DRAFT

Groundwater Level Changes in the Tanque Verde Valley

Sonoran Desert Conservation Plan

January 2001

Pima County, Arizona
Board of Supervisors
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County Administrator
Chuck Huckelberry

MEMORANDUM

Date: January 16, 2001

To: The Honorable Chair and Members
Pima County Board of Supervisors

From: C.H. Huckelberry
County Administrator

Re: **Groundwater Level Changes in the Tanque Verde Valley**

Background

In the early 1990s, a study of the Tanque Verde Creek by Dr. Julie Stromberg and others described the relationship between the depth to groundwater and the health of the mesquite woodland habitat in the area. Along the six mile stretch of the Tanque Verde from Wentworth Road to Sabino Canyon Creek, mesquite trees became stressed when groundwater depths fell from 16 to 59 feet. When the depth to water exceeded 59 feet, trees began to show signs of near-lethal stress. Following the publication of the Stromberg study, Tucson Water adopted a policy of "last on, first off" for wells along the Tanque Verde Creek. The attached report entitled *Groundwater Level Changes in the Tanque Verde Valley* revisits the Stromberg study to describe variations in groundwater levels since the report was completed early last decade.

Relevance of Groundwater Level Changes to the Sonoran Desert Conservation Plan

Groundwater Level Changes in the Tanque Verde Valley provides information that is valuable to both the Riparian Element of Sonoran Desert Conservation Plan and the Water Resources Element of the Comprehensive Plan. The Tanque Verde Creek and Agua Caliente Wash were identified in the Riparian Element of the draft *Preliminary Sonoran Desert Conservation Plan* as major opportunities for discharge or aquifer restoration since hydrogeologic conditions are favorable to restore localized aquifers. We have learned from recently completed mapping for the Sonoran Desert Conservation Plan that there are around 3,000 acres of riparian vegetation in the Tanque Verde-Agua Caliente shallow groundwater zone defined by Pima Association of Governments. At a minimum, the water demand for the existing riparian vegetation would be 3,000 acre feet per year, a substantial percent of the overall water budget for the study area.

Relevance of Groundwater Level Changes to the Pima County Comprehensive Plan

A Water Resources Element is required by the state law which defines the Elements of the Comprehensive Plan. This Element must describe water availability, and analyze how future population growth will be adequately served. The Tanque Verde Valley is separated from the Tucson Water Central wellfield. But, because the Tanque Verde Valley is a source of high quality shallow groundwater, wells were installed by Tucson Water in the 1980s, and withdrawals increased from 8,161 acre feet in 1984 to 12,417 acre feet in 1989. As the attached study states, "this rate of withdrawal exceeded the average annual recharge to the Tanque Verde Valley, estimated to be 4,800 acre feet for Tanque Verde at Agua Caliente Wash, and 7,500 acre feet per year inclusive of Sabino Creek."

Report

Groundwater Level Changes in the Tanque Verde Valley was drafted by Pima County staff members and a Pima Association of Governments Water Quality Planner who has teamed with County staff in prior study efforts. Peer review by the author and contributors to the original Stromberg study improved the final draft, as did the review by experts from Metropolitan Water District and Pima Association of Governments. Divided into ten major sections that include as many maps, figure and graphs, some highlights of the report are:

- "The Tanque Verde Valley is a regionally significant riparian ecosystem. It is identified as a conservation site by The Nature Conservancy's Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion, largely on the basis of the mesquite woodlands and cottonwood-willow found there." ... "A survey of dry washes in metropolitan Tucson found eastern Tanque Verde Creek to have the highest species richness of riparian birds and neotropical migrants." (P. 1)

- "A previous study of groundwater decline along a six mile reach of the Tanque Verde Creek found that as groundwater depths fell from 16 to 59 feet, mesquite trees exhibited increasing signs of stress. ... At water levels less than 16 feet, the trees were measurably healthier .... At water levels deeper than 59 feet, trees showed evidence of near-lethal stress. ... The study prompted Tucson Water to adopt a 'last on, first off' policy for their wells along the Tanque Verde Creek." (P. 1)

- "For this report, annual groundwater elevations were obtained from Tucson Water for 17 wells in the study area, the same wells as used by Stromberg. ... The depth-to-water at wells ranges from 6 to 161 feet. ... [O]nly water levels in wells 1-3 are generally less than 16 feet; in wells 4-10 levels are between 16 and 59 feet; and in wells 11-17, levels are generally greater than 59 feet." (P. 5)

- "[B]oth deep and shallow water levels rose between December 1990 and 1992, under the influence of recharge (December 1990), and introduction of CAP water and associated supply well shutdowns (December 1992)." (P. 11)

- "Since December 1993, after the CAP was discontinued and rainfall was average or below average, the net result has been a decline in water levels. In the reach upstream of Houghton Road, where the groundwater table is generally shallow, water levels in wells have declined below levels associated with mesquite stress in the Stromberg study, despite the wet 'El Nino' year of 1998." (P. 12)

- "In 1984 Tucson Water withdrew 8,161 acre feet from the Northeast area, increasing to 12,417 acre feet in 1988. This rate of withdrawal exceeded the average annual recharge to the Tanque Verde Valley, estimated to be 4,800 acre feet for Tanque Verde at Agua Caliente Wash, and 7,500 acre feet inclusive of Sabino Creek." (P. 14)

- Between 1994 and 1998, the average annual pumpage by major water users, including private wells, was 6,545 acre feet, with a range from 5,910 to 7,826. "These rates of withdrawal are in excess of the 4,800 acre feet average annual recharge for the Tanque Verde Valley, if infiltration along Sabino Creek and its tributaries is not included in the water budget." (P. 14-15)

- The 3000 acres of existing riparian vegetation have a minimum water demand of 3,000 acre feet per year. (P. 15)

- "Since December 1993, water levels have generally declined." (P. 17)

- "Compared to water levels measured in 1990 by Stromberg and others, water levels today are little different than those demonstrated to be associated with stress to mature mesquite trees along the Tanque Verde Creek. ... Near lethal stress occurs in mesquite at depths-to-water greater than 59 feet. Data from December 1999 shows seven of the seventeen sampled wells had depths-to-water greater than 59 feet." (P. 17)

- "The Tanque Verde Valley's unique hydrogeology would allow for management of groundwater resources to promote shallow groundwater conditions and restoration of riparian and aquatic habitats. The Valley is structurally isolated from the groundwater depletions which have occurred in the central Tucson Basin, and the Valley enjoys large periodic recharge events derived from the adjacent mountains. From a conservation perspective, even though the stream no longer flows, the area has regionally significant riparian resources. Decreased pumping could improve habitat conditions along Tanque Verde Creek, particularly during wetter years." (P. 19)

- "Two considerations bode well for the potential to restore the aquifer. The first is that alternate sources of water exist for drinking and irrigation needs .... CAP utilization could provide the opportunity for Tucson Water to retire or partially retire production wells in the Valley. ... Extensions of the reclaimed system to the Tanque Verde Valley would also reduce demands...." "The second is that some of the mesquite bosque north of the Tanque Verde Creek may be maintained by a perched aquifer ... mitigating the impacts of pumping in the vicinity of the greatest declines in the regional aquifer."

- The report concludes with two recommendations: further study to determine the presence of confined and / or perched aquifers, and the establishment of monitoring wells in the mesquite bosques to directly determine water levels associated with plant communities. (P. 20)

Conclusion

Groundwater Level Changes in the Tanque Verde Valley provides a specific demonstration of the difficult trade offs that will be present as we develop the Sonoran Desert Conservation and Comprehensive Land Use Plan. It also shows that thoughtful decision making about use of water sources and future infrastructure investment might lead to greater balance where there is direct competition for a single resource in a specific geographic location.

GROUNDWATER LEVEL CHANGES IN THE TANQUE VERDE VALLEY

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Draft of October 2000
by Elizabeth Hill, Julia Fonseca, and Staffan Schorr

Introduction

The Tanque Verde Valley (Figure 1) is a regionally significant riparian ecosystem. It is identified as a conservation site by The Nature Conservancy's *Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion (2000),* largely on the basis of the mesquite woodlands and cottonwood-willow woodland found there.

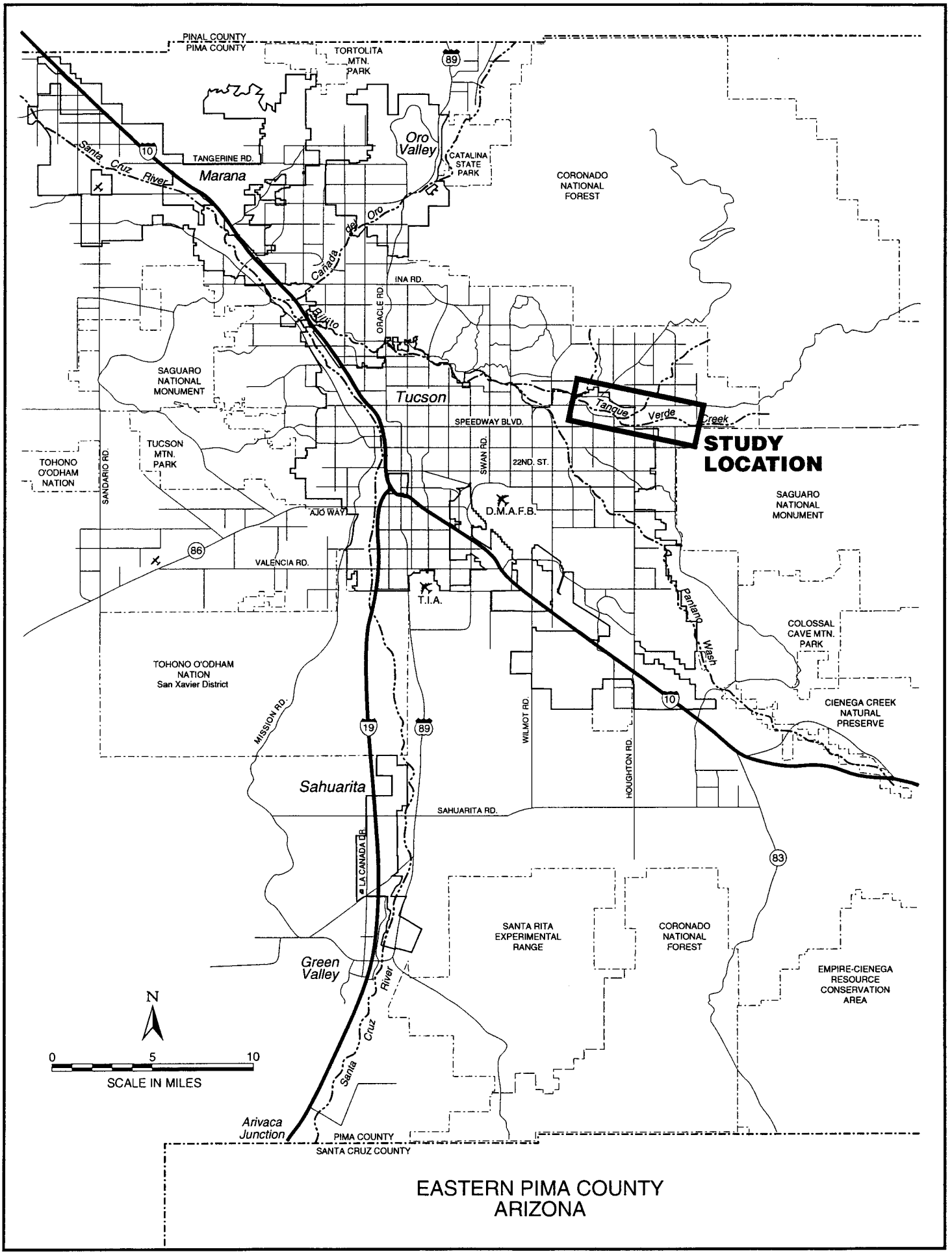
Historically, Tanque Verde Creek below Coronado National Forest supported an aquatic fauna that included native fish and leopard frogs. The endangered Gila Topminnow, for instance, was collected from Tanque Verde Creek as recently as 1941 and from a spring "50 feet west of Tanque Verde Creek at the Tanque Verde Ranch" in 1943 (Minckley, 2000). Today, perennial flow is no longer present outside of the Coronado National Forest.

