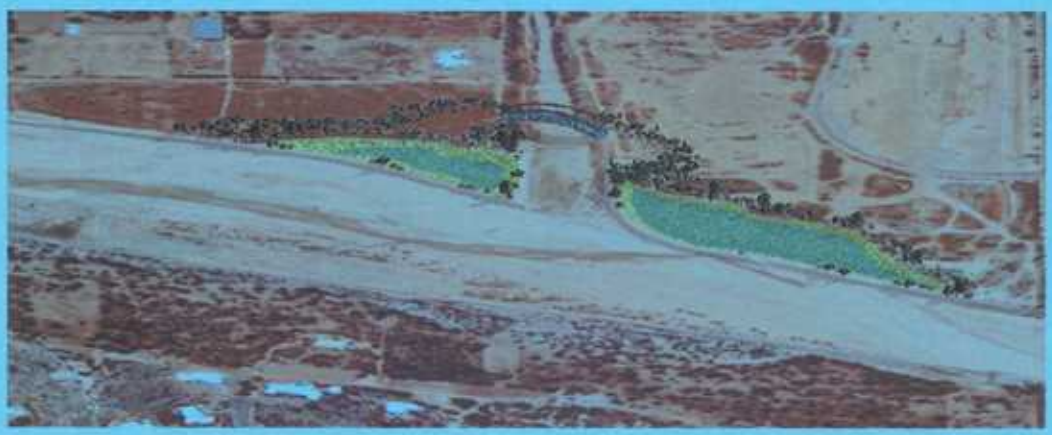
US ARMY CORPS OF ENGINEERS

LOS ANGELES DISTRICT

EL RIO ANTIGUO
RILLITO RIVER ENVIRONMENTAL RESTORATION



Documentation for Groundwater Studies

PIMA COUNTY

DEPARTMENT OF TRANSPORTATION
& FLOOD CONTROL DISTRICT
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TUCSON, ARIZONA 85701-1207

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U. S. Army Corps of Engineers
Los Angeles District

Pima County Department of Transportation and Flood Control District
Flood Control Engineering Division
March, 2002

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to present without-project groundwater studies in support of feasibility study for El Rio Antiguo, Rillito River Environmental Restoration Project. Specific objective is to provide the following information:

1. Collection and analyses of existing groundwater data including groundwater elevations, aquifer characteristics, and review of previous studies for Rillito River watershed.

2. Collection of water quality data under existing conditions.

3. Water budget analysis under existing conditions, including mass balance calculations based on inflow (infiltration and reclaimed water/effluent), outflow (pumping at well exempt and non-exempt well locations), and plant consumptions (evapotranspiration).

Brief discussions on the hydrogeologic setting, geology and aquifer characteristics based on previous studies for Rillito River watershed support the water budget analysis and data collection phase of the restoration project.

1.2 Project Area Description and Location

The Rillito River is a major watercourse that runs east to west along the toe of the Santa Catalina Mountain Foothills in Pima County, Arizona. Climatic conditions are semi-arid, characterized by long hot summers and short mid winters. More than half of the precipitation in the project area occurs during the months of July, August, and September, as a result of monsoon thunderstorms. The Rillito River consists primarily of a sand bed channel varying in depth up to a maximum of approximately twelve feet in places. The overbanks vary in composition from heavily vegetated areas to urbanized areas to undeveloped desert shrub depending on the location within the study limits. Nearly all segments of the Rillito River have been channelized and or bank stabilized over the last twenty years, with many segments having been improved since 1993.

The study area is located in the Upper Santa Cruz groundwater sub-basin of the Tucson Active Management Area (Figure 1), and consists of Sections 20, 21, 26, 27, 28, and 29 of Township 13 and Range 14. The study area is the Rillito River reach between Craycroft Road and Campbell Avenue. The digitally generated Figure 2 shows the project boundary and major roadways along the Rillito River study reach.

2. PREVIOUS STUDIES

The Rillito River Recharge Project is a cooperative study involving the Arizona Department of Water Resources (ADWR), the U.S. Geological Survey (USGS), Pima County Flood Control District, the City of Tucson Water Department, and the University of Arizona. The project was conceived to study the potential control of flood waters, and groundwater augmentation by recharge in the Rillito River channel. The basic groundwater data collection study for the Rillito River Recharge Project was completed in August of 1988, in cooperation with the U.S. Geological Survey, the City of Tucson Water Department, and Pima County Flood Control District (Barnes, 1988). Rillito River Recharge feasibility study was completed by Camp Dresser & McKee, Inc. in January of 1990. Since then, several USGS technical reports have been published on the project. Study areas include, but are not limited to hydrogeologic evaluation of the aquifer system, data collection, infiltration estimates, groundwater flow simulation, water budget analysis, and water quality monitoring.

Keith and Rasmussen (1980) performed a literature survey on stream channel recharge and referred to notable work on infiltration estimates by Matlock (1965). Based on stream channel infiltration tests and analysis of experimental and filed data, Matlock attempted to clarify the relationship between stream flow velocity, suspended sediment, and infiltration rate in order to more accurately predict recharge from a flashy, silt-laden flow events that is typical during the summer in the Tucson Basin (Davidson, 1973; Anderson, 1987).

