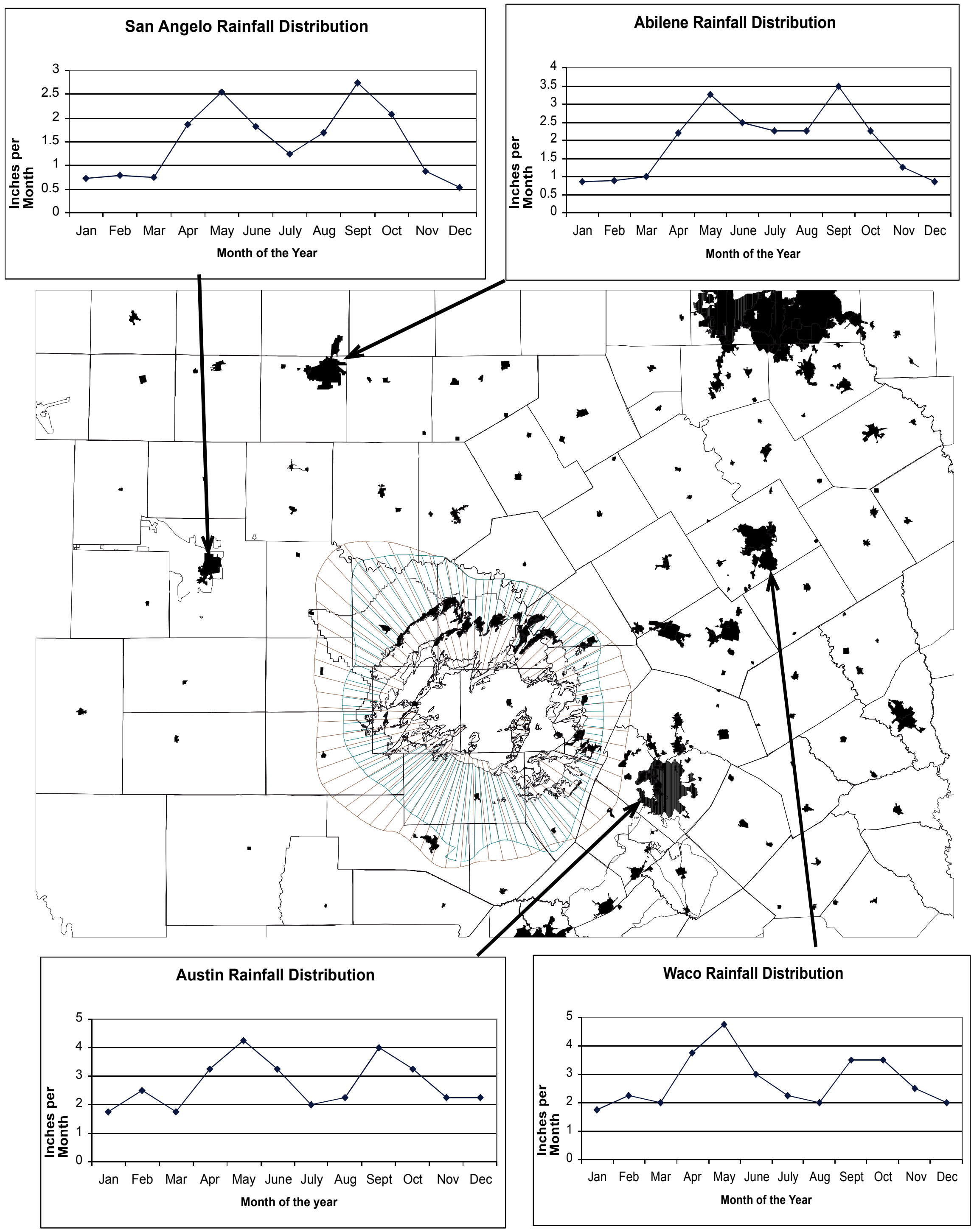

Figure 9-2: Rainfall distributions for a sequence of stations bordering on the study area.

The faults trend northeast-southwest and have displacements ranging from a few feet to over 500 feet (Figure 9-3). The San Marcos Arch is apparently a subsurface extension of the Llano Uplift (Young and Kay, 1972). It is a broad anticlinal feature that plunges to the southeast from central Blanco County across Comal and Hays counties (Figure 9-3). This feature is recognized mostly in the Paleozoic rocks but causes some thinning in the overlying Cretaceous. The Fredericksburg high, which extends south-south west from north-central Gillespie County through Kendall and Kerr counties to Bandera County, is probably associated with the San Marcos Arch (Young , 1972). It represents a high ridge in the Paleozoic and Precambrian rocks, but may be a long fault block or a connected series of fault blocks.

The Balcones Fault Zone is an elongate system of normal faults that stretches around the study area on the south and east. It is associated with the buried Ouachita fold belt, which is the remnant of an ancient highly eroded mountain range (Young , 1972). The fault zone represents a line of flexure between the more stable central Texas area and the periodically sinking coastal plain (Young , 1972).

Stratigraphy

The Precambrian formations of the study area consist of a complex sequence of meta-sedimentary and meta-igneous rock fractured and intruded by igneous rocks. The major meta-sedimentary rock units are the Packsaddle Schist and the Valley Spring Gneiss. The Coal Creek Serpentine, Big Spring Gneiss, and Red Mountain Gneiss are meta-igneous. The Lost Creek Gneiss is either meta-igneous or meta-sedimentary. Igneous rocks of the area include the Llanite Quartz Porphyry, the Sixmile Granite, the Oatman Creek Granite, and the Town Mountain Granite. These rocks outcrop in the center of the area and are overlain by the younger sediments around the uplift (Figures 9-4 and 9-5). The stratigraphy of these sediments is very complicated, and, since it does not directly effect the other aquifers, in-depth descriptions are not deemed necessary for this investigation.

The highly irregular Precambrian erosional surface exposed in the center of the Llano basin is probably similar to the surface present when the Hickory Sandstone Member of the Riley Formation of the Moore Hollow Group was deposited. The maximum local relief was about 800 feet with granite domes towering above the surrounding low relief topography developed on the gneisses, schists, and softer granitic rocks. These Precambrian hills extended up into the overlying Cap Mountain Limestone or even higher in some places. The Hickory Sandstone ranges in thickness up to about 500 feet, and its thickness is locally controlled by the topography of the underlying Precambrian rock surface (Barnes and Bell, 1977).