A survey of dry washes in metropolitan Tucson found eastern Tanque Verde Creek to have the highest species richness of riparian birds and neotropical migrants (Frederick, 1996). This study also found that total canopy cover, mesquite density and absence of bank stabilization were factors which correlated positively with species richness for birds. The dark-toned areas on Figure 2 (aerial photo, 1998) show riparian vegetation associated with the valley floor.

A previous study of groundwater decline along a six mile reach of the Tanque Verde Creek found that as groundwater depths fell from 16 to 59 feet, mesquite trees exhibited increasing signs of stress (Stromberg et al., 1992, Appendix 1). Stresses included decreased leaflet size, leaflet number, and canopy height. At water levels less than 16 feet, the trees were measurably healthier, with large leaflets, tall stature and greater vegetation volume. At water levels deeper than 59 feet, trees showed evidence of near-lethal stress. Figure 3 illustrates how water stress affects mesquite woodlands. Study measurements for the Stromberg study were taken in May, June, August and October, 1990. Summer rains and seasonal surface flow temporarily reduced stress, but did not offset the effects of groundwater decline. The study prompted Tucson Water to adopt a "last on, first off" policy for their wells along Tanque Verde Creek.

Purpose

The purpose of this report is to investigate variations in groundwater levels since the Stromberg study was conducted in 1990. Available groundwater level information and influences on groundwater levels for an area of the Tanque Verde Creek from approximately Wentworth Road to Sabino Canyon Creek have been evaluated in this report. This was the area previously studied by Stromberg and others.



EASTERN PIMA COUNTY
ARIZONA

Pima County Graphic Design 6/30/99 pc

Figure 1. Location Map

Figure 2. Location of Tucson Water wells used in this study.

Healthy mesquite bosque, Cienega Creek

Canopy dieback, Tanque Verde Creek at Pantano Wash
November 1999

Former mesquite bosque, Casa Grande

Figure 3. Decline of Mesquite Bosques

Groundwater Levels

For this report, annual groundwater elevations (December 1988-December 1999) were obtained from Tucson Water for 17 wells in the study area, the same wells as used by Stromberg. The wells are located on Figure 2 and described in Appendix B. For ease of reference, Tucson Water well names have been numbered simply from 1 to 17. Water surface elevations in wells located upstream of Houghton Road are generally higher; the direction of groundwater movement is generally westerly.

Figure 4 shows the plots of the water surface elevations generated for the 12 year period. Figure 5 shows the plots of depths-to-water, which were generated by subtracting the fixed land surface elevation for each well from the varying water surface elevations measured each year. The depth-to-water at wells ranges from 6-161 feet. According to the Stromberg study, mesquites are stressed when water depths are between 16 and 59 feet, while near-lethal and lethal stress occurs in mesquites at water levels greater than 59 feet. As shown on Figure 5, only water levels in wells 1-3 are generally less than 16 feet; in wells 4-10, levels are between 16 and 59 feet; and in wells 11-17, levels are generally greater than 59 feet. Wells 1,2,3,4,7,8,10,11,16 and 17 are at or close to the elevation of the mesquite bosque. Areas of former mesquite bosque were interpreted from 1941 aerial photographs.

Figure 6 is based on work by Schwalen and Shaw (1957). The top map shows the groundwater table as it existed in spring 1956. To "visualize the changes which have taken place in the water table at various times over a period of years as a result of pumping," the authors constructed longitudinal profiles along the axis of Tanque Verde Creek for several years between 1947 and 1956. We have superimposed 1999 water levels on the Figure 6 profile to compare with 1947 water levels. As Schwalen and Shaw state, the 1947 water levels reflect groundwater depletions. Our review of 1941 aerial photographs shows much of the Tanque Verde corridor was in irrigated agriculture at that time.

Comparison of Figure 6 water levels shows that 1999 water levels in wells upstream of Tanque Verde Loop Road are similar to 1947 conditions, while 1999 water levels in wells downstream of Houghton Road are lower than 1947 levels by up to 60 feet.

Central Arizona Project Water

Two significant dates of Central Arizona Project (CAP) water delivery are noted on Figures 4 and 5, with delivery beginning in November 1992, and ending approximately one year later in November 1993. As CAP water was introduced to the potable water delivery system, Tucson Water began taking water supply wells out of production.

The graphs in Figure 7, extracted from a Tucson Water report (1996), illustrate the general effect of CAP water delivery on groundwater level and pumpage in the Tucson Water central wellfield, and on total area pumpage. A continuous hydrograph of Well B-052A, located in the Tucson Water central wellfield near Grant/Craycroft, shows the resulting rise in water surface elevation during CAP delivery and supply well shut-down. The decrease in pumpage associated with the supply well shut down is illustrated in the lower graph; in 1993, with CAP water supplementing the delivery system, there was a significant decrease in total area pumpage, (which would include the Tanque Verde Valley), and Tucson Water central wellfield pumpage, when compared to previous years.

Figure 7 also reflects the increase in consumer demand which occurs in hot, dry years, such as 1989 and 1994.

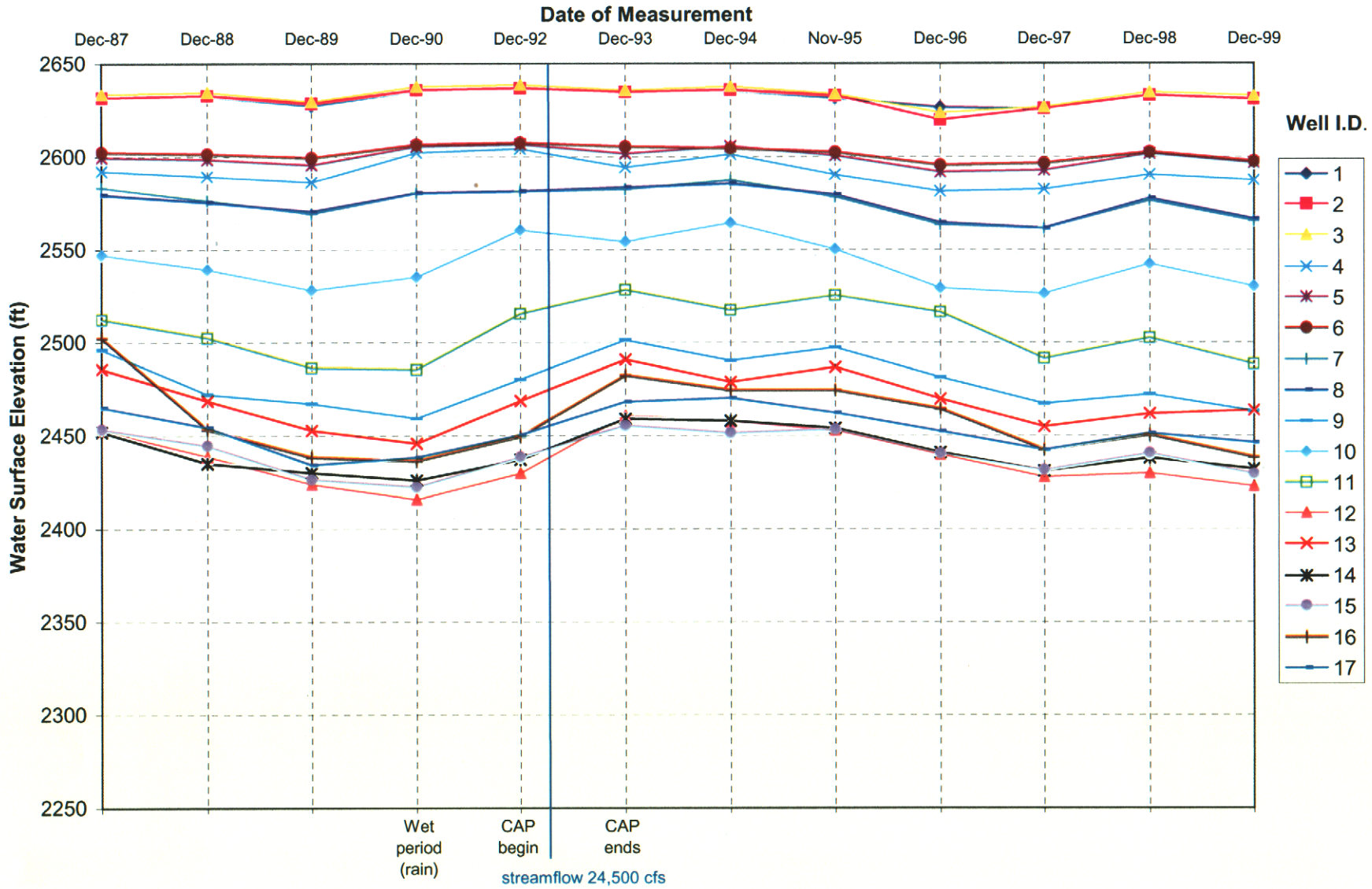


FIGURE 4: WATER SURFACE ELEVATIONS

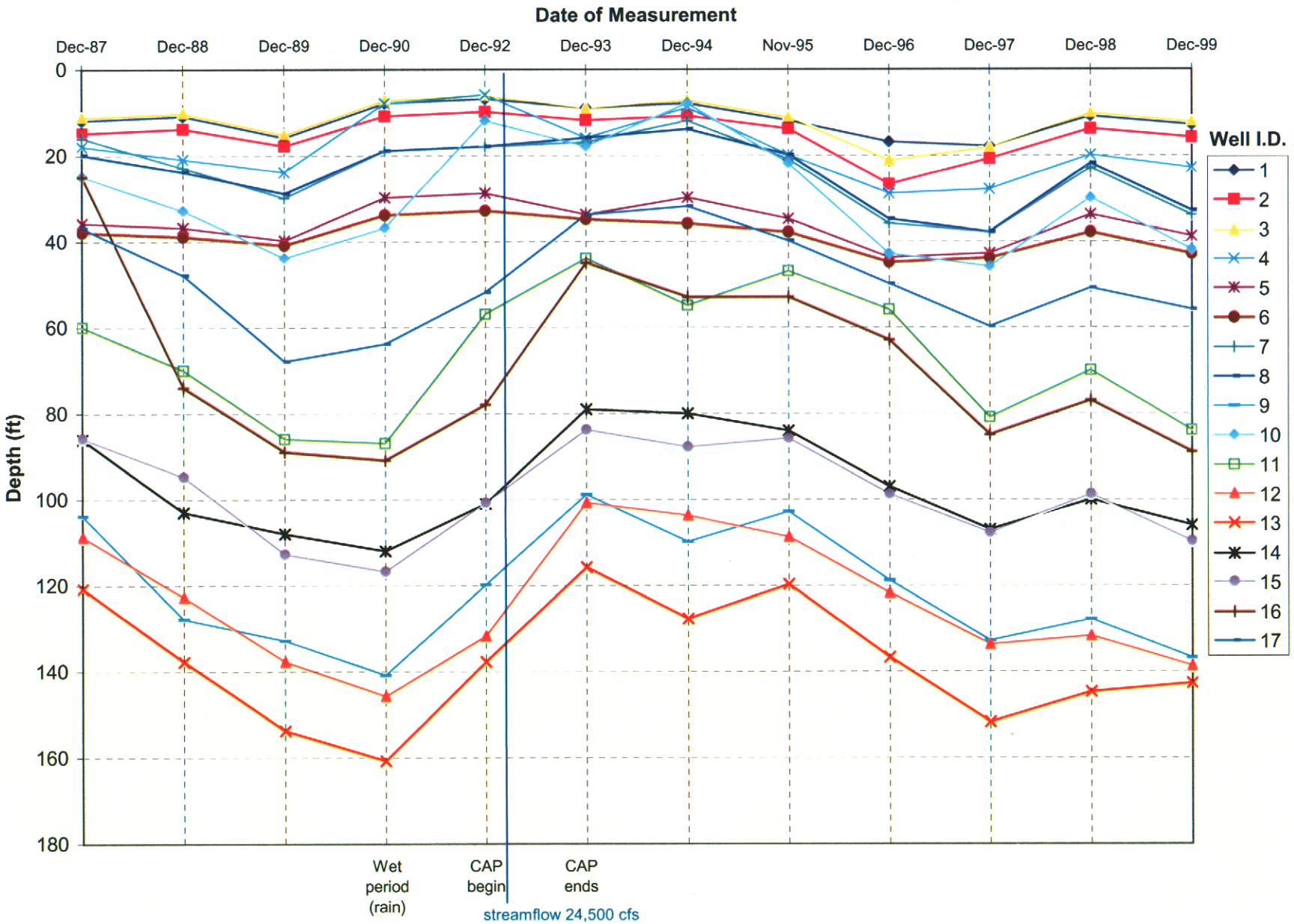


FIGURE 5: DEPTH TO WATER

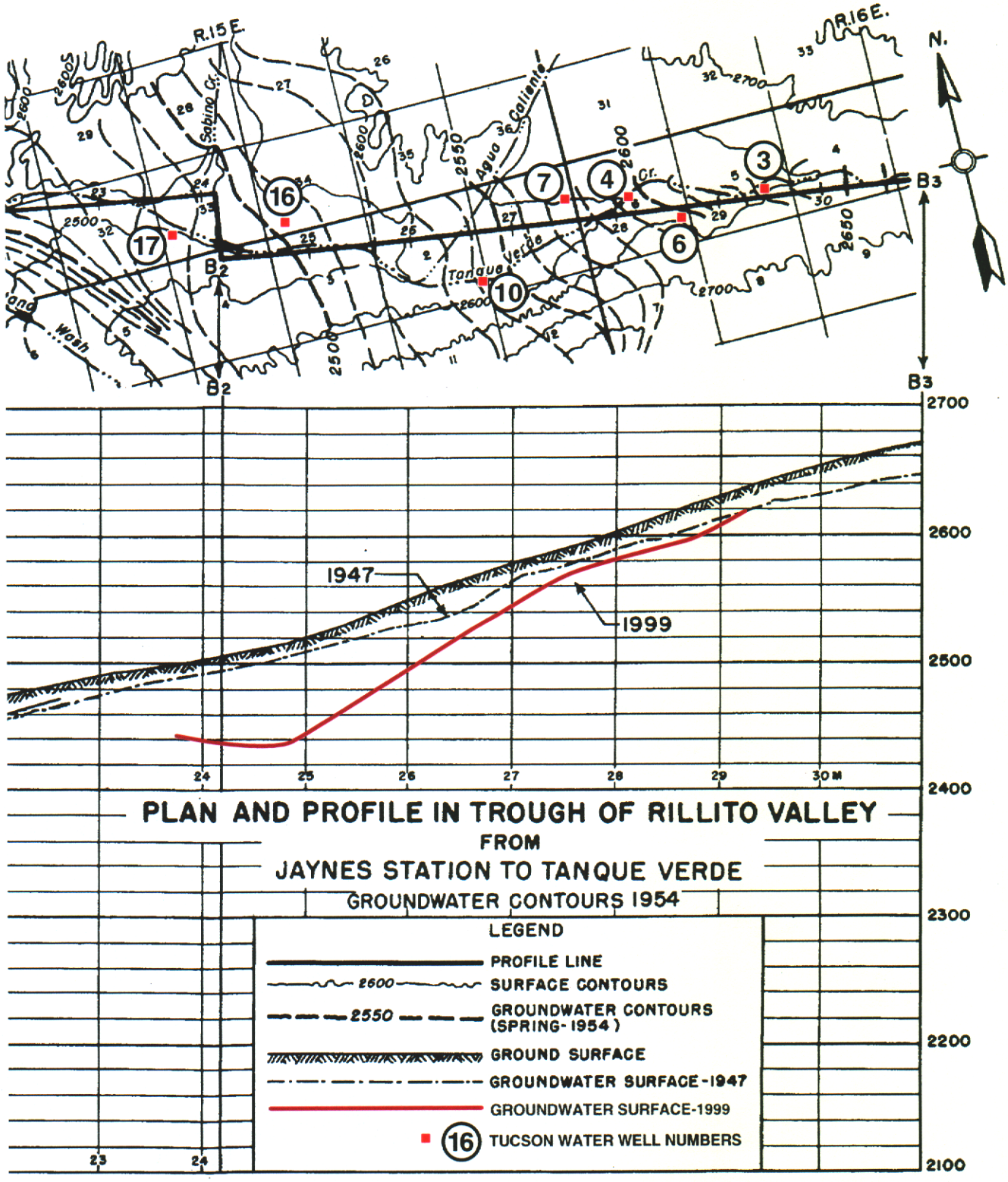


Figure 6. Water levels in 1947 and 1999.

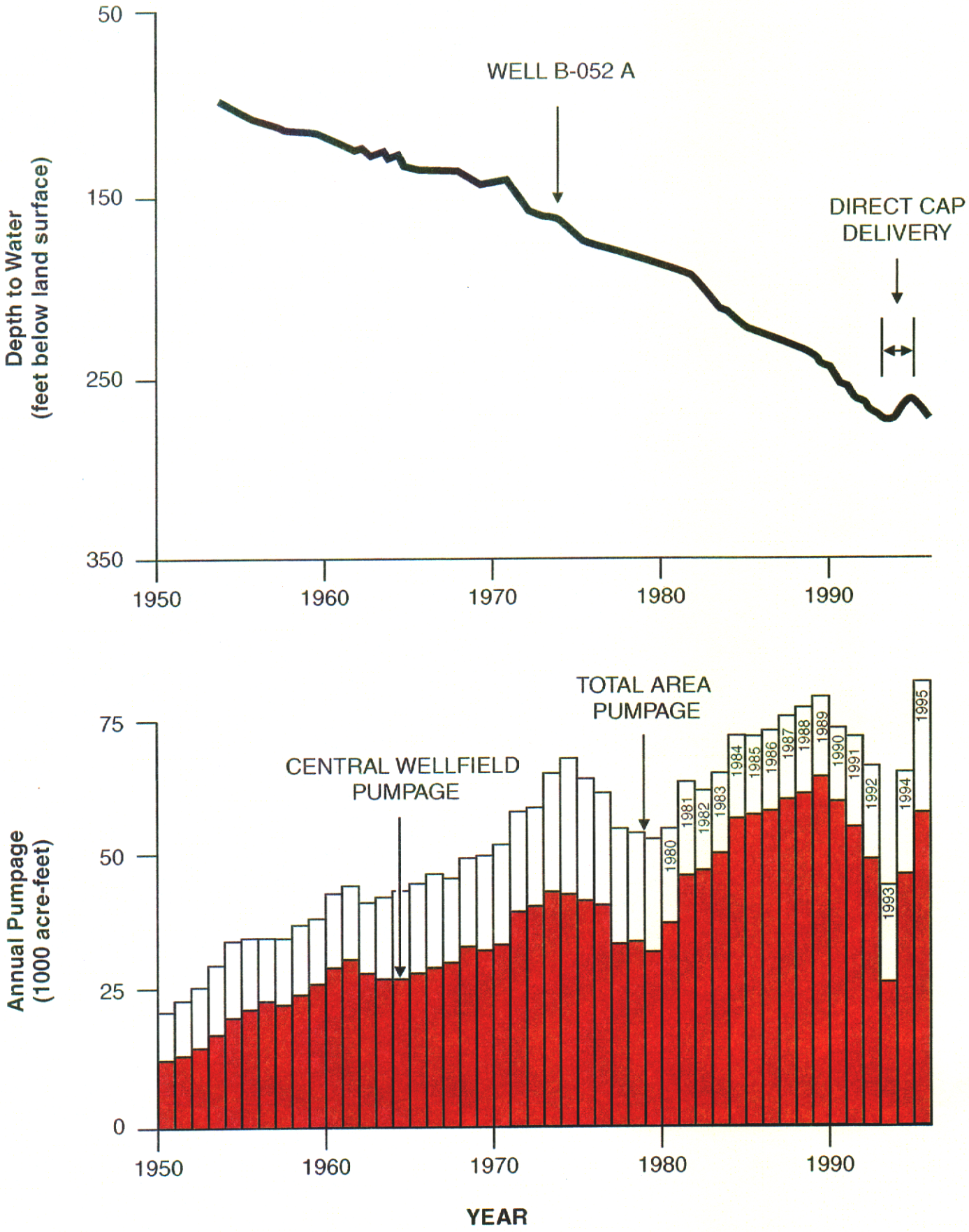


Figure 7. Tucson Water Central Wellfield Pumpage and Hydrograph of Well B-052 A

The following table compares annual depths-to-water for all study wells in both 1990 and 1992, two years during which significant water resource influences occurred. Prior to 1990, water levels were generally declining, then a large summer runoff event occurred in 1990, and CAP water was introduced in November 1992 . For comparison purposes, the most recent available data is shown for December 1999. Data for May 1990 (prior to the major runoff event) was available only for the six continuous recorder wells.

Table 1. Depth-to-Water in 1990, 1992 and 1999

Tucson Water Well Name	Well Number	Depth-to-Water (ft)			
		May 90	Dec. 90	Dec. 92	Dec. 99
E-20A	1	12	8	7	13
E-22-A	2	-	11	10	16
CL-33A	3	-	7	6	12
TV1-A	4	-	8	6	23
D-053A	5	-	30	29	39
WR-51A	6	-	34	33	43
D-62A	7	-	19	18	34
D-063A	8	-	19	18	33
C-118A	9	-	141	120	137
C-75A	10	48	37	12	42
C-75B	11	-	87	57	84
SD-1A	12	144	146	132	139
C85-A	13	-	161	138	143
C83-A	14	114	112	101	106
C83-B	15	-	117	101	110
C-84A	16	90	91	78	89
C-73A	17	68	64	52	56

- Data Not Available

As the table shows, both deep and shallow water levels rose between December 1990 and 1992, under the influence of recharge (Dec. 90), the introduction of CAP water and associated supply well shutdowns (Dec. 92).

Flow Data

The United States Geological Survey operates a gauging station at Site #09484500 located at the intersection of Sabino Canyon Road and Tanque Verde Creek (Figure 2). The data contained in Figure 8 is arranged by Water Year, which runs from October 1 to September 30 of the following year.

Annual stream discharge measured in acre-feet (ac-ft) was available for nine years, 1991 to 1999, and is shown graphically on Figure 8, top. Annual discharge in Water Year 1993 was over 100,000 acre-feet, while 1994, 1996 and 1997 reflect very dry conditions.

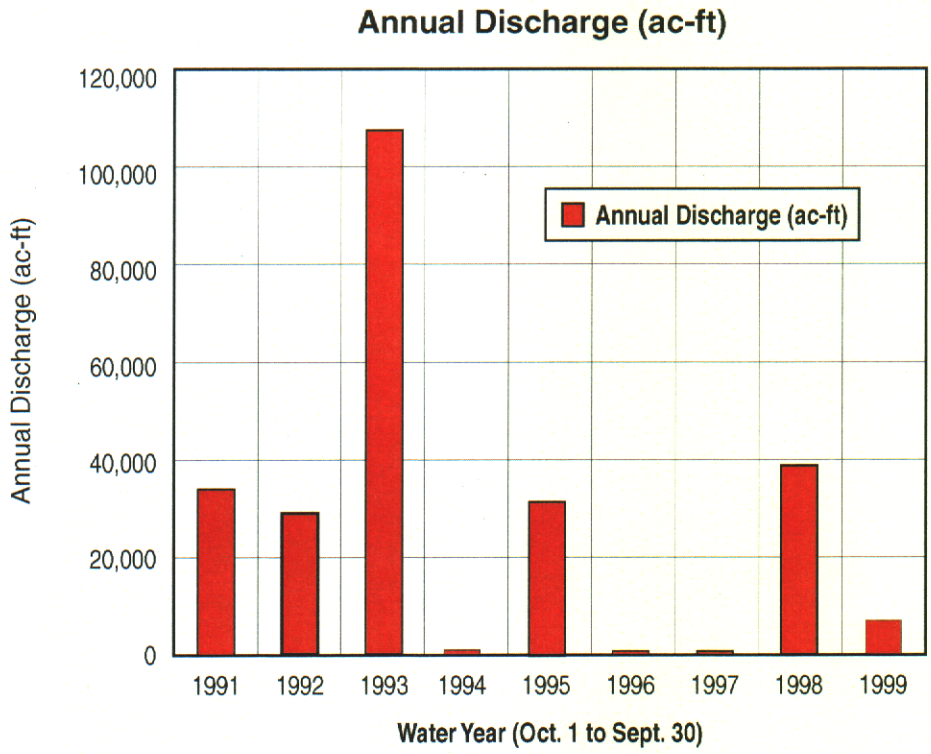
Annual peak discharge information measured in cubic feet per second (cfs) was available for the 12 year study period and is shown graphically on Figure 8, bottom. Water Year 1993 shows a significant runoff event, while the peaks in the previous years are much less than the 100 year event for the gauging station. Noted on the groundwater level Figures 4 and 5 is the peak flow for the study period which occurred in January, 1993 and measured 24,500 cfs. Water Years 1994, 1996 and 1997 were extremely dry.

Recharge Response

In order to describe the effect of runoff on aquifer recharge, data can be compared between Figure 5 (Depth-to-Water) and Figure 8 top (annual flows in ac-ft). Note that the annual discharge on Figure 8 is the sum of what occurs between October 1 and September 30 (water year), and the well water level readings on Figure 5 are measured in December. Therefore, the effect of a "wet" year like 1993 could show up as an increasing well water level between December 1992 and December 1993.

Since December 1993, after the CAP was discontinued and rainfall was average or below average, the net result has been a decline in water levels. In the reach upstream of Houghton Road, where the groundwater table is generally shallow, water levels in wells have declined below levels associated with mesquite stress in the Stromberg study, despite the wet "El Nino" winter of 1998.

Very generally, there appears to be a decline in water levels following "dry" water years such as 1994, 1996 and 1997, and a rise in water levels following "wet" water years such as 1993 and 1995, suggesting that streambed recharge affects groundwater levels along the Creek. All of the wells do not exhibit this rise-and-fall response trend, however, and it is possible that another variable, such as increased pumping may be influencing water levels to such an extent that natural recharge is reduced or ineffective.



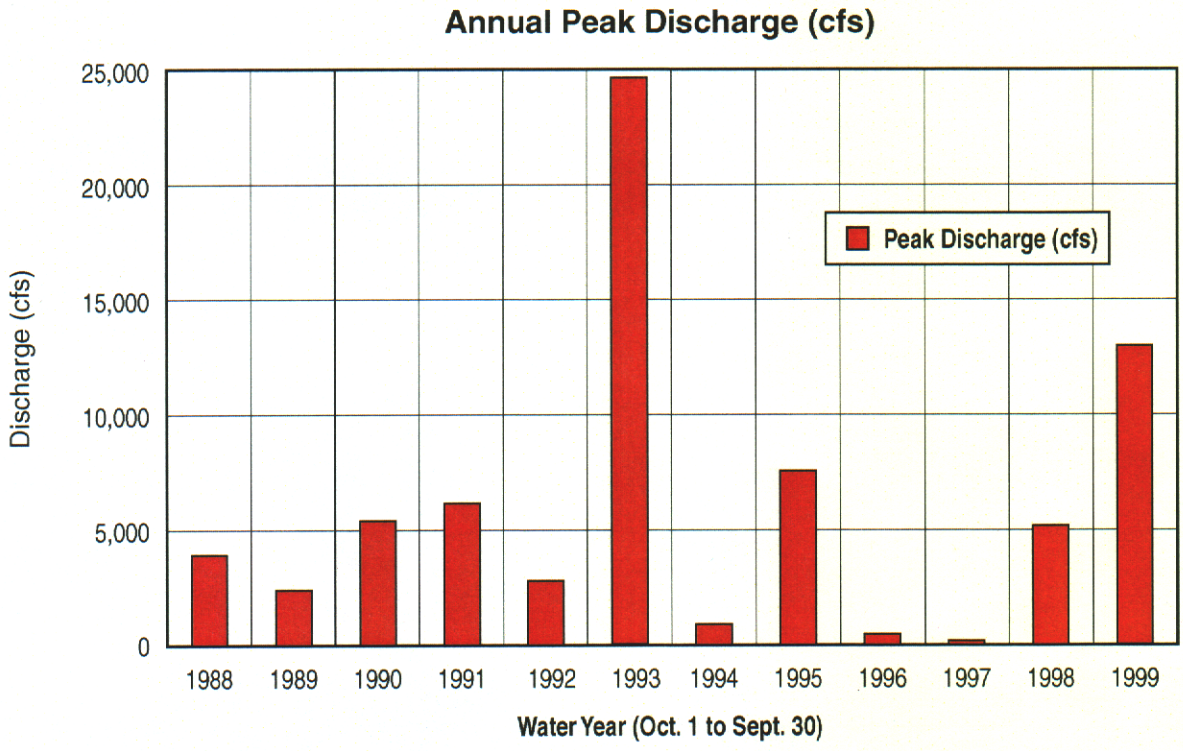


Figure 8. Tanque Verde Creek USGS Gauge #9484500

Historic Pumping in the Tanque Verde Valley

A trough of highly permeable sediments extends roughly from Tanque Verde Loop Road on the east to approximately Sabino Canyon Road on the west. The western end of the trough is delimited by a deep fault, which separates the Tanque Verde Valley from Tucson Water's Central wellfield. In the 1980's this trough of highly permeable material was targeted by Tucson Water as a source of high quality, shallow groundwater. To supply increasing consumer demands, five new wells were constructed in the late 1980's and were permitted by the Department of Water Resources to withdraw approximately 11,000 ac-ft per year (1989). In 1984 Tucson Water withdrew 8,161 ac-ft from the Northeast area, increasing to 12,417 ac-ft in 1988 (1989). This rate of withdrawal exceeded the average annual recharge to the Tanque Verde Valley, estimated to be 4,800 ac-ft for Tanque Verde at Agua Caliente Wash, and 7,500 ac-ft/yr inclusive of Sabino Creek (Burkham, 1970).

Pumpage Data

For the study period, pumpage data was obtained from Pima Association of Governments (PAG). Table 2 contains data prepared for a previous study on groundwater withdrawals near streams identified for the Sonoran Desert Conservation Plan (2000). Data in Table 3 was compiled by PAG from spreadsheets provided by the Arizona Department of Water Resources for all non-exempt wells (pumpage greater than 35 gpm) within a one mile radius of Tanque Verde Creek from Wentworth Road to Sabino Creek (Appendix C and D). Wells were identified from the ADWR Well Registry CD ROM (3rd edition). The following table shows the major users and their average annual withdrawal amounts.

TABLE 2: Average Annual Pumpage by Water User

Major Water User	Average Annual Pumpage (1994-1998)
Tucson Water	4,404 ac-ft
MDWID	1,053 ac-ft
49ers Country Club Estates	735 ac-ft
Others (private)	353 ac-ft
TOTAL	6,545 ac-ft

Tucson Water is the principal entity pumping wells located along Tanque Verde Creek. Metropolitan Domestic Water Improvement District (MDWID) and Forty-Niners Country Club Estates are the second and third biggest users of groundwater from the study area.

The following table shows annual withdrawals by water user.

TABLE 3: Total Annual Pumpage by Water User

	Number of Wells[1]	Total Reported Annual Withdrawals (ac-ft)				
		1994	1995	1996	1997	1998
Tucson Water	25	5449	3722	3837	4814	4196
MDWID	5	1055	1100	1055	1062	992
49ers Country Club Estates	4	864	821	732	599	659
Others (private)	109	458	372	286	326	323
Total	143	7,826	6,015	5,910	6,801	6,170

[1] Not every well reported pumpage and some did not pump any amount.

Figure 9 shows the locations of all registered non-exempt wells, along with water user jurisdictional boundaries. Exempt wells, which are pumped at a rate of less than 35 gallons per minute (gpm), are not shown on Figure 9. There are 120 exempt wells in the Tanque Verde Valley, pumping an estimated one ac-ft per year, each (Riparian Element Report 2000).

These rates of withdrawal are in excess of the 4800 acre-feet average annual recharge for the Tanque Verde Valley, if infiltration along Sabino Creek and its tributaries is not included in the water budget. Evapotranspiration and groundwater pumping along Sabino Creek and Agua Caliente Wash reduce the likelihood that the full amount of infiltration from Sabino Creek and tributaries becomes available to the Tanque Verde Valley. In addition, some portion of the infiltration along Tanque Verde Creek itself is lost to evapotranspiration.

Vegetation mapping recently completed for the Sonoran Desert Conservation Plan indicates that there is around 3000 acres of riparian vegetation overlying the Tanque Verde-Agua Caliente shallow groundwater zone defined by PAG (2000). Estimated consumptive use for dense to medium dense mesquite woodland would be 20 to 30 inches per year in Tucson, based on ADWR estimates (1991). At even a minimal use rate of one foot per year, it can be seen that water demand by riparian vegetation constitutes 3000 acre-feet per year, a considerable portion of the water budget.

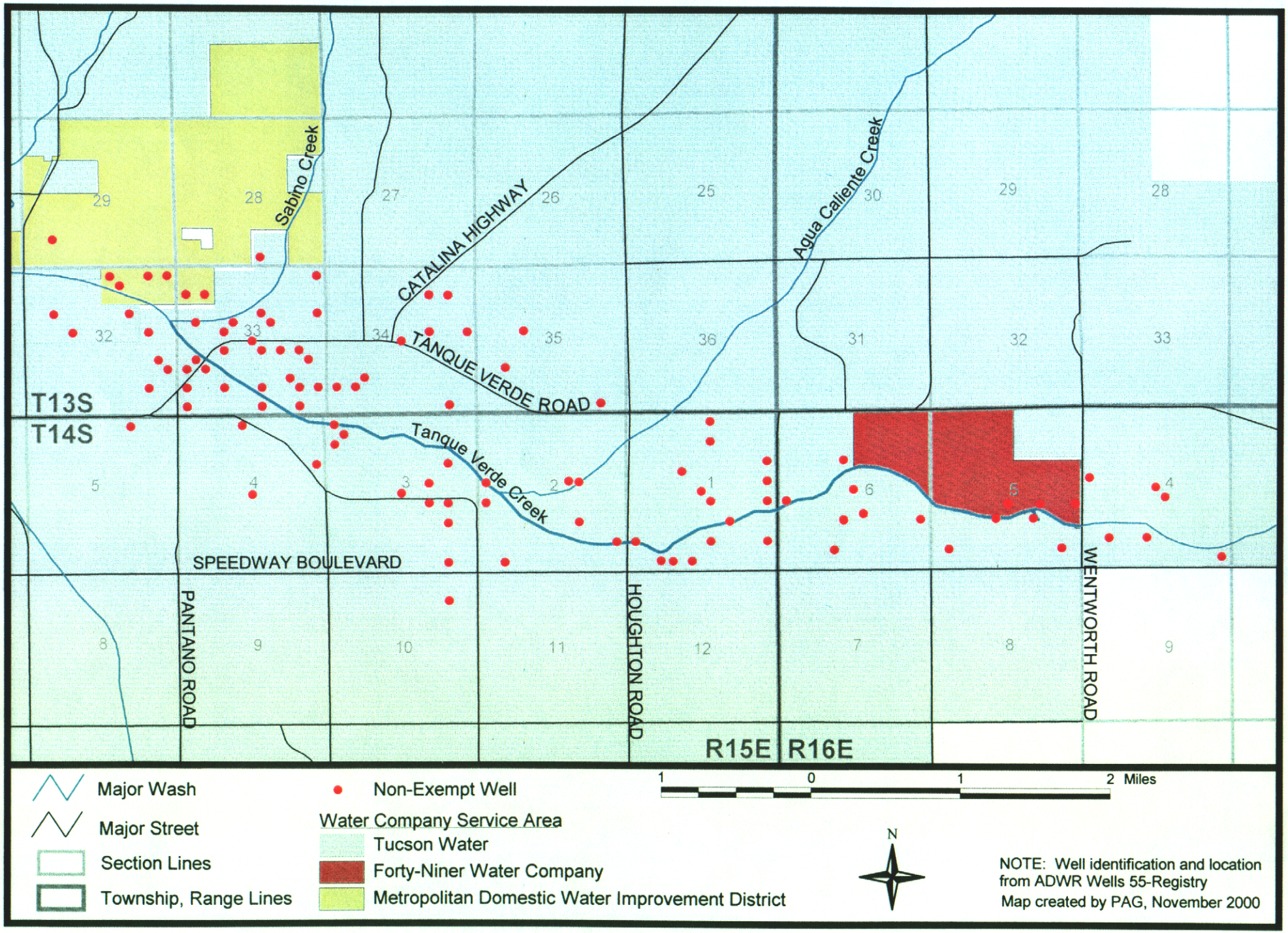


Figure 9. Non-Exempt Wells and Water Companies within One Mile of Tanque Verde Creek, Wentworth Rd to Sabino Creek

Discussion

In the three years following the 1990 measurements of water stress to mesquites by Stromberg, water levels in the Tanque Verde Creek generally rose, probably in response to decreased pumping by Tucson Water and natural groundwater recharge which followed the January 1993 flood. The shallowest groundwater levels in the period 1990 to present generally were measured in December, 1993. (Figures 4 and 5).

Since December 1993, water levels have generally declined. The declines are more apparent in the lower reaches of the Tanque Verde Valley than the upper reaches.

Compared to water levels measured in 1990 by Stromberg and others, water levels today are little different than those demonstrated to be associated with stress to mature mesquite trees along Tanque Verde Creek. As the study mentioned, near-lethal stress occurs in mesquite at depths-to-water greater than 59 feet. Data from December 1999 (Table 1) shows seven of the seventeen sampled wells had depths-to-water greater than 59 feet.

Figure 10 shows a depth-to-water plot of ten wells that are in mesquite and former mesquite bosque, as determined from historic aerial photographs, typical of healthy riparian and aquatic ecosystems. Two wells, 11 and 16, have current water levels that are in excess of the limit of mesquite survival. However, recent field observation of mesquite around Well 11 did not show mortality or severe dieback that would be associated with these water depths. Also a young stand of cottonwood trees is present in the channel bottom near Wells 10 and 11. It is possible that a perched aquifer is sustaining this portion of the mesquite bosque, and Well 10 is tapping a perched aquifer. Wells 4,7,8,10, and 17 suggest current water levels that would indicate increasing stress to mesquite. These wells are located in mesquite bosque near Houghton Road and along Tanque Verde Loop Road.

It is possible that some of the Stromberg study observations of near-lethal water stress to mesquites might have been affected by the rate of groundwater decline (Stromberg, pers. comm.). Mesquite could survive deeper groundwater levels than 59 feet, if the rate of decline were quite gradual. However, canopy cover and aboveground biomass of the mesquite would still decline greatly. In addition, many other biotic components of riparian ecosystems are lost as groundwater declines (Stromberg, pers. comm.). Conversely, many desirable ecosystem components would recover as groundwater levels increase.

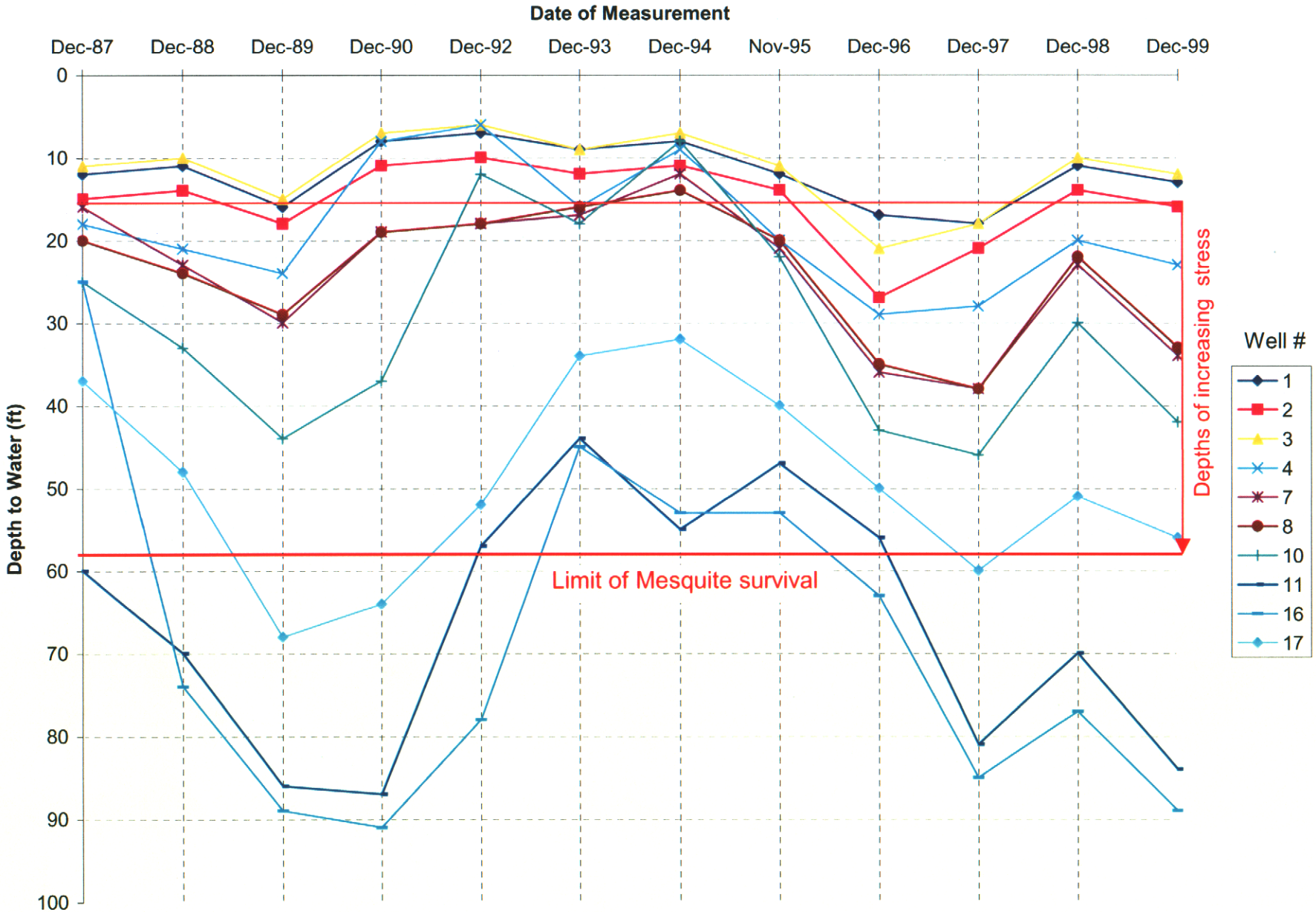


Figure 10 : Depth to Water in Mesquite and Former Mesquite Bosque

Conclusions

Groundwater depletion along Tanque Verde Creek upstream of Sabino Creek was well underway by 1947. Groundwater depletion increased in the late 1980's.

Declines in the water table during the late 1980's occurred due to drought and increased consumer demand for water in the Tanque Verde Valley. Observed declines led to 1990 investigations of water stress in mesquite trees by Stromberg and others (1992). The confirmation of water stress to riparian trees, coupled with outcry from shallow well owners, led the City Council to adopt a "last on, first off" policy for wells in this area.

This report finds that adoption of this policy has not been sufficient to restore the water table in the reach below Houghton Road, where a substantial acreage of mesquite woodland exists. Water levels rose in this area in response to the January 1993 flood event and the 1993 delivery of CAP water. For the period 1994 to 1998, reported withdrawals are some 6000 to 7000 acre-feet per year, from three water companies and over 100 private wells. Water budget analysis suggests that the current usage only perpetuates the depleted aquifer conditions. Current (1999) water levels are similar to those which existed at the time of the study by Stromberg and others.

The Tanque Verde Valley's unique hydrogeology would allow for management of groundwater resources to promote shallow groundwater conditions and restoration of riparian and aquatic habitats. The Valley is structurally isolated from the groundwater depletions which have occurred in the central Tucson Basin, and the Valley enjoys large periodic recharge events derived from the adjacent mountains. From a conservation perspective, even though the stream no longer flows, the area has regionally significant riparian resources. Decreased pumping could improve habitat conditions along Tanque Verde Creek, particularly during wetter years.

Two other considerations bode well for the potential to restore the aquifer. The first is that alternate sources of water exist for drinking and irrigation needs of the human population in the Tanque Verde Valley. CAP utilization could provide the opportunity for Tucson Water to retire or partially retire production wells in the Tanque Verde Valley. Additional use of renewable supplies could be facilitated if Metropolitan and Forty-Niner's water utilities connected to Tucson Water's potable and reclaimed delivery systems. Extensions of the reclaimed system to the Tanque Verde Valley would also reduce demands, if the community is willing to pay the price.

The second is that some of the mesquite bosque north of Tanque Verde Creek may be maintained by a perched aquifer. The perched aquifer conditions may be mitigating the impacts of pumping in the vicinity of the greatest declines in the regional aquifer.

Recommendations

A more complete description of the Tucson Water wells (i.e. perforation intervals) might reveal the presence of confined and/or perched aquifers. Since groundwater levels obtained from wells are influenced by the type of aquifer that is being tapped, this information could explain areas of good mesquite vigor where water levels appear to be at lethal levels, and areas of poor mesquite vigor where water levels appear to be adequate.

The locations and depths of the 17 Tucson Water wells are not optimal in terms of correlating groundwater levels with mesquite vigor. Establishing a series of monitoring wells in the mesquite bosques would more directly determine water levels associated with the plant communities. The possibility that existing large irrigators along the channel may be locally mitigating the reduced availability of water to the riparian areas through incidental recharge might be considered.

A biologic assessment of the bosques around the Tucson Water and monitor wells, such as was done in the Stromberg study, would allow a more detailed comparison of water levels and mesquite vigor.

Acknowledgements

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References

Arizona Department of Water Resources, 1991. Hydrologic Survey of the San Pedro Watershed. ADWR, Phoenix, Arizona.

Burkham, D.E., 1970. Depletion of Streamflow by Infiltration in the Main Channels of The Tucson Basin, Southeastern Arizona. Geological Survey Water Supply Paper 1939-B.

City of Tucson, 1988-1999. Annual Static Water Level Basic Data.

City of Tucson, 1989. Northeast Area Water Level Decline Report, Tucson Water Planning Division.

City of Tucson, 1996. Assessment of CAP Water Recharge Alternatives. Compilation by Pima County Flood Control District in a document entitled Central Wellfield Recharge Alternatives.

Frederick, T.M. 1996. Patterns of Habitat Use by Birds and Lizards in Urban River Corridors of Tucson, Arizona. M.S. Thesis, Renewable Natural Resources, University of Arizona.

Minckley, W.L. 2000. Pima Co. Fish. Database dump for Pima County, Arizona (includes AGFD Records, not checked). Taxonomy corrected by W.L. Minckley, 23 August 2000.

Pima Association of Governments (PAG), 2000. Water Usage along Selected Streams in Pima County. Sonoran Desert Conservation Plan, Pima County.

Riparian Element Report 2000. Riparian Protection, Management and Restoration. Riparian Element, Sonoran Desert Conservation Plan. Preliminary, September 2000, Prepared by Pima County.

Rogers, S.R., 1987. Hydrogeologic Investigation of the Northeast Area of the Tucson Basin, Structure and Stratigraphy, Tucson Water Open File Report WRS-97-1, October 1987.

Stromberg, J.C., Tress, J.A., Wilkins, S.D., & Clark, S.D. 1992. Response of Velvet Mesquite to Groundwater Decline. Journal of Arid Environments, 23:45-58.

United States Geological Survey, 1988-1999. Water Resources Data-Arizona. Water-Data Report AZ-Yr-1.

Schwalen, H.C., Shaw, R.J. October, 1957. Groundwater Supplies of Santa Cruz Valley of Southern Arizona Between Rillito Station and the International Boundary, Bulletin 288.

APPENDIX A

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Response of velvet mesquite to groundwater decline

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Mesquite (*Prosopis velutina*) bosques are groundwater-dependent riparian woodlands that were once widespread in the American Southwest. Groundwater withdrawal from the aquifer below an ephemeral creek in the Sonoran Desert of Arizona created the opportunity to quantify relationships between groundwater depths and bosque traits. Temporal and spatial variation in plant water potential, leaflet size, leaflet number, canopy height, and live and dead vegetation volume all indicate that the bosque requires a shallow aquifer and that bosque traits change continuously with groundwater depth. The bosque had high water potentials, large leaflets (>7 cm^2), tall stature (>12 m), and large vegetation volume (>2 m^3/m^2) only where the water table was <5 m below the surface. Trees became increasingly stressed as groundwater declined to 15–18 m. Summer rains and seasonal surface flow temporarily reduced water stress and increased leaflet size for some trees, but did not offset effects of groundwater decline. Trees in areas of greatest groundwater decline (18–30 m) were under sublethal stress, as evidenced by low stem water potentials (<−4 MPa), reduced leaflet size (<5·5 cm^2), and high levels of canopy mortality (>45%). These deepest groundwater levels are in the range of those documented to be lethal to mesquite in other bosque systems.

APPENDIX B

Tucson Water Wells Used in This Study

Well #	Tucson Well Name	Cadastral Location	Max Depth Cased (ft BLS*)	Status (1997)
Township 14 South Range 16 East				
1	E-020A	(D-14-16)05 DBD1	49	Continuous Recorder
2	E-022A	(D-14-16)05 DBD3	43	Water Level Monitor
3	CL-033A	(D-14-16)05 DBD4	47	Water Level Monitor
4	TV-001A	(D-14-16)06 BDA	106	Not in Use
5	D-053A	(D-14-16)06 DAD1	103	Water level Monitor
6	WR-051A	(D-14-16)06 DAD3	60	Water Level Monitor
Township 14 South Range 15 East				
7	D-062A	(D-14-15)01 ADA1	128	Monitor
8	D-063A	(D-14-15)01 ADA2	87	Monitor
9	D-118A	(D-14-15)02 CCD	839	Active Production Well
10	C-075A	(D-14-15)02 DDA1	500	Datalogger
11	C-075B	(D-14-15)02 DDA2	625	Active Production Well
12	SD-001A	(D-14-15)03 CAB	532	Continuous Recorder
13	C-085A	(D-14-15)03 DDC	545	Active Production Well
14	C-083A	(D-14-15)04 BAA	402	Datalogger
15	C-083B	(D-14-15)04 BAA	640	Active Production Well
Township 13 South Range 15 East				
16	C-084A	(D-13-15)34 CCA	300	Continuous Recorder
17	C-073A	(D-13-15)33 CBC	100	Datalogger

*Below Land Surface

APPENDIX C

ADWR Pumping Records for Non-Exempt wells within one mile of Tanque Verde Creek, Wentworth Rd to Sabino Canyon Confluence (sorted by well owner)

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
503963	14-16-5	SW	NE	SE	49ER WATER CO.	105
617300	14-16-5	SE	NE	NE	49ER WATER CO.	277
617301	14-16-5	SE	NE	NW	49ER WATER CO.	202
617302	14-16-2	SE	NW	NW	49ER WATER CO.	151
801906	13-15-33	SW	NW		ARONOW, WILLARD F.	0
626378	14-15-1	SW	SE	SE	BARTELS, PETER H	0
801131	14-15-3	NE	SW	SE	BELL, GALE S.	0
801968	13-15-33				BENNETT, JAMES H.	27
530916	13-15-33	SW	SW	SW	BENNETT, JAMES,H	NA
800736	13-15-33	SE	SW	SW	CELLA, FLORENCE & PAUL/CELL, PAUL W.	4
520583	13-15-33	SE	SW	SW	CELLA, PAUL,W	NA
801967	13-15-34				CONTINENTAL SVC CORP	4
619256	14-15-3	SE	NW	NE	CONWAY, WILLIAM E.	7

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
625709	13-15-33	NW	SW		COONAN, ANN A.	0
618075	13-15-33	NW	NW	SW	COTE, ROBERT T.	0
617211	13-15-33	SE	NW	NE	CRARY, CHARLES E.	0
604250	14-16-4	NW	SW	SW	CROSBY, WILLIAM F.	22
628874	14-15-2	SW	NW	NW	CURRIER, CATHY	7
800922	13-15-35	SW	NW	SE	DECARLO, DANIEL C	2
801104	14-15-4	NE	SE	NE	DIXON,T J	NA
801176	14-16-6	SW	SE		DORAN, THOMAS E.	0
608182	14-16-4	SE	SE	SE	DRYDEN, ROBERT M.	13
608183	14-16-4	SE	SE	SE	DRYDEN, ROBERT M.	0
600039	14-16-6				ELLIOTT	NA
606494	13-15-33				EMMERSON, DAVID A.	0
527986	13-15-33	SW	NE	NW	EMMERSON, DAVID,A	NA
803452	14-15-1	SW	SW	NW	ERWIN, ELDON U.	0
801182	14-16-5	SE	SE		FERGANCHICK, BERT A.	0

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
501580	13-15-33	SE	SE	NE	FISSELL, JAMES C. & SUSAN Z.	9
620736	13-15-33	SE	SE	NE	FISSELL, JAMES C. & SUSAN Z.	8
557971	13-15-33	SE	SW	NW	FORD, RODGER G. & AMY R.	38
628080	13-15-33	SE	SW	NW	FORD, RODGER G. & AMY R.	50
575575	14-16-6	SW	NE	SE	GARDNER	NA
801928	13-15-34	SE	SE	SW	GOEBEL, GEORGE M	0
606057	13-15-32	NW	SW	NE	GOLDEN HERITAGE CORP,	NA
803490	14-15-1	SE	NW	NW	GONDA, GERALD,	NA
526006	14-15-3	NE	SE	NW	GRIGGS, DENIS C	0
801159	13-15-33				HASSEY, NEMER E.	0
801241	14-16-6	SW	NE	SE	HECKER, RICHARD H. & ANN E./GARDNER, DAVID K.	6
623019	13-15-33	NE	SE	NE	HELLER, GENEVE C. TRUST	0
616963	13-15-33	SW	NW	SE	HENKEL, JOHN H. & JOANNA M.	0
620857	14-16-6				HILL, LEONARD C.	3
514243	14-16-4	SE	NW	NW	HOOVER, RICHAR D./URSO, FRANK P.	4

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
610266	14-16-4				HOUSTON, JOANNE	0
801135	14-16-4	SW	SE	NE	HOWELL, JACK R. JR. & KELLY J.	0
527836	13-15-32	NE	NE	NE	HUB WATER CO	NA
616902	13-15-33	NW	NW	SE	HUB WATER CO.	337
616903	13-15-29	SW	SW	NE	HUB WATER CO.	250
616904	13-15-32	NE	NW	NW	HUB WATER CO.	200
616905	13-15-32	NE	NE	NE	HUB WATER CO.	246
623270	14-15-2	NE	SW	SE	INDEPENDENT TRUST CORP.	0
503670	14-15-2	SE	NW	SE	INDEPENDENT TRUST CORP./WOOTTON, JAMES C. & DIANE M.	27
624223	13-15-33	SW	SE	NW	JONES, MARSHALL W.	0
606055	13-15-32	NE	SW	NE	K & V WATER CO,	NA
606058	13-15-32	NW	SE	SW	K & V WATER CO.	0
629424	13-15-34	NE	NE	SW	KARTCHNER, MARK,	NA
621379	14-16-6	SW	SE		KING, JIM L./KING, JIM L. & CAROLYN K.	1
629213	13-15-33				KNIGHT, DORIS L.	0

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
527101	13-15-33	SW	SW	NW	KNIGHT, DORIS,	NA
609943	13-15-33	SE	NE		KOEPKE, GEORGE L./TVV INVESTMENT GROUP, L.L.C.	14
805661	13-15-32	SE	SE	NW	LEWIS TEXAS TRUST,	NA
805662	13-15-32	SE	SE	NW	LEWIS TEXAS TRUST,	NA
801373	14-15-1	SW	SW	SE	LIGHT, DAVID M./SHARER, KEVIN B.	5
502740	14-15-1	NE	NW	SW	LIVINGSTON, PETER ARTHUR	3
801627	13-15-33	NE	NE	NE	MATHEWS, WILLIAM R. JR.	5
801039	14-15-1	NW	SE		MEAD, OVIS O.	9
613764	14-15-4				MENICK, FRED	0
613644	14-15-3	NW	NW	NW	METZ, RICHARD E.	0
621623	14-15-1	SE	SW	NW	MILLER, NOLA E./BARTERS, PETER & GUERLIND	8
621624	14-15-1	SE	NW	SE	MILLER, NOLA E./BARTERS, PETER & GUERLIND	0
800803	13-15-33	SE			MOONEY, B.J.	3
617984	13-15-33	NW	SE	SW	PALSER, WALT DEAN	0
621014	14-15-1	SE	SE	NE	PARK, WILLIAM G.	2

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
621346	14-15-1	SE	NE	NE	PARK, WILLIAM G.	0
628505	14-15-1	NE	SE	SE	PARK, WILLIAM GENE	0
643146	13-15-32	NE	NE	NW	PHILLIPS,M K	NA
801133	13-15-33	SE	SE	NW	PIERSON, JOE NICHOLAS	0
623878	13-15-33	SE	NW	NE	PIMA CTY DEPT TRANS.,	NA
548666	13-15-33	SE	SE	NW	POZEZ, MITCHELL T.	6
643147	13-15-33	SE	SE	NW	POZEZ, MITCHELL T./TRIANO, PAMELA A.	6
517255	14-15-1	SE	NE	NE	R.E. MILLER PAVING,	NA
517256	14-15-1	SE	NE	NE	R.E. MILLER PAVING,	NA
517257	14-15-1	SE	NE	NE	R.E. MILLER PAVING,	NA
517258	14-15-1	SE	NE	NE	R.E. MILLER PAVING,	NA
517259	14-15-1	SE	NE	NE	R.E. MILLER PAVING,	NA
606056	13-15-32	NW	SE	SW	RANCHO DEL RIO,	NA
611930	14-15-3				RANDALL, BRADLEY W.	0
618919	13-15-33	NW	SE		RICE, GAIL M. SANDERS	6

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
625819	14-16-6	SE	NW	SW	SABBAGH, ADIB	20
526049	14-15-1	SW	SW	NW	SEAL	NA
521442	14-15-3	SE	NE	SW	SHEPHERD, PAUL R.	0
628973	14-15-3	SE	NE	SW	SHEPHERD, PAUL R.	0
617197	13-15-33	NE	SW	NW	SIMONS, BERNARD W. JR.	1
623480	13-15-33	NE	SW		SIMONS, RALPH S	4
638875	13-15-34	SW	SW	NW	SMITH, RICHAR L./MAJESKY, RUSSELL	7
621657	13-15-32	SE	NE		SOTTNEK,L L	NA
600345	13-15-34	SW			SPEAR H D	0
631270	14-16-6	SW	NW	NW	STACKHOUSE, HAMILTON L.	0
628567	14-16-4	SW	SW	NE	STACY, ROBERT E.	0
801298	13-15-34	SW	SW	NW	STARKE, DOROTHY/LA PALOMA VENTURES LLC/ZIEHLER, TONY AND BARBARA	0
508096	13-15-34	SW	SW	NW	STARKE, PAUL/STARKE, DOROTHY/LA PALOMA VENTURES LLC/ZIEHLER, TONY AND BARBARA	2
611932	14-15-3				STEPHENS, CECIL,	NA
800437	13-15-33	SE	SE	SW	STROPKO, LANNY/STROPKO-CAMPBELL, LANNY/CRAY CLOUD L.	6

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
621625	14-16-5	SW	SW		STURTZ, JOEL M.	0
801036	14-15-2	NW	SW	SW	SWAIM, ROBERT & DONNA	1
532441	13-15-33	SE	NW	NW	TANKERSLEY, RON,	NA
604332	14-15-3	NW	NW	SW	TAPPAN, EDWARD	0
611426	14-15-3	NW	NW		TAPPAN, EDWARD	0
502179	14-15-2	SE	SE	NE	TUCSON, CITY OF	211
510879	14-15-2	SW	SW	SE	TUCSON, CITY OF	543
513674	14-15-4	NW	NE	NE	TUCSON, CITY OF	557
619934	14-16-6	NW	SE	NE	TUCSON, CITY OF	0
619957	13-15-28	SE	SW	SW	TUCSON, CITY OF	0
619965	13-15-33	SW	NW	SW	TUCSON, CITY OF	0
619967	14-15-2	SE	SE	NE	TUCSON, CITY OF	0
619973	14-15-4	NW	NE	NE	TUCSON, CITY OF	0
619974	13-15-34	SW	SW	NE	TUCSON, CITY OF	0
619975	14-15-3	SE	SE	SW	TUCSON, CITY OF	355

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
620072	14-15-10	NE	NE	SW	TUCSON, CITY OF	616
620079	13-15-35	SE	SE	SW	TUCSON, CITY OF	0
620080	13-15-35	SE	SE	SW	TUCSON, CITY OF	1188
620088	14-16-6	SE	NE	SE	TUCSON, CITY OF	0
620092	13-15-34	NE	NW	SE	TUCSON, CITY OF	0
620093	13-15-34	NE	SE	SE	TUCSON, CITY OF	0
620094	13-15-35	NW	SE	SW	TUCSON, CITY OF	0
620096	14-15-1	NE	SE	NE	TUCSON, CITY OF	0
620097	14-15-1	NE	SE	NE	TUCSON, CITY OF	0
620118	14-16-5	SE	NW	SE	TUCSON, CITY OF	0
620119	14-16-5	SE	NW	SE	TUCSON, CITY OF	0
620120	14-16-5	SE	NW	SE	TUCSON, CITY OF	0
626408	13-15-32	SE	NE	SE	TUCSON, CITY OF	0
800356	14-15-5	NE	NW	NE	TUCSON, CITY OF	518
523906	13-15-32	NE	SW	NE	TUCSON, CITY OF/K & V WATER CO.	416

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

ADWR Registry ID	*Cadastral Location*	*Acre 160*	*Acre 40*	*Acre 10*	*Well Owner*	*Average Reported Annual Withdrawls (ac-ft)**
803492	14-15-1	NE	NW	NW	TURNER, WILLIAM H.	0
501108	13-15-34	NE	SW	SE	VISTAS DE SIERRAS ASSOC	0
631191	13-15-32	NE	SE	SW	VIVONE JR,J A	NA
506124	14-15-1	SW	SE	SW	VOEVODSKY, PETER/VOEVODSKY, PETER & JOSEPHINE R.	1
613649	14-15-1				VOEVODSKY,P	NA
800848	14-15-3	SE	NE	NW	WALKER, JOSEPH A.	3
610672	13-15-32	NE	NW		WOODDELL, ROBERT D./WOODDELL, ROBERT	0
502533	14-15-2	NE	SW	SW	WOOTTON, JAMES C. & DIANE M.	52
621611	13-15-33	SE	NE	NW	ZIMMERMAN, LIND LOU	7
531337	13-15-33	SE	NE	NW	ZIMMERMAN, LINDA,	NA

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

APPENDIX D

ADWR Pumping Records for Non-Exempt Wells within One Mile of Tanque Verde Creek, Wentworth Rd to Sabino Canyon Confluence (sorted by cadastral location)

Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
13-15-28	SE	SW	SW	619957	TUCSON, CITY OF	0
13-15-29	SW	SW	NE	616903	HUB WATER CO.	250
13-15-32	SE	NE		621657	SOTTNEK,L L	NA
13-15-32	NW	SE	SW	606056	RANCHO DEL RIO,	NA
13-15-32	NE	NE	NW	643146	PHILLIPS,M K	NA
13-15-32	SE	SE	NW	805662	LEWIS TEXAS TRUST,	NA
13-15-32	SE	SE	NW	805661	LEWIS TEXAS TRUST,	NA
13-15-32	NW	SE	SW	606058	K & V WATER CO.	0
13-15-32	NE	SW	NE	606055	K & V WATER CO,	NA
13-15-32	NE	NE	NE	616905	HUB WATER CO.	246
13-15-32	NE	NW	NW	616904	HUB WATER CO.	200
13-15-32	NE	NE	NE	527836	HUB WATER CO	NA
13-15-32	NW	SW	NE	606057	GOLDEN HERITAGE CORP,	NA
13-15-32	NE	NW		610672	WOODDELL, ROBERT D./WOODDELL, ROBERT	0

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
13-15-32	NE	SW	NE	523906	TUCSON, CITY OF/K & V WATER CO.	416
13-15-32	SE	NE	SE	626408	TUCSON, CITY OF	0
13-15-32	NE	SE	SW	631191	VIVONE JR,J A	NA
13-15-33	SW	SW	NW	527101	KNIGHT, DORIS,	NA
13-15-33	SE	NE		609943	KOEPKE, GEORGE L./TVV INVESTMENT GROUP, L.L.C.	14
13-15-33	SE	SW	SW	800736	CELLA, FLORENCE & PAUL/CELL, PAUL W.	4
13-15-33	SW	SW	SW	530916	BENNETT, JAMES,H	NA
13-15-33	NE	NE	NE	801627	MATHEWS, WILLIAM R. JR.	5
13-15-33	SE			800803	MOONEY, B.J.	3
13-15-33	NW	NW	SE	616902	HUB WATER CO.	337
13-15-33	SE	SE	NW	801133	PIERSON, JOE NICHOLAS	0
13-15-33	SE	NW	NE	623878	PIMA CTY DEPT TRANS.,	NA
13-15-33	SE	SE	NW	548666	POZEZ, MITCHELL T.	6
13-15-33	SE	SE	NW	643147	POZEZ, MITCHELL T./TRIANO, PAMELA A.	6
13-15-33				801968	BENNETT, JAMES H.	27

Note:
ADWR Well Registry (3rd edition) used to identify wells.
** Pumpage data provided by ADWR, for years 1994-1998. "NA" = no data available.*

Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
13-15-33	NW	SE		618919	RICE, GAIL M. SANDERS	6
13-15-33	SW	NW		801906	ARONOW, WILLARD F.	0
13-15-33	SE	NE	NW	531337	ZIMMERMAN, LINDA,	NA
13-15-33	NW	SE	SW	617984	PALSER, WALT DEAN	0
13-15-33	SW	NE	NW	527986	EMMERSON, DAVID,A	NA
13-15-33	SE	SE	NE	501580	FISSELL, JAMES C. & SUSAN Z.	9
13-15-33	SE	SE	NE	620736	FISSELL, JAMES C. & SUSAN Z.	8
13-15-33	SE	SW	NW	557971	FORD, RODGER G. & AMY R.	38
13-15-33	SE	SW	NW	628080	FORD, RODGER G. & AMY R.	50
13-15-33				801159	HASSEY, NEMER E.	0
13-15-33				629213	KNIGHT, DORIS L.	0
13-15-33	SW	NW	SE	616963	HENKEL, JOHN H. & JOANNA M.	0
13-15-33	SE	SW	SW	520583	CELLA, PAUL,W	NA
13-15-33	SE	NW	NE	617211	CRARY, CHARLES E.	0
13-15-33	NE	SW	NW	617197	SIMONS, BERNARD W. JR.	1

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Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
13-15-33	NW	NW	SW	618075	COTE, ROBERT T.	0
13-15-33	SW	SE	NW	624223	JONES, MARSHALL W.	0
13-15-33	NW	SW		625709	COONAN, ANN A.	0
13-15-33				606494	EMMERSON, DAVID A.	0
13-15-33	NE	SE	NE	623019	HELLER, GENEVE C. TRUST	0
13-15-33	SE	NE	NW	621611	ZIMMERMAN, LIND LOU	7
13-15-33	NE	SW		623480	SIMONS, RALPH S	4
13-15-33	SW	NW	SW	619965	TUCSON, CITY OF	0
13-15-33	SE	NW	NW	532441	TANKERSLEY, RON,	NA
13-15-33	SE	SE	SW	800437	STROPKO, LANNY/STROPKO-CAMPBELL, LANNY/CRAY CLOUD L.	6
13-15-34	NE	SE	SE	620093	TUCSON, CITY OF	0
13-15-34	SW	SW	NE	619974	TUCSON, CITY OF	0
13-15-34	SW	SW	NW	508096	STARKE, PAUL/STARKE, DOROTHY/LA PALOMA VENTURES LLC/ZIEHLER, TONY AND BARBARA	2
13-15-34	SW	SW	NW	801298	STARKE, DOROTHY/LA PALOMA VENTURES LLC/ZIEHLER, TONY AND BARBARA	0
13-15-34	SE	SE	SW	801928	GOEBEL, GEORGE M	0

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Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
13-15-34	SW			600345	SPEAR H D	0
13-15-34				801967	CONTINENTAL SVC CORP	4
13-15-34	SW	SW	NW	638875	SMITH, RICHAR L./MAJESKY, RUSSELL	7
13-15-34	NE	NW	SE	620092	TUCSON, CITY OF	0
13-15-34	NE	NE	SW	629424	KARTCHNER, MARK,	NA
13-15-34	NE	SW	SE	501108	VISTAS DE SIERRAS ASSOC	0
13-15-35	NW	SE	SW	620094	TUCSON, CITY OF	0
13-15-35	SW	NW	SE	800922	DECARLO, DANIEL C	2
13-15-35	SE	SE	SW	620080	TUCSON, CITY OF	1188
13-15-35	SE	SE	SW	620079	TUCSON, CITY OF	0
14-15-1	NW	SE		801039	MEAD, OVIS O.	9
14-15-1	SW	SW	SE	801373	LIGHT, DAVID M./SHARER, KEVIN B.	5
14-15-1	SE	SE	NE	621014	PARK, WILLIAM G.	2
14-15-1	NE	SE	NE	620096	TUCSON, CITY OF	0
14-15-1	SE	NW	NW	803490	GONDA, GERALD,	NA

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14-15-1	NE	NW	SW	502740	LIVINGSTON, PETER ARTHUR	3
14-15-1	SE	NE	NE	517256	R.E. MILLER PAVING,	NA
14-15-1	SW	SE	SE	626378	BARTELS, PETER H	0
14-15-1	SW	SW	NW	526049	SEAL	NA
14-15-1				613649	VOEVODSKY,P	NA
14-15-1	SW	SE	SW	506124	VOEVODSKY, PETER/VOEVODSKY, PETER & JOSEPHINE R.	1
14-15-1	SE	NE	NE	517259	R.E. MILLER PAVING,	NA
14-15-1	SW	SW	NW	803452	ERWIN, ELDON U.	0
14-15-1	SE	NE	NE	517257	R.E. MILLER PAVING,	NA
14-15-1	SE	SW	NW	621623	MILLER, NOLA E./BARTERS, PETER & GUERLIND	8
14-15-1	SE	NE	NE	517255	R.E. MILLER PAVING,	NA
14-15-1	NE	NW	NW	803492	TURNER, WILLIAM H.	0
14-15-1	NE	SE	SE	628505	PARK, WILLIAM GENE	0
14-15-1	SE	NE	NE	621346	PARK, WILLIAM G.	0
14-15-1	NE	SE	NE	620097	TUCSON, CITY OF	0

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Cadastral Location	*Acre 160*	*Acre 40*	*Acre 10*	*ADWR Registry ID*	*Well Owner*	*Average Reported Annual Withdrawals (ac-ft)**
14-15-1	SE	NW	SE	621624	MILLER, NOLA E./BARTERS, PETER & GUERLIND	0
14-15-1	SE	NE	NE	517258	R.E. MILLER PAVING,	NA
14-15-10	NE	NE	SW	620072	TUCSON, CITY OF	616
14-15-2	NE	SW	SE	623270	INDEPENDENT TRUST CORP.	0
14-15-2	SW	NW	NW	628874	CURRIER, CATHY	7
14-15-2	SE	NW	SE	503670	INDEPENDENT TRUST CORP./WOOTTON, JAMES C. & DIANE M.	27
14-15-2	SE	SE	NE	619967	TUCSON, CITY OF	0
14-15-2	NW	SW	SW	801036	SWAIM, ROBERT & DONNA	1
14-15-2	SW	SW	SE	510879	TUCSON, CITY OF	543
14-15-2	NE	SW	SW	502533	WOOTTON, JAMES C. & DIANE M.	52
14-15-2	SE	SE	NE	502179	TUCSON, CITY OF	211
14-15-3	NW	NW	SW	604332	TAPPAN, EDWARD	0
14-15-3	NW	NW	NW	613644	METZ, RICHARD E.	0
14-15-3				611930	RANDALL, BRADLEY W.	0
14-15-3	NW	NW		611426	TAPPAN, EDWARD	0

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14-15-3	SE	NW	NE	619256	CONWAY, WILLIAM E.	7
14-15-3	SE	SE	SW	619975	TUCSON, CITY OF	355
14-15-3				611932	STEPHENS, CECIL,	NA
14-15-3	SE	NE	NW	800848	WALKER, JOSEPH A.	3
14-15-3	SE	NE	SW	521442	SHEPHERD, PAUL R.	0
14-15-3	SE	NE	SW	628973	SHEPHERD, PAUL R.	0
14-15-3	NE	SE	NW	526006	GRIGGS, DENIS C	0
14-15-3	NE	SW	SE	801131	BELL, GALE S.	0
14-15-4	NW	NE	NE	619973	TUCSON, CITY OF	0
14-15-4				613764	MENICK, FRED	0
14-15-4	NW	NE	NE	513674	TUCSON, CITY OF	557
14-15-4	NE	SE	NE	801104	DIXON,T J	NA
14-15-5	NE	NW	NE	800356	TUCSON, CITY OF	518
14-16-2	SE	NW	NW	617302	49ER WATER CO.	151
14-16-4				610266	HOUSTON, JOANNE	0

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14-16-4	SE	SE	SE	608182	DRYDEN, ROBERT M.	13
14-16-4	SE	SE	SE	608183	DRYDEN, ROBERT M.	0
14-16-4	SW	SW	NE	628567	STACY, ROBERT E.	0
14-16-4	SW	SE	NE	801135	HOWELL, JACK R. JR. & KELLY J.	0
14-16-4	SE	NW	NW	514243	HOOVER, RICHAR D./URSO, FRANK P.	4
14-16-4	NW	SW	SW	604250	CROSBY, WILLIAM F.	22
14-16-5	SE	NE	NE	617300	49ER WATER CO.	277
14-16-5	SE	NE	NW	617301	49ER WATER CO.	202
14-16-5	SE	NW	SE	620118	TUCSON, CITY OF	0
14-16-5	SE	NW	SE	620120	TUCSON, CITY OF	0
14-16-5	SW	NE	SE	503963	49ER WATER CO.	105
14-16-5	SW	SW		621625	STURTZ, JOEL M.	0
14-16-5	SE	SE		801182	FERGANCHICK, BERT A.	0
14-16-5	SE	NW	SE	620119	TUCSON, CITY OF	0
14-16-6	SW	NW	NW	631270	STACKHOUSE, HAMILTON L.	0

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14-16-6	SE	NW	SW	625819	SABBAGH, ADIB	20
14-16-6				600039	ELLIOTT	NA
14-16-6	SW	SE		801176	DORAN, THOMAS E.	0
14-16-6	SW	NE	SE	801241	HECKER, RICHARD H. & ANN E./GARDNER, DAVID K.	6
14-16-6	SE	NE	SE	620088	TUCSON, CITY OF	0
14-16-6				620857	HILL, LEONARD C.	3
14-16-6	SW	SE		621379	KING, JIM L./KING, JIM L. & CAROLYN K.	1
14-16-6	NW	SE	NE	619934	TUCSON, CITY OF	0
14-16-6	SW	NE	SE	575575	GARDNER	NA

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