Hanson and Benedict (1994) reported on simulation of groundwater flow and potential land subsidence for the upper Santa Cruz basin which includes the Rillito River study area. The numerical groundwater flow model was developed to evaluate pre-development conditions in 1940, groundwater withdrawals for 1940-86, and potential water-level declines and land subsidence for 1987-2024. Among other modeling parameter, Hanson and Benedict (1994) reports recharge through infiltration at the rate of 820 acre-feet per year along the Rillito River, from Craycroft Road to Santa Cruz River confluence. Measurement of groundwater storage change and specific yield near Rillito River was reported by Pool and Schmidt (1997). Using temporal-gravity method they estimated groundwater storage change for periods between early December 1992 and early January 1994, and specific yield values near Rillito River. Estimated increase in groundwater storage from December 1992 through early March 1993, mid-May 1993, late August 1993, and early January 1994 were calculated as 7900, 8000, 6300, and 3700 ac-ft, respectively. Groundwater recharge for the study period was estimated to be 10900 ac-ft using a water-budget approach that accounted for estimated groundwater withdrawals and groundwater flow across the study area boundaries. Most of the recharge occurred before early March 1993. Pool and Schmidt (1997) concluded that the downgradient areas at the southern extent of the study area are hydraulically well connected with the part of the recharge area west of Swan Road. The contrast in the ability of the aquifer to transmit water downgradient on either side of Swan Road was consistent with geology inferred from well logs and geophysical information.

Barnes (1988) reported on the water quality sampling program that was initiated in 1986 by the Rillito River Recharge program cooperators. Sampled wells were selected based on areal distribution within the project area, depth of well, perforated interval, and lithology. Analysis of these samples revealed the existence of certain organic and inorganic constituents in some wells at concentrations potentially harmful to public health. USGS performed several groundwater quality tests in the early 90s (Tadayon, 1993, 1994). Tadayon (1994) reports on quality of groundwater in the then proposed artificial recharge project area in the Rillito Creek Basin. Samples were collected from monitoring wells (D-13-14)26cbb2 and (D-13-14)26dcb2 in January, May, July and October of 1994. Physical and chemical composition of samples were analyzed and reported. Brief summary of Tadayon's report is discussed in the Water Quality section of this report.

3. HYDROGEOLOGIC CHARACTERISTICS

The hydrogeologic system in the study area is characterized by periodic recharge along the ephemeral stream channel of Rillito River, groundwater flow to the south-southwest through basin-fill deposits, and discharge to municipality wells south and west of the study area (Figure 2). Periodic streamflow occurs in response to precipitation and snowmelt from the Santa Catalina and Rincon Mountains. Infiltration occurs through the highly permeable stream-channel deposits and flow downgradient through moderately to highly permeable basin-fill deposits.

The aquifer system consists of basin-fill deposits of alluvial sediments underlain by crystalline rocks. Sedimentary units from oldest to youngest include the Pantano Formation, lower and upper Tinaja beds (Tsl and Tsu), Fort Lowell Formation (Qf), and surficial deposits of alluvium (Qs) that include the terrace and stream-channel deposits along Rillito River (Anderson, 1988). The main aquifer is the moderately to highly permeable Fort Lowell Formation. Highly permeable stream-channel deposits also are an important water bearing unit where the deposits are saturated along the flood plain of Rillito River. Groundwater also flows through the upper Tinaja beds of moderate to low permeability. The lower Tinaja beds are much less permeable than the upper Tinaja beds and are an effective lower boundary of the groundwater flow system.

Hydraulic conductivity values for the Fort Lowell Formation range from 20 to 95 ft/d, and well yields range from 500 to 1,500 gal/min in the Tucson Basin. Hydraulic conductivity values for the upper and lower Tinaja beds range from 1.3 to 54 ft/d (Davidson, 1973; Pool and Schmidt, 1997).

Thickness of the lower Tinaja beds is poorly known because no wells are known to penetrate the unit. Lower Tinaja beds typically are comprised of mudstone and clay and contain inter-beds of sand, silt, and gravel. Upper Tinaja beds are the main water-bearing unit north of the flood plain of Rillito River and the south boundary of the area between Craycroft and Fort Lowell Roads. The unit typically consists of moderately consolidated sand, gravel, clay, and silt and typically is described as conglomerate or cemented sand

and gravel (Pool and Schmidt, 1997). Thickness of individual beds averages 66 ft on the basis of driller's logs.

The Fort Lowell Formation is the main water-bearing unit south of Rillito River (Figure 4). The unit typically consists of inter-bedded layers of clay, silt, sand, gravel and boulders. Thickness of individual beds averages 47 ft on the basis of driller's logs. The most permeable unit is the stream-channel deposits of the young alluvium along Rillito River. The unit consists of sand, gravel, and boulders and minor amounts of silt and clay. Thickness of individual beds averages 20 ft on the basis of driller's logs. Thickness of the unit exceeds 50 ft in places but generally is about 30 ft.

4. GROUNDWATER DATA INVENTORY

4.1 Well Inventory and Pumpage

The Arizona Department of Water Resources and the Tucson Water Department maintain extensive inventory of wells. The pumping wells for this project were selected on the basis of aerial distribution within the project area (Figure 2), proximity to the Rillito River, and utility in definition of the direction of groundwater movement. Data obtained from the available well inventories was divided into following categories:

1. Depth to Water (DTW)
2. Water Table Elevation (WTE)
3. Annual withdrawal estimate for exempt wells at <35 gpm
4. Annual withdrawal estimate for non-exempt wells

DTW and WTE data and seasonal hydrographs for selected exempt and non-exempt wells are provided in Appendix A. Explanation of well numbering system used in Arizona is provided in Figure 3. According to Arizona Department of Water Resources (ADWR), some exempt wells are associated with groundwater rights. Historic situations sometimes allow these small wells to be attached to groundwater rights, however, according to ADWR this is not currently allowed. Withdrawal rates for exempt and non-exempt wells were obtained from ADWR query and are provided in Appendix B.