Above the Hickory Sandstone are confining beds of the Cap Mountain Limestone Member of the Riley Formation. The Cap Mountain Limestone has a gradational contact with the underlying Hickory Sandstone. This contact is mapped as the point where the lime content of the formation exceeds the sand content. As a consequence, the upper Hickory Sandstone may contain lime rich sands and the lower Cap Mountain Limestone may contain sandy limestone beds. Crossbedded quartz sandstone is the predominate

Figure 9- 3: Tectonic map of the Llano Uplift (after Preston and others, 1996).

Geologic Units						
Era	System	Group	Formation	Member or Unit	Hydrogeologic Units	
Cenozoic	Quaternary	Pleistocene to Recent floodplain (alluvium and fluviatile terrace deposits)			localized alluvial aquifers	
Mesozoic	Cretaceous	Edwards Group	Segovia Formation		Edwards Plateau Aquifer	Edwards Trinity aquifer
			Fort Terrett Formation	Kirchburg evaporite Mbr.		
				Dolomite Member		
				Burrowed Member		
				Basal Nodular Bed Member	confining bed	
		Trinity Group	Glen Rose Limestone	Upper Member	Upper and Middle Trinity Aquifer	
			Travis Peak equivalent: Hensell Sand / Bexar	Lower Member		
			Travis Peak equivalent: Cow Creek Limestone			
			Travis Peak equivalent: Hammett Shale		confining bed	
			Travis Peak equivalent: Sligo / Sycamore Sand / Hosston		Lower Trinity aquifer	
Paleozoic	Pennsylvanian	Canyon Group	undivided		confining beds	
		Strawn Group	undivided			
		Bend Group	Smithwick	undivided		
			Marble Falls Limestone		Marble Falls aquifer	
	Mississippian and Devonian	Composed of youngest to oldest -- Barnett Formation(Miss.),Chappel Limestone(Miss) Houy Formation(Dev) and the Stribling Formation (Dev)			Usually confining beds	
	Ordovician	Ellenberger Group	Honeycut Formation	undivided	Ellenburger-San Saba aquifer	
			Gorman Formation	undivided		
			Tanyard Formation	Staendebach Member		
				Threadgill Member		
	Cambrian	Moore Hollow Group	Wilberns Formation	San Saba Member		
				Point Peak Member	confining beds	
				Morgan Creek Limestone Mbr		
				Welge Sandstone Member	Mid-Cambrian aquifer	
			Riley Formation	Lion Mountain Sandstone Mbr		
				Cap Mountain Limestone Mbr	confining beds	
				Hickory Sandstone Member	Hickory aquifer	
Precambrian			Llanite; Six Mile Granite; Town Mountain Granite; Red Mountain Gneiss; Mafic igneous rocks; Lost Creek Gneiss	Oat Creek Granite; Pegmatite and quartz veins; Melaryolite dikes; Coal Creek Serpertine; Packsaddle Schist; Valley Springs Gneiss	Usually confining beds	

Figure 9-4: Geologic and hydrogeologic units in the area of interest (after Preston and others, 1996).

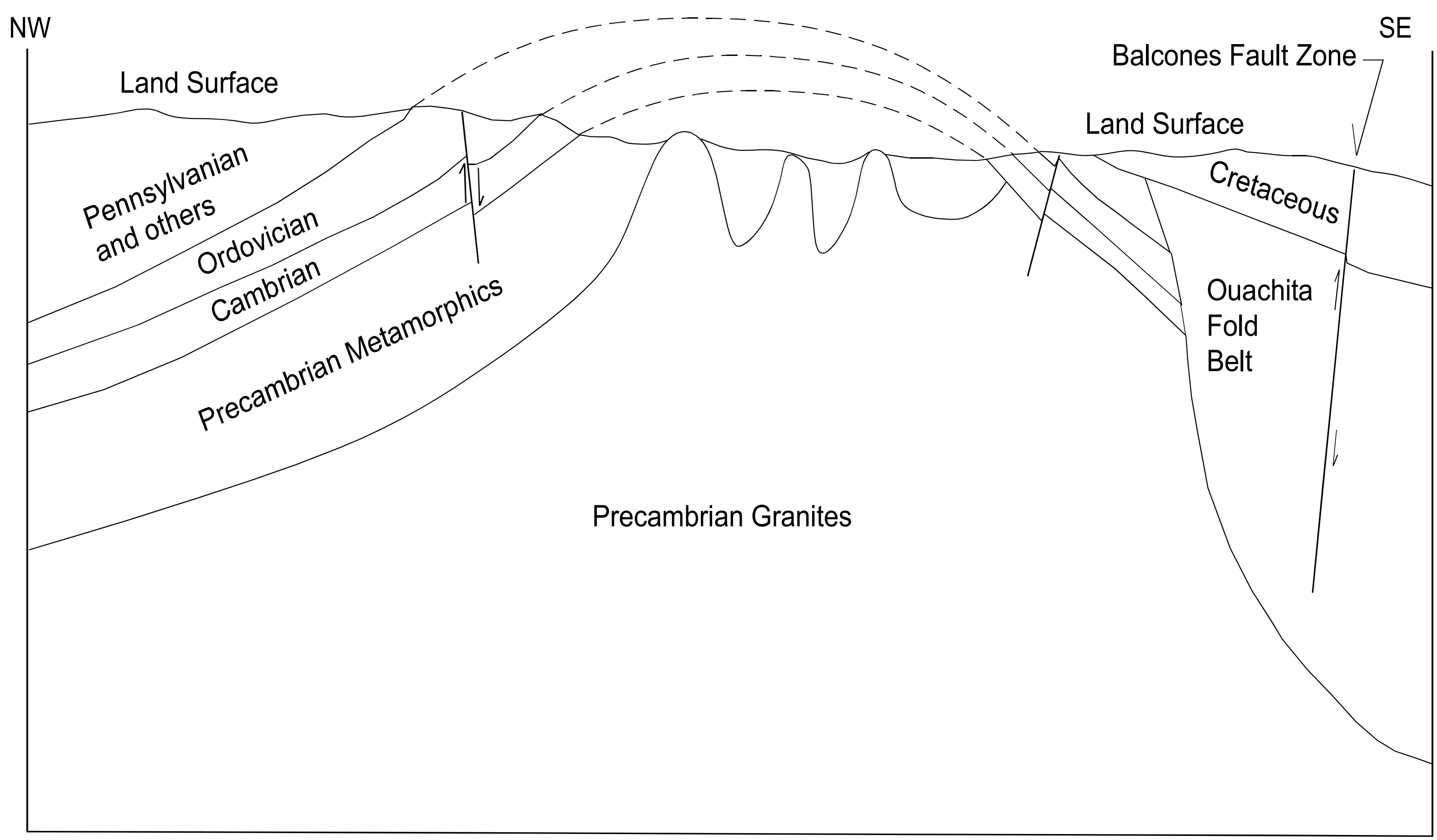

Figure 9-5: Schematic cross-section of the Llano Uplift area, not to scale (after Preston and others, 1996).

constituent of the Hickory Sandstone. It is thin-bedded in the upper third, medium to thick bedded in the middle third, and massively bedded in the basal third. The upper part of the Hickory Sandstone in outcrop is a dark red-black, highly indurated sandstone with obvious cross-bedding and some lenses of gravel to cobble size material. Overall, the Hickory Sandstone varies from light brown to yellow to dark brown. As an aquifer, moderate to large amounts of groundwater are produced from the Hickory Sandstone from wells ranging from shallow to over 3,000 feet deep. Well yields from public supply wells vary from 200 to 790 gpm and irrigation wells have production rates of 25 to 325 gpm (Bluntzer, 1992).

Separated for the most part from the Hickory Sandstone is the Mid-Cambrian aquifer. Although it is not recognized as a named aquifer by the Texas Water Development Board, this aquifer has been noted in Texas Water Development Board reports as a water bearing unit. The Mid-Cambrian is composed of the uppermost member of the Riley Formation, the Lion Mountain Sandstone Member, and the lowermost member of the Wilberns Formation: the Welge Sandstone Member. The Cap Mountain Limestone Member acts as a confining layer between the Hickory Sandstone and the overlying Mid-Cambrian aquifer. The Cap Mountain Limestone Member varies from 500 to 650 feet thick, and the contact between the Cap Mountain Limestone Member and the Lion Mountain Sandstone is considered an unconformity.

The Lion Mountain Sandstone is composed of glauconitic quartz sandstone, trilobite “hash” or coquinite, fossiliferous limestones, quartz rich green sand, and thin beds of silt and shale. All bedding is thin, and cross bedding is prevalent. Thickness of the member ranges from 25 to 85 feet. Overlying the Lion Mountain Sandstone, but still a part of the Mid-Cambrian aquifer, is the Welge Member of the Wilberns Formation. The contact between the Riley and Wilberns Formations also appears to be an unconformity. The major difference between the Lion Mountain Sandstone and the Welge Member is the dramatic decrease of glauconite in the Welge Member. The medium grained quartz sands of the Welge Member range in thickness from 5 to 30 feet and vary from brown to yellow. Groundwater production from the Mid-Cambrian is generally small with average yields of 20 gpm (Bluntzer, 1992). A public supply test well in south-central Gillespie County produced 60 gpm.

The Morgan Creek Member and the Point Peak Member (also called the Point Peak Shale) of the Wilberns Formation are confining layers between the Mid-Cambrian and the Ellenburger-San Saba aquifers. The Morgan Creek Member, which is a thick to thin bedded limestone, is unconformable with the underlying Welge Member. The thickness of the Morgan Creek Member is 90 to 190 feet and consists of fossiliferous, granular, glauconitic limestone beds that vary from pink to reddish-brown to greenish and brownish gray. The Point Peak Member is dominated by beds of laminated siltstone with some beds of limestone and shale. Some sands have been reported in western McCulloch and eastern Concho counties in this member, and at least one well in the vicinity of Melvin, Texas, is reported to produce from this zone (Preston and others 1996).

The San Saba Limestone is the uppermost member of the Wilberns Formation. This thin to thick bedded, fine-grained member is a gray to brown to yellow limestone and dolomite sequence. Thickness of the San Saba Limestone ranges from 250 to 850 feet and thins to the north. In conjunction with the overlying Ellenburger Group, the San Saba Limestone forms an aquifer which produces moderate to large amounts of groundwater from depths as much as 2,000 feet deep. The upper part of the San Saba is considered Ordovician, and the contact between the San Saba Limestone and the Ellenburger Group is conformable over most of its extent.

Three formations form the Ellenburger Group. From oldest to youngest, the formations are the Tanyard, Gorman, and Honeycut. The Tanyard Formation varies from 475 to 730 feet thick. The lower part of the Tanyard Formation is the Threadgill Member with light gray medium- to coarse-grained dolomite that may grade locally into a light-gray limestone. The upper Staendebach Member is a thin- to thick-bedded, fine-grained, light-gray cherty limestone. Above the Tanyard Formation, the Gorman Formation is a fine grained light gray limestone in its upper section and a micro-granular to fine-grained pink to gray and yellowish-gray dolomite in the lower part. Thickness of the Gorman Formation varies from 280 to 500 feet. Finally, the Honeycut Formation, 0 to 850 feet thick, is a thin- to thick-bedded, light-gray, fine-grained limestone interbedded with thin to thick beds of fine-grained to micro-granular, gray dolomite. The entire Ellenburger Group is overlain by thin discontinuous Devonian and Mississippian formations in the study area which consist of dark shales, petroliferous limestone, crinoidal limestone, cherts, and micro-granular limestone with chert.

The Ellenburger-San Saba aquifer yields very small to very large quantities of fresh to slightly saline water. If a well bore intersects fractures or other cavities, then groundwater production can be quite prolific (as much as 1,000 gpm). However, if no such features are encountered, then yields will be quite small (less than 5 gpm). When limestone is encountered (calcium carbonate), then yields can be significantly increased by acidizing the well bore.

Pennsylvanian rocks unconformably overlie either the Ellenburger Group or the Devonian-Mississippian Formations. The lowest-most formation in the Pennsylvanian is the Marble Falls Formation, which in turn is the lowest formation in the Bend Group. The Bend Group, from oldest to youngest, consists of the Marble Falls Formation and the Smithwick Formation. The Marble Falls Formation, which has an upper and lower unit, is about 385 to 460 feet thick and comprises the Marble Falls aquifer. The lower unit is a very fine-grained, mostly massive, gray limestone with thin shale beds at the very base of the unit. The upper unit is composed of fine-grained, cherty, thin- to thick-bedded, brownish to olive gray limestone which is fossiliferous in part. Well yields are small to moderate and can be increased by acidizing. Marble Falls wells have not been used for public supply. Yields of rural domestic and livestock wells range from 1 to 100 gpm, and irrigation wells are reported to produce from 100 to 200 gpm. Acting as confining beds are the remainder of the Pennsylvanian section consisting of the Smithwick Formation, which is composed of claystone, siltstone, and sandstone, and the Strawn Group, which is composed of limestone, shale, and fine-grained sandstone (Young, 1972).

The Cretaceous aquifers have a high degree of connection to the underlying Paleozoic aquifers throughout the Hill Country area. The Hensell Sand Member of the Middle

Trinity aquifer and the Hosston Sand Member of the Lower Trinity aquifer have a direct hydrological connection to the Hickory, Mid-Cambrian, Ellenburger-San Saba and Marble Falls aquifers over a wide area (Figures 9-6a and 9-6b).

Mississippian and Devonian rocks, as indicated earlier, are considered confining beds separating the Marble Falls aquifer from the underlying Ellenburger-San Saba aquifer. However, due to the discontinuous lateral extent of the Mississippian and Devonian rocks, the Ellenburger-San Saba and the Marble Falls aquifers are frequently in direct hydrologic connection.

The late Paleozoic faulting, which probably occurred at the end of the Pennsylvanian, resulted in the displacement of along some faults of thousands of feet. Paleozoic aquifers were then juxtaposed with one another and are considered hydrologically connected. This can be seen along several of the large faults in the area such as the buried fault under the Guadalupe River which juxtaposes the Ellenburger-San Saba aquifer with the Marble Falls aquifer and the buried fault under the Pedernales River which juxtaposes the Ellenburger-San Saba aquifer with the Hickory Sandstone and the Welge Sandstone Member and Lion Mountain Sandstone (Figure 9-6a). Also, numerous fracture zones associated with the faulting has provided a vertical means for flow between aquifers.

Recharge and Groundwater Movement

Preston and others (1996) estimated recharge to the Paleozoic aquifers. These estimates are based on average rainfall, areal extent of the aquifer outcrop, and a regard for the amount and location of major faults associated with the aquifers (Table 9-1). Confirmation of the recharge estimates are made by comparing the amount of water pumped from the various aquifers with resulting water-level changes. These numbers are based on five to ten percent of total annual rainfall (Preston and others, 1996). These percentages should be re-examined by conducting additional studies using the most recent data for the area. Gain-loss studies to the west and south of the Llano uplift (Ashworth, 1983) indicate a recharge percentage of four percent.

Groundwater movement throughout the region is dominated by the presence of faults and is not simply controlled by radial dip from the uplift area. Flow is generally south and southeast in Blanco and Gillespie counties. Flow regimes west and north of the area are dominated by buried faults, and local flow patterns probably mirror all points of the compass. A detailed analysis of recharge and flow patterns should be undertaken for the entire study area.

Water Levels

Well hydrographs for selected wells in the Hickory aquifers are shown in Figures 9-7 and 9-8, and hydrographs for Ellenburger-San Saba and Marble Falls are shown in Figures 9-9 and 9-10. Declines for the most part appear to be limited to the central Gillespie County and Mason County area in the Hickory Sandstone. Water levels in the Ellenburger-San

Table 9-1: Average annual recharge for area aquifers (in acre-feet; after Preston and others, 1996).

Aquifer	**Effective Recharge**	**Blanco**	**Burnet**	**Gillespie**	**Llano**	**McCulloch**	**Mason**	**San Saba**	**Kimble**	**Lampasas**	**Menard**
Hickory	46,149	800	4,747	2,000	10,982	3,000	18,882	5,738	0	0	0
Mid-Cambrian	1,260	300	100	300	30	130	200	200	-	-	-
Ellenburger-San Saba	34,912	4,600	3,736	4,000	900	4,271	4,200	12,106	256	654	189
Marble Falls	26,400	300	5,625	-	-	3,912	-	12,380	-	4,183	-
Trinity	-	1,600	1,835	3,400	-	-	-	-	-	1,733	-
Edwards-Trinity (Plateau)	-	100	-	1,400	-	4,456	2,359	-	26,734	-	19,133
Total	108,721	7,700	16,043	11,100	11,912	15,769	25,641	30,424	26,990	6,570	19,322

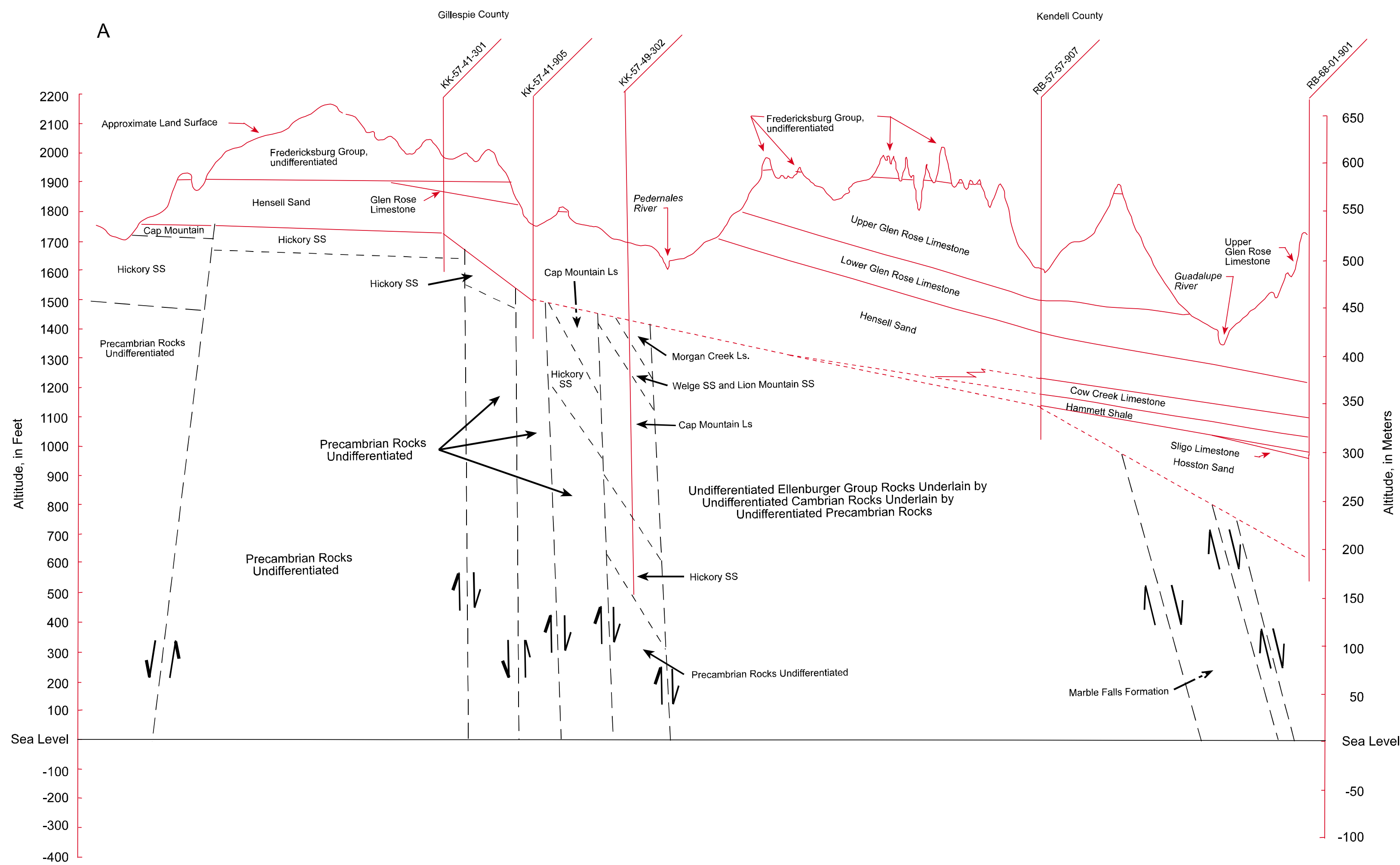

Figure 9-6a: Cross-section from north to south of the uplift area (after Bluntzer, 1992), continued in Figure 9-6b.

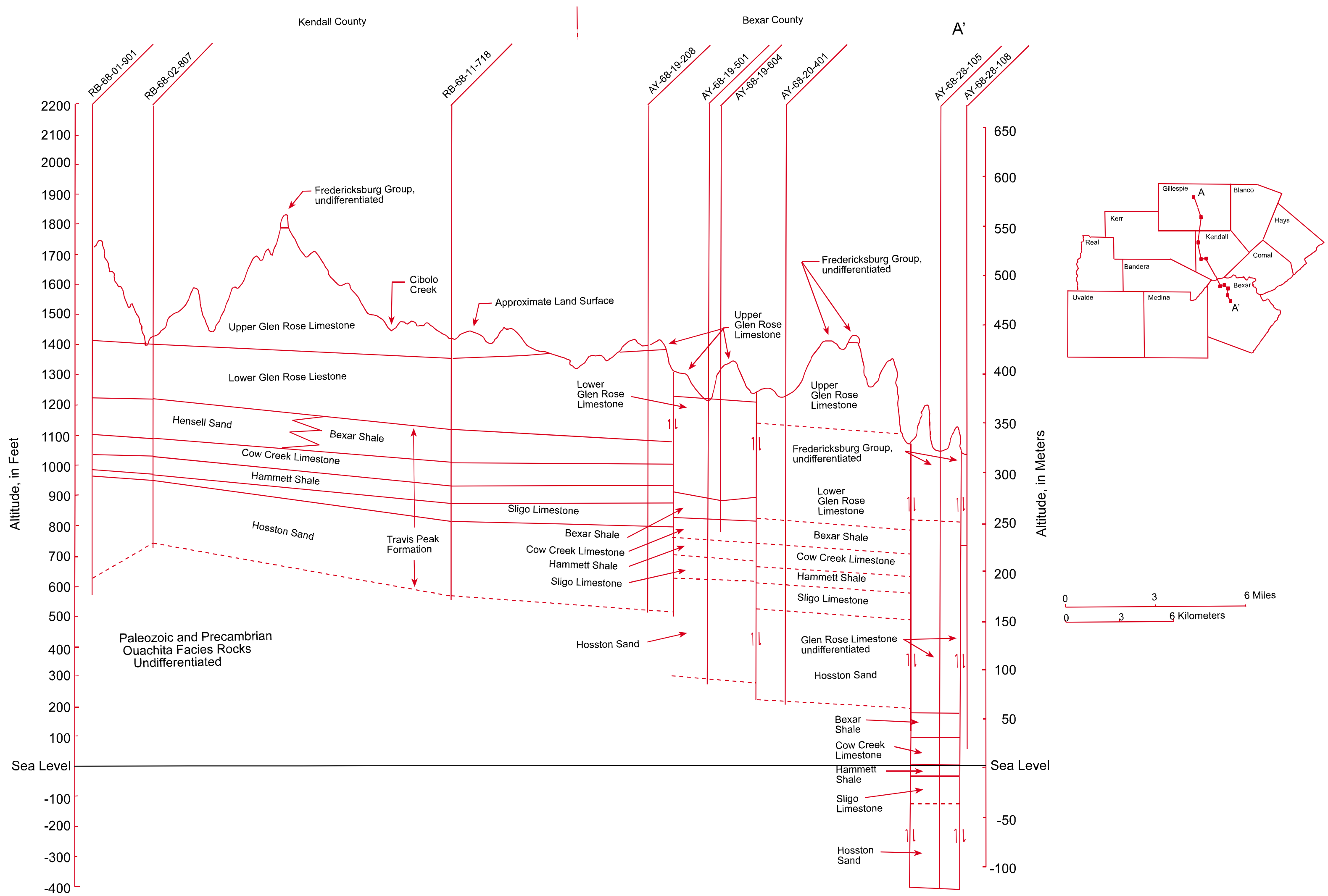

Figure 9-6b: Continuation of Figure 9-6a (after Bluntzer, 1992).

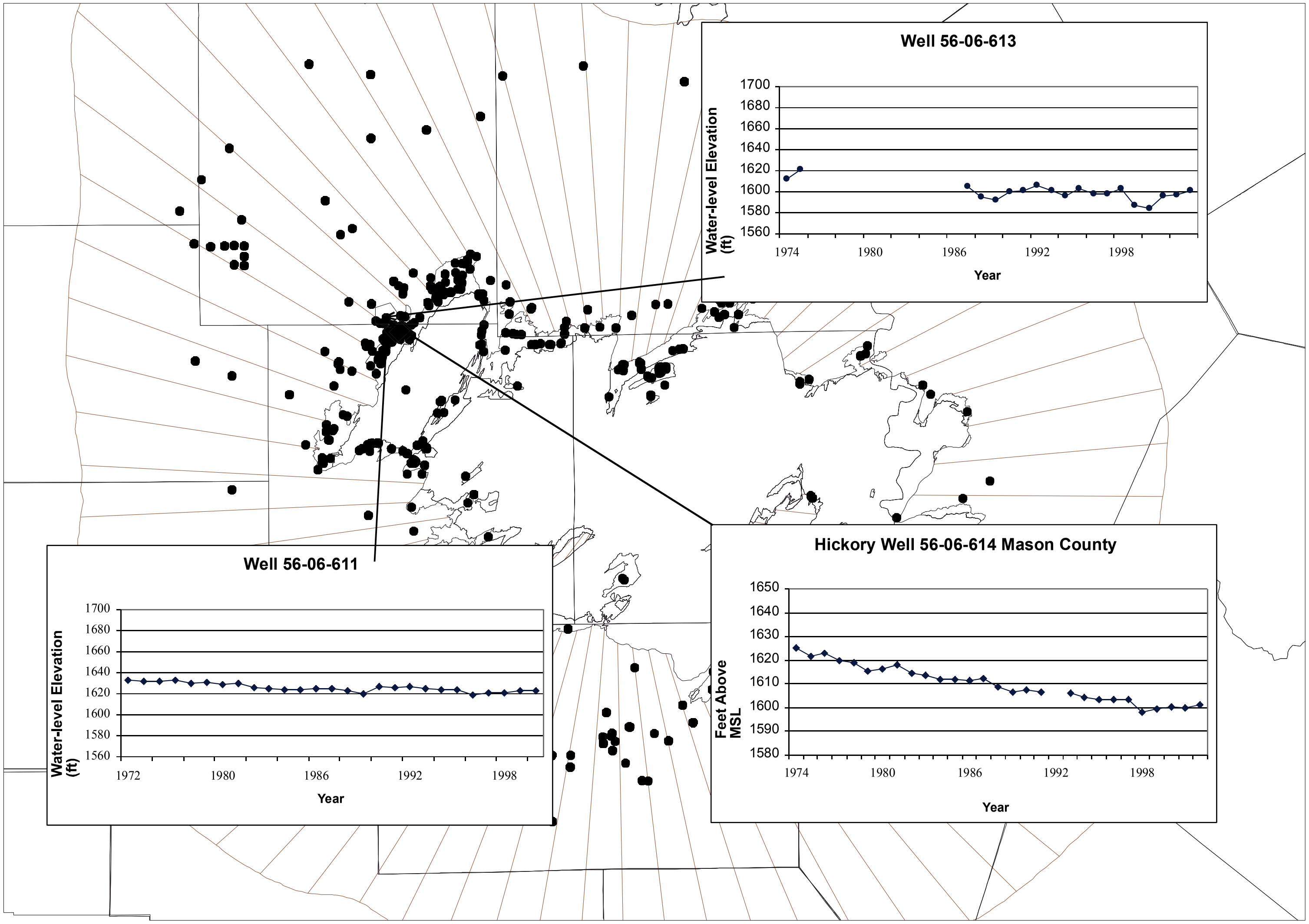

Figure 9 -7: Locations of wells and selected hydrographs for the Hickory aquifer.

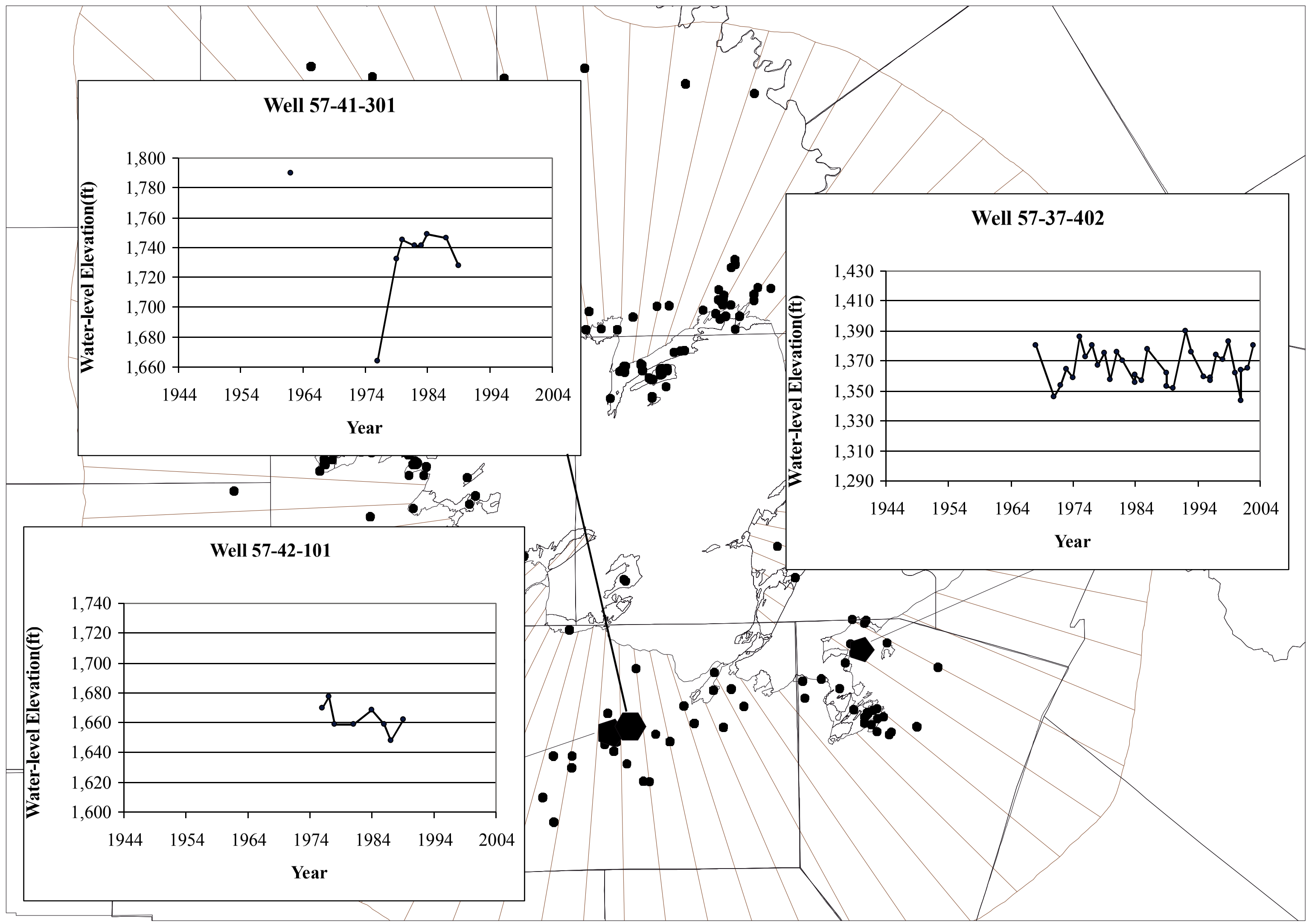

Figure 9-8: Locations of wells and selected hydrographs for the Hickory aquifer.

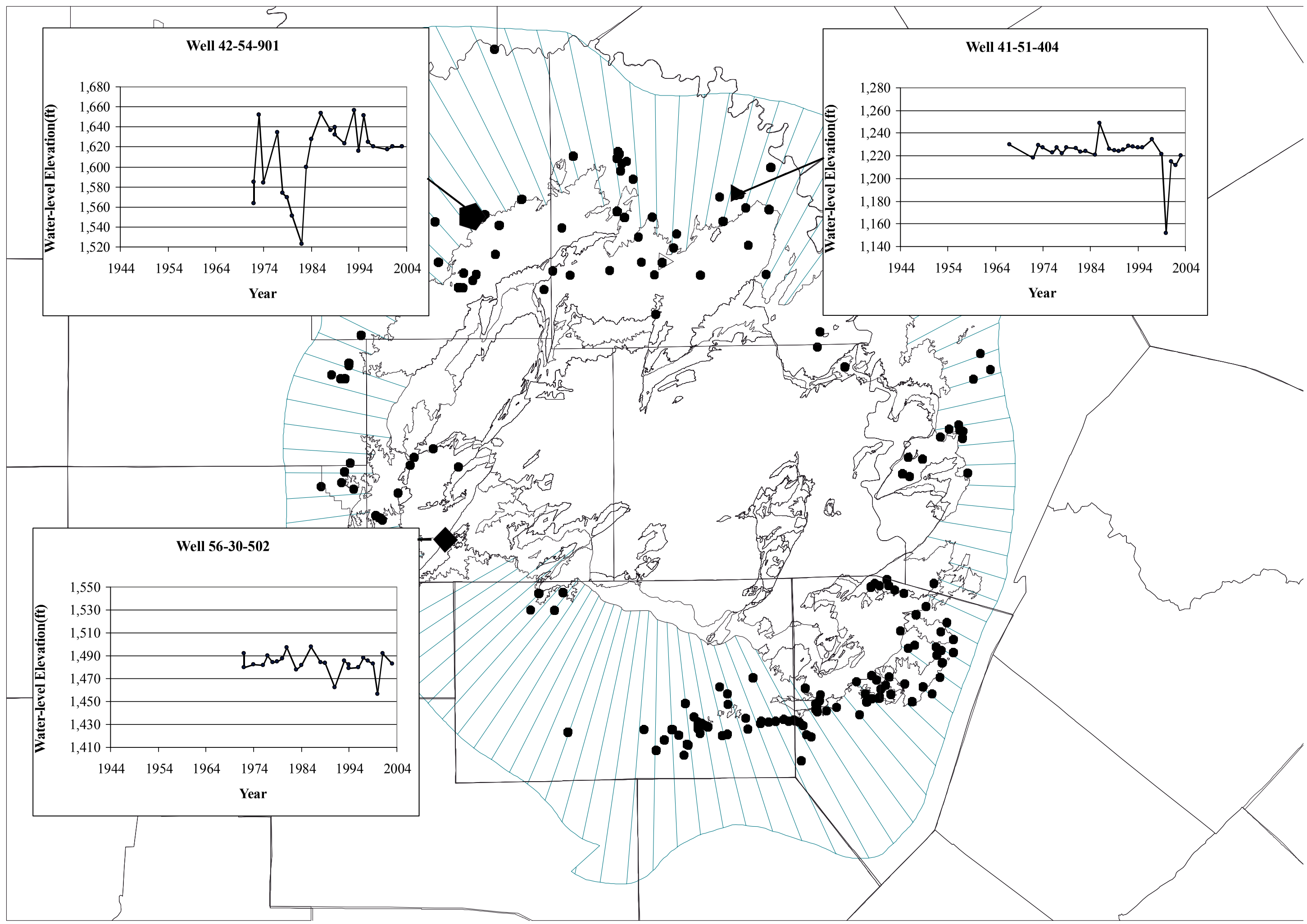

Figure 9-9: Locations of wells and selected hydrographs for the Ellenburger-San Saba aquifer.

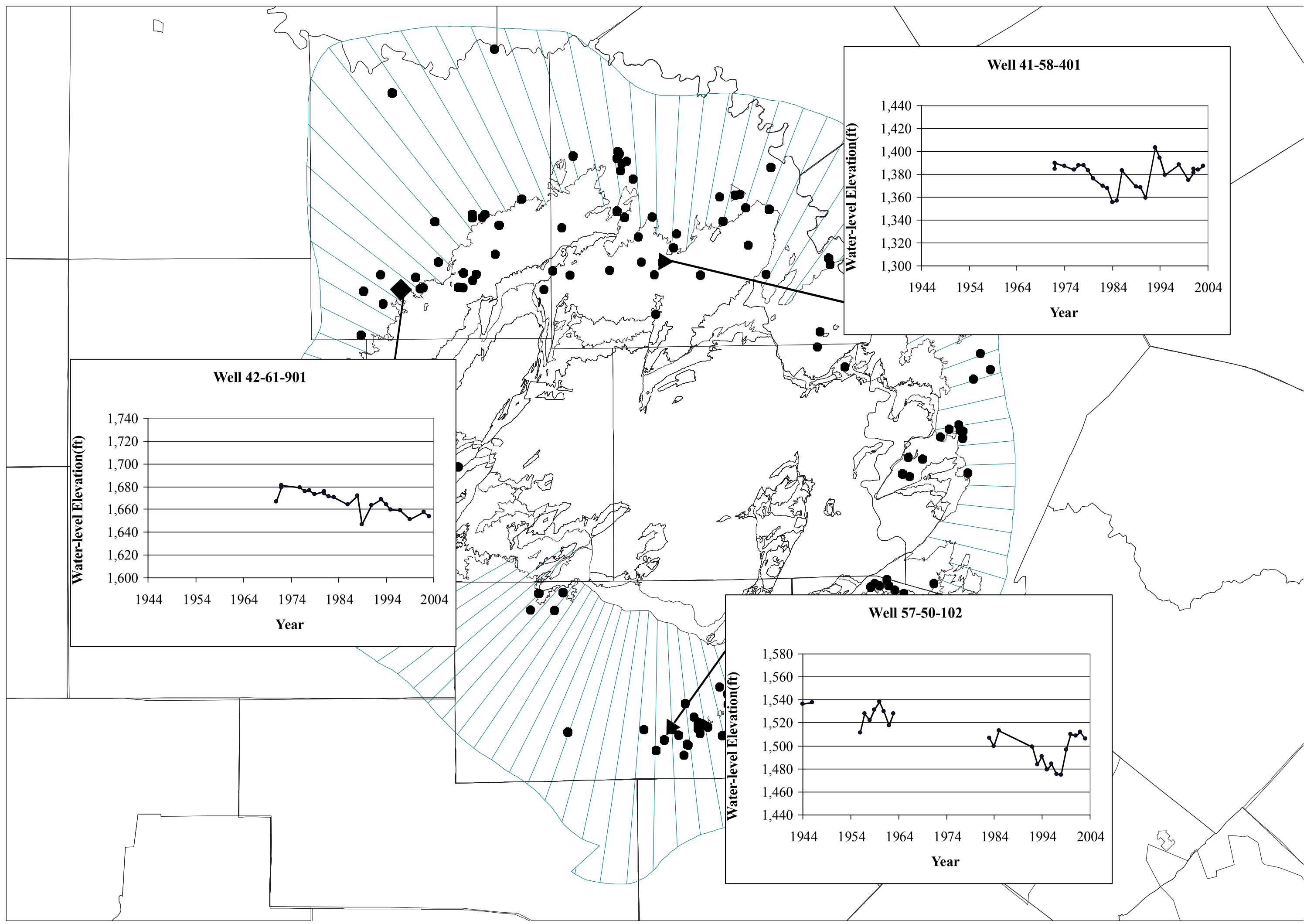

Figure 9-10: Locations of wells and selected hydrographs for the Ellenburger-San Saba aquifer.

Saba aquifer appear stable to slightly declining throughout much of the area with only a few wells indicating limited drawdown from historical levels.

Conclusions

Structurally and stratigraphically, the Llano Uplift area is extremely complex and presents a complicated groundwater picture. The principal aquifers in the core area of interest centered on Llano County are the Hickory, Ellenburger-San Saba and the Marble Falls. A little used aquifer locally known as the Mid-Cambrian aquifer is also present, although it is not recognized as a named aquifer by the Texas Water Development Board. Most pumpage comes from the Hickory aquifer followed by the Ellenburger-San Saba aquifer and then the Marble Falls aquifer. Good data is not available for the Mid-Cambrian aquifer. Water-level declines are occurring in the Hickory aquifer in Gillespie and Mason counties, and the Ellenburger-San Saba aquifer has small water -level declines from historic levels. The present recharge estimates are based on simple analyses of five (and in some cases 10) percent of average annual rainfall. Therefore, new recharge estimates need to be made throughout the area, especially since these estimates are often used as availability values.

References

Ashworth, J. B., 1983, Ground-water availability of the Lower Cretaceous formations in the Hill Country of south-central Texas: Texas Department of Water Resources Report 273, 173 p.

Barnes, V. E., and Bell, W. C., 1977, The Moore Hollow Group of Central Texas: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No, 88, 169 p.

Bluntzer, R. L., 1992, Evaluation of ground-water resources of the Paleozoic and Cretaceous aquifers in the Hill Country of Central Texas: Texas Water Development Board Report 339, 130 p.

F&N, 2001, Region "F" Water Supply Plan, Prepared for the TWDB by Freese and Nichols, January 2001, 358 pages.

Preston, R. D., Pavlicek, D. J., Bluntzer, R. L., Derton, J., 1996, The Paleozoic and related aquifers of Central Texas: Texas Water Development Board, Report 346, 85p.

Young, K., 1972, Mesozoic history, Llano region: *in* Barnes, V. E., Bell, W. C., Clabaugh, S. E., and Cloud, P. E., eds., Geology of the Llano region and Austin area, field excursion: The University of Texas at Austin, Bureau of Economic Geology Guidebook 13, 77 p.

TC&B, 2000, Region K Water Supply Plan for the Lower Colorado Regional Water Planning Group, Volume I: Prepared for the TWDB by Turner Collie and Braden, Inc., October 2000, 298 pages.

This page intentionally blank.