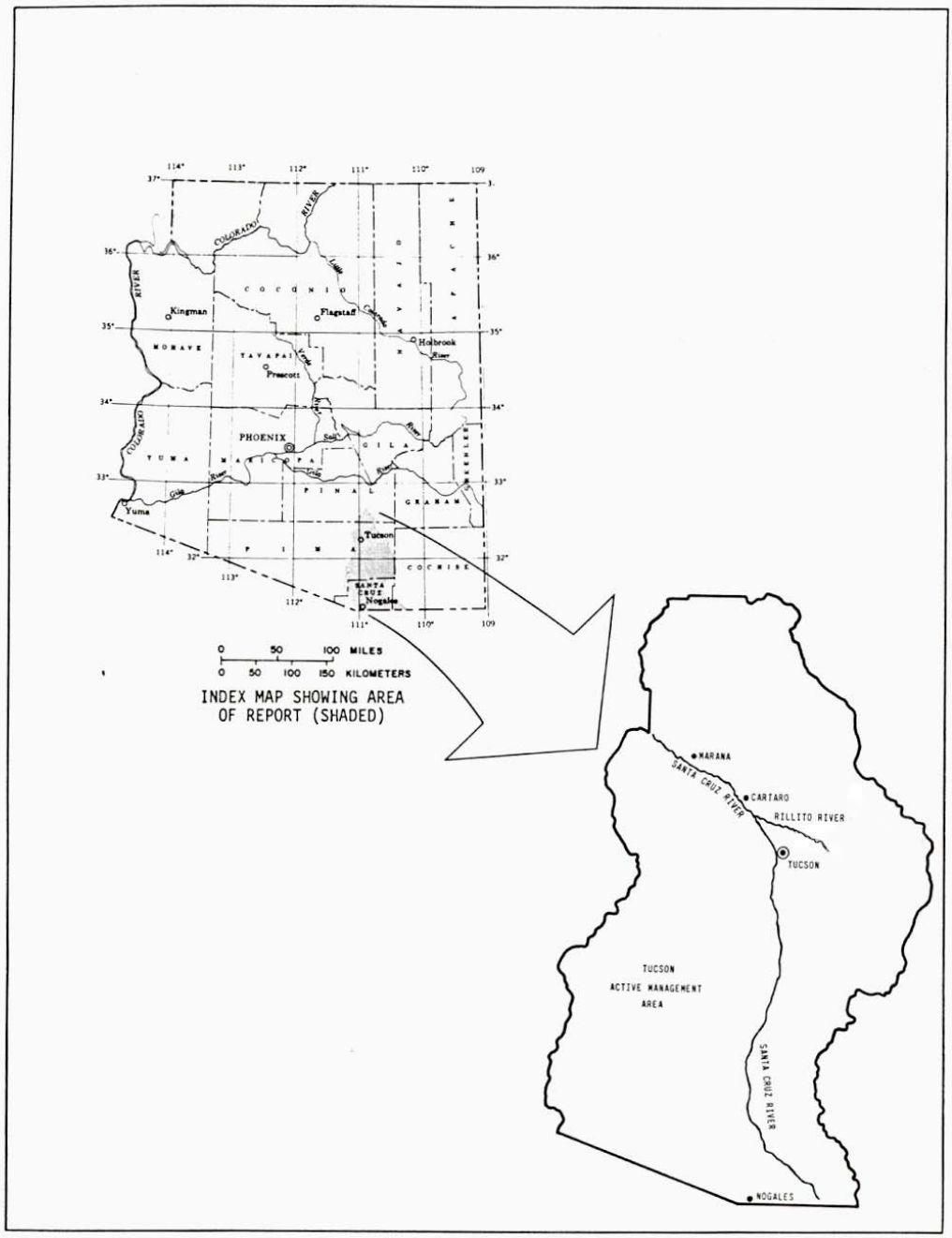

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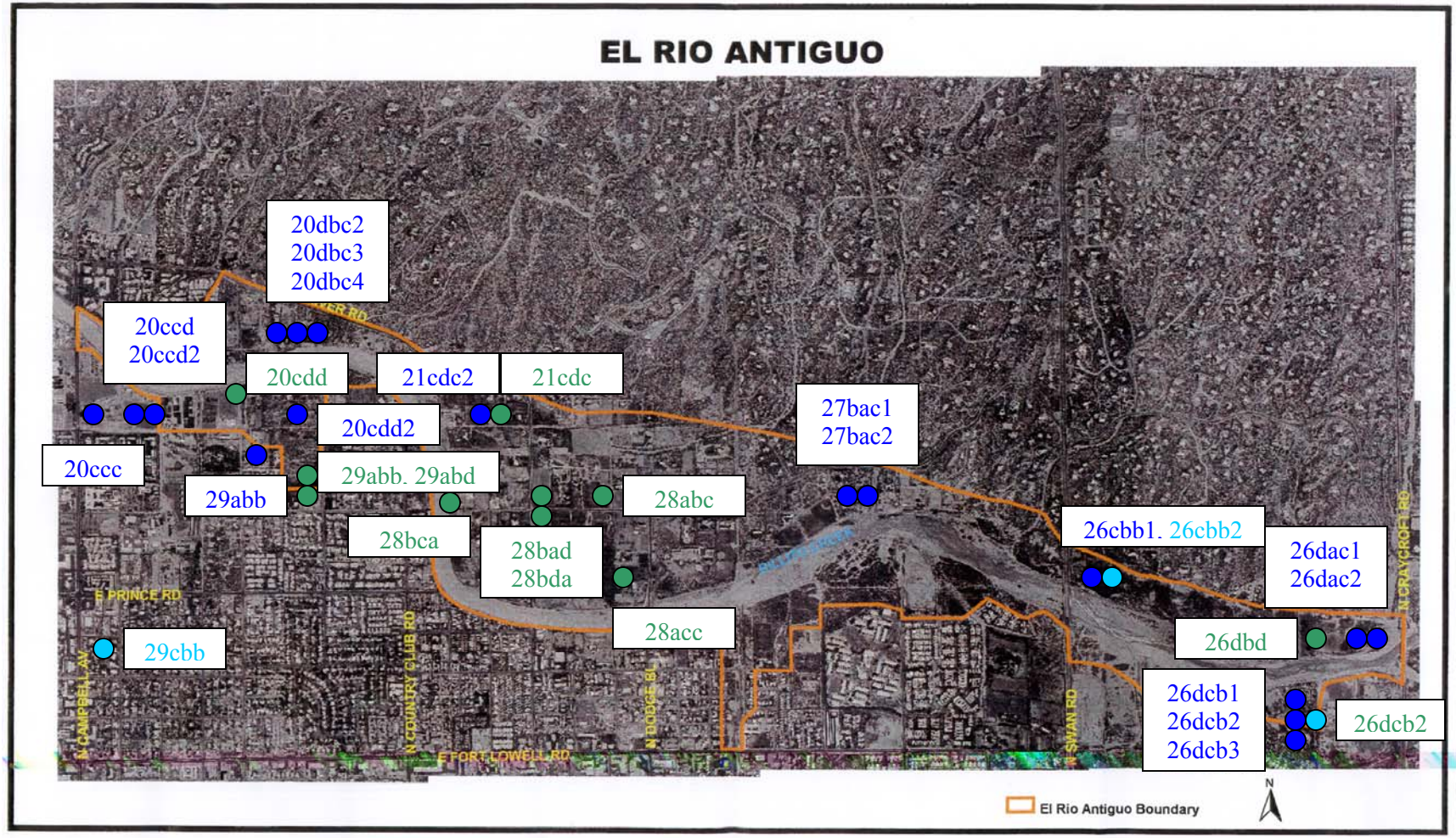
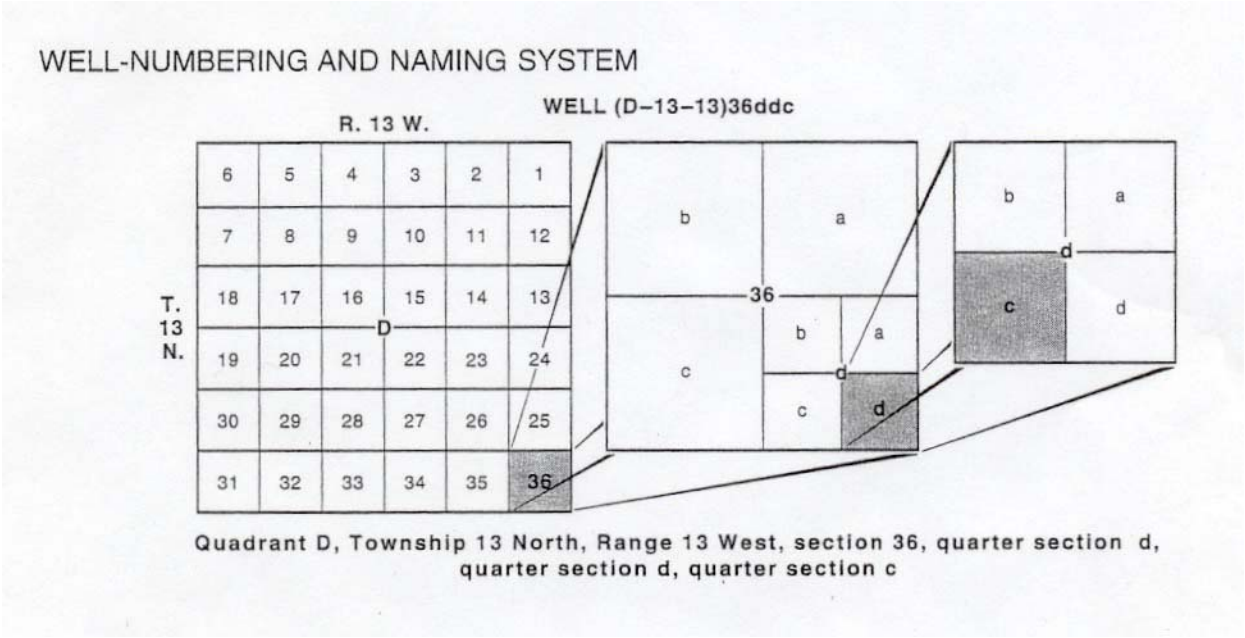
Figure 1. Tucson Active Management Area (AMA) map



DTW & WTE reporting well Pumping well Water quality sampling well

Figure 2. Project boundary and well locations



The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the state into four quadrants and are designated by capital letters A, B, C, and D in a counterclockwise direction, beginning in the northeast quarter. The first digit of a well number indicates the township, second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicates the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northwest quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-13-13)36ddc designates the well as being in the SE1/4, SE1/4, SW1/4, section 36, Township 13 North, and Range 13 West. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3. Well-numbering and naming system

Figure 4. Hydrogeologic characteristics
(Atlas Attached to Report)

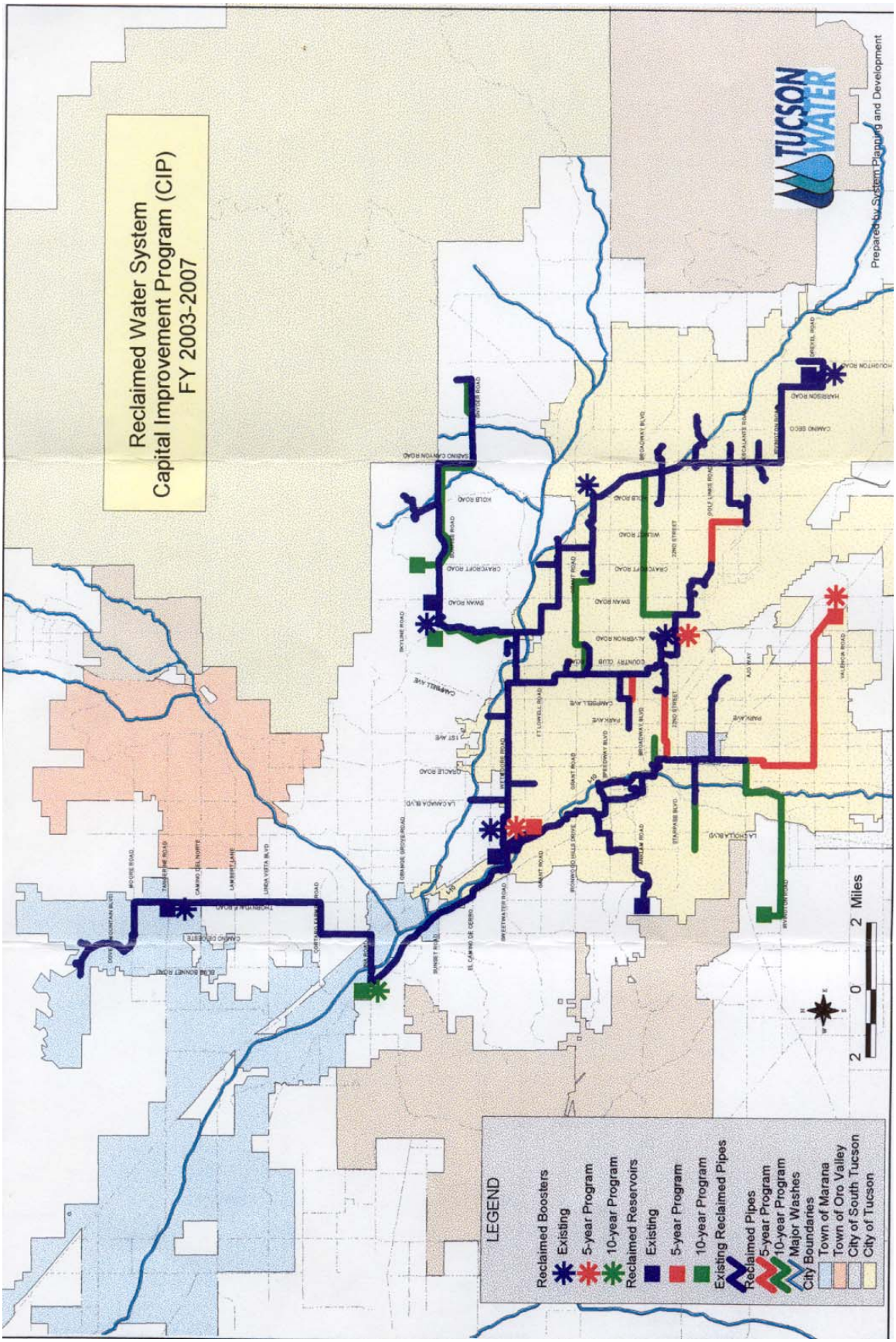
4.2 Reclaimed Water

Secondary effluent generated by the Pima County Wastewater Management Department (PCWMD) sewage system receives additional treatment. Subsequent filtration and disinfection of secondary effluent produces reclaimed water which is suitable for irrigation, industrial uses and groundwater recharge. Tucson Water Department owns this reclaimed water and delivers it through the Tucson Water reclaimed water distribution system to the City of Tucson Department of Parks & Recreation and to private users for non-potable uses, primarily turf irrigation. The reclaimed water is also made available to recharge facilities.

Reclaimed water for the Rillito study area comes from Roger Road Water Reclamation Facility, located on Sweetwater Drive west of I-10, adjacent to the PCWMD Roger Road Water Pollution Control Facility. This plant treats sewage from the area of metropolitan Tucson lying generally to the southwest of Rillito River and Pantano Wash. The existing plant had a capacity of 9,000 ac-ft per year as of 1990. An expansion to 28,000 ac-ft per year was projected in the 1989-1999 Capital Improvement Plan (CIP).

Reclaimed water is taken from the Roger Road Water Reclamation Facility through a 36-inch pipeline along Roger Road to Alvernon Way. From this point, a 30-inch line takes reclaimed water south along Alvernon Way to Fort Lowell Road and east on Fort Lowell Road to Laurel Avenue. The line continues east from Laurel Avenue along Glenn Street. An 8-inch lateral runs north along Craycroft Road to the South side of the Rillito. Local reclaimed water users include Davidson Elementary School, McCormick Park, Whitmore Elementary School, the Tucson Medical Center, Fort Lowell Park, and St. Gregory's School.

Existing and proposed Tucson Water Reclaimed Water System under the fiscal year 2003-2007 Capital Improvement Program (CIP) is shown in Figure 5.


Reclaimed Water System
Capital Improvement Program (CIP)
FY 2003-2007
TUCSON WATER
Prepared by System Planning and Development
LEGEND
Reclaimed Boosters
Existing
5-year Program
10-year Program
Reclaimed Reservoirs
Existing
5-year Program
10-year Program
Existing Reclaimed Pipes
Reclaimed Pipes
5-year Program
10-year Program
Major Washes
City Boundaries
Town of Marana
Town of Oro Valley
City of South Tucson
City of Tucson
2 0 2 Miles

4.3 Infiltration

A major factor affecting the streamflow in Rillito River is channel infiltration losses. Previous studies have estimated that approximately half of the incoming runoff in Rillito River and its tributaries infiltrate into the streambed. Estimates from these studies show approximately 5100 to 6800 acre-feet or annual runoff from Rillito River to the Santa Cruz River are potential sources available for recharge (CDM, 1990).

Groundwater flow simulation study by Hanson and Benedict (1994) identifies recharge at the rate of 820 acre-feet per year along the Rillito River, from Craycroft Road to Santa Cruz River confluence.

Infiltration tests were performed along the Rillito River under dry and flowing conditions (Matlock, 1965; Keith and Rasmussen, 1980). Two types of infiltration tests were conducted at selected sites in Rillito River. The first series of tests were performed in the dry river bed using cylinder infiltrometers and buffer ponds, and the second type under flowing conditions. As opposed to lumped infiltration value along the Rillito, these tests provide distributed infiltration quantities at selected locations on the river bed. Figure 6 shows the test points along the river and Table 4.3.1 summarizes infiltration test results. Locations 5 through 11 fall within the study area.

Table 4.3.1 Infiltration rate under flowing conditions (Keith and Rasmussen, 1980)

Location along Rillito River (See Figure 6)	Infiltration Rate (gpd/ft^2)
1	6200
2	2900
3	3600
5	1300
8	1400
9	2100
11	1000
12	200
14	200

Studies of recharge along the length of Rillito River conducted by the University of Arizona indicate that infiltration is approximately 478 ac-ft per day (Katz, 1985; PCFCD, 1986). An estimated 240 ac-ft per day was used for the El Rio Antiguo study area (approximately 5 miles) in the water budget calculations.

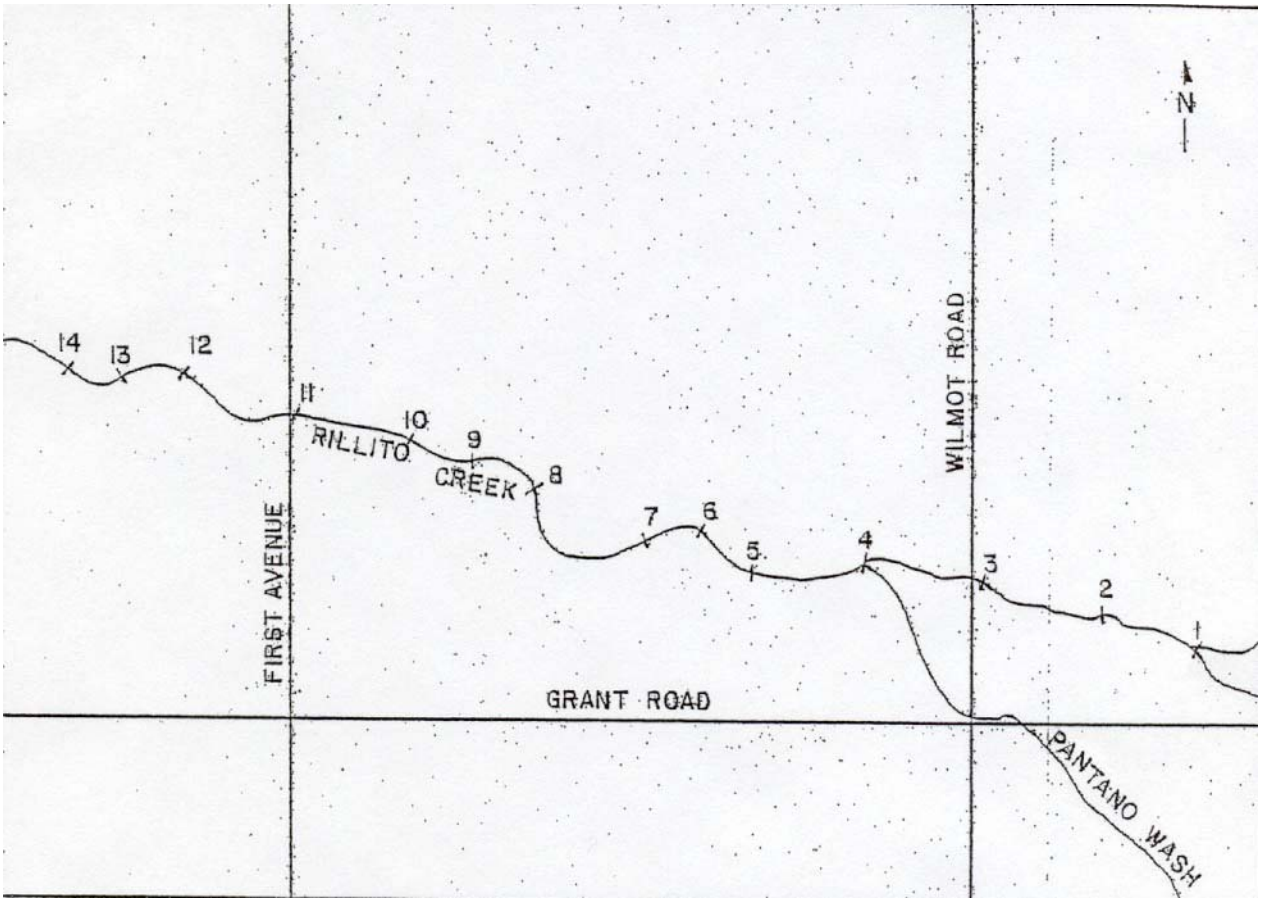


Figure 6. Section of Rillito Creek showing locations of infiltration tests (Keith and Rasmussen, 1980)

5. WATER QUALITY

5.1 Groundwater

A water quality sampling program was initiated in 1986 by the Rillito River Recharge program cooperators as a means of documenting background quality for future use in evaluating possible pollution in the project area, as a result of recharge from urban runoff and river flow. Sampled wells were selected based on areal distribution within the project area, depth of well, perforated interval, and lithology. Water quality samples were collected at eleven sites. Analysis of these samples revealed the existence of certain organic and inorganic constituents in some wells at concentrations potentially harmful to public health. Wells within the study area of this report that contained water with constituent concentrations of health concern are (Barnes, 1988):

(D-13-14)26BBB	-nitrates 18.0 mg/l exceeded Primary MCL of 10 mg/l expressed as nitrogen (N) -toulene 3.2 µg/l
(D-13-14)26DAC3	-tentatively identified organic compounds of potential health concern
(D-13-14)27BDB4	-sulfonamides 221 µg/l and other tentatively identified organic compounds of potential health concern

As a result of these findings, the wells in question were re-sampled in June, 1987 and the presence of these constituents of potential health concern was confirmed. The results of both the August-September 1986 and the June 1987 water quality analyses were reported by Barnes (1988).

Groundwater samples were collected from USGS monitoring wells (D-13-14)26cbb2 and (D-13-14)26dcb2 in January, May, July, and October 1994 (Tadayon, 1994) to determine the variability of groundwater quality throughout the year and changes in quality since samples were collected in 1989 and 1993. Monitoring well (D-13-14)26cbb2 is located west of Swan Road and well (D-13-14)26dcb2 is located between Craycroft and Swan Roads within the then proposed area for artificial recharge facility (Figure 2). Both wells were located south of the Rillito River. Values of pH, hardness, alkalinity, and total dissolved solids concentration were largest in samples from well (D-13-14)26cbb2. The data indicated that the water from well (D-13-14)26cbb2 is moderately hard to hard and water from well (D-13-14)26dcb2 is moderately hard. The pH of one sample from (D-13-14)26dcb2 was less than the USEPA SMCL minimum. Concentrations of calcium, sodium, and bicarbonate were larger in samples from well (D-13-14)26cbb2 than in samples from well (D-13-14)26dcb2. Calcium and sodium were dominant cations, and bicarbonate was the dominant anion.

Table 5.1.1 summarizes the water quality data for monitoring wells (D-13-14)26cbb2 and (D-13-14)26dcb2. No recent USGS data exist for these monitoring wells.

Groundwater quality data was obtained from six Tucson Water wells. Noteworthy constituent concentrations are given in Table 5.1.2. Concentrations of calcium, magnesium, and bicarbonate were larger in samples from well (D-13-14)33add than in samples from any other wells. Analogous

to USGS well data, calcium and sodium were dominant cations, and bicarbonate was the dominant anion. Tucson well data ranges between year 2001 and 2002.

Table 5.1.1 Water quality data at representative USGS monitoring wells (Tadayon, 1994)

Well ID (D-13-14)	pH	Hardness as $CaCO_3$ [mg/l]	Dissolved Solids [mg/l]	Sodium [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]
26cbb2	6.8-7.4	<130	208-222	8-18	32-47	2.9-3.9	1.0-1.4
26dcb2	6.2-7.1	<120	148-201	8-18	32-47	2.9-3.9	1.0-1.4

Well ID (D-13-14)	Bicarbonate as $CaCO_3$ [mg/l]	Sulfate [mg/l]	Chloride [mg/l]	Fluoride [mg/l]	Silica [mg/l]	Dissolved Nitrate [mg/l]	Fecal Coliform [col/100ml]
26cbb2	149-176	21-23	3.6-4.7	0.1-0.2	30-35	-	0-240
26dcb2	90-107	20-29	8.5-12	0.2	17-19	0.01	2-500

Table 5.1.2 Water quality data at representative Tucson Water wells

Well ID	pH	Hardness as $CaCO_3$ [mg/l]	Dissolved Solids [mg/l]	Sodium [mg/l]	Calcium [mg/l]	Magnesium [mg/l]	Potassium [mg/l]
(D-13-14)29cbb	7.67-7.94	97	203-213	28	33-34	3.3-3.4	1.2-1.3
(D-13-14)30dbb	7.82-8.10	94	203-210	34	31-33	3.0	1.3-1.4
(D-13-14)33add	7.41-7.8	167	245-252	27-37	43-60	3.6-4.4	1.3-1.4
(D-13-13)25abb*	1.90-8.00	85	197-209	33-34	30-31	2.6-2.8	1.2-1.3
(D-14-15)06bbb*	8.68-7.39	95	188-223	26-36	27-34	2.3-2.6	1.1-1.3
(D-14-15)06adb*	7.88	108	220-223	30-34	34-40	1.5-2.0	1.2-1.3

Well ID (D-13-14)	Bi-carbonate as $CaCO_3$ [mg/l]	Sulfate [mg/l]	Chloride [mg/l]	Fluoride [mg/l]	Silica [mg/l]	Dissolved Nitrate [mg/l]	Fecal Coliform [col/100ml]
(D-13-14)29cbb	109-110	20-21	9.0-9.2	0.11-0.18	15	3.9-4.1	NEG
(D-13-14)30dcb	118-123	21-22	10-11	0.18-0.22	14	3.3-4.0	NEG
(D-13-14)33add	144-177	28-41	9.8-15	0.1-0.11	14	2.1-2.6	NEG
(D-13-13)25abb*	125-126	19-20	8.2-8.6	0.18-0.22	14	1.5-1.6	NEG
(D-14-15)06bbb*	76-117	24-32	10-14	0.10-0.22	19	1.4-2.2	NEG
(D-14-15)06adb*	119-126	34-36	8.3-9.6	0.10	16-17	0.75-1.0	NEG

* Near Grant and Wilmot Roads
Data Source: Tucson Water, February, 2002.

5.2 Reclaimed Water

Reclaimed water quality information on twelve constituents for year 2000 and 2001 were obtained from Tucson Water. The data was from the Tucson Water Re-use Permit Compliance Point 522. Table 5.2.1 lists the ranges of these constituents for the years 2000-2001.

Table 5.2.1. Reclaimed water quality data ranges for year 2000-2001

Constituent	Concentration Ranges (mg/L)
Ammonia As N	2 - 11
Nitrate As N	2.1 - 5.3
Nitrite As N	0.1 - 3.5
Total Phosphate As P	1 - 3
Biochemical Oxygen Demand (BOD)	3 - 110
Total Suspended Solids	1 - 3.3
Total Dissolved Solids	572 - 698
Sulfate	96 - 150
Calcium	58 - 79
Chloride	92 - 140
Magnesium	10 - 14
Potassium	6 - 9
Sodium	120 - 151

Source: Tucson Water, March, 2002.

6. WATER BUDGET ANALYSIS

The water budget analysis was generated based on total inflow and outflow in ac-ft/yr along the study reach of the Rillito River in Township 13, Range 14. Following is a short description of contributing factors in the water budget calculations.

Infiltration as inflow to aquifer

Limited data is available on infiltration/recharge into aquifer in the study area. Majority of the tests were performed locally, giving infiltration rate in ft/day at various locations along the Rillito River reach. Studies of recharge along the length of Rillito River conducted by the University of Arizona indicate that infiltration is approximately 478 ac-ft per day (Katz, 1985; PCFCD, 1986). A Constant infiltration rate of 240 ac-ft per day was used for the El Rio Antiguo study area (approximately 5 miles between Craycroft Road and 1st Avenue) in the water budget calculations. USGS streamflow data plots (Appendix C) support the ephemeral behavior of the Rillito River. Data for water years 1995-2000 suggests that on the average, Rillito River flows 11 days per year. Based on this information, the infiltration rate was estimated to be 2640 ac-ft per year.

Reclaimed water as inflow to aquifer

Reclaimed water is mostly used for turf irrigation purposes. An estimate for the years 1995-2001 was obtained from Tucson Water Planning and Engineering Division. Table 6.1 lists the estimated annual reclaimed water use in ac-ft/yr in Township 13 and Range 14.

Table 6.1 Reclaimed water deliveries in Township 13, Range 14

Year	Reclaimed Water (ac-ft/yr)
1995	1236.28
1996	1352.18
1997	1172.11
1998	1098.39
1999	1292.94
2000	1433.48
2001	1380.68

Source: Tucson Water, March, 2002

Withdrawal at well locations as outflow

Pumping well data for Township 13, Range 14 was obtained from ADWR query. The withdrawal rates at the non-exempt wells in the study area not significant. These rates are tabulated in Appendix B. DTW and WTE data and seasonal hydrographs for selected exempt and non-exempt wells are provided in Appendix A. According to Arizona Department of Water Resources (ADWR), some exempt wells are associated with groundwater rights. Historic situations sometimes allow these small wells to be attached to groundwater rights, however, according to ADWR this is not currently allowed.

Evapotranspiration as outflow

In collaboration with Sage Landscape, Pima County Flood Control District's Planning Division compiled vegetative cover information for the El Rio Antiguo study reach. Table 6.2 lists the type of vegetation typical in the study area. Based on typical evapotranspiration rate (ft/day), total loss in ac-ft/yr was used on water budget calculations.

Table 6.2 Vegetative Cover Categories

Category	**Total Area of Coverage (ac)**	**Description**
AGCROP	91	Farms and croplands in the uplands
SCRUBSHRUB	27	Existing Scrub-shrublands in the active channel – Rabbitbush, Quailbush, Ironwood, and Saltbush
UPLANDBUFF	112	Existing and newly developed upland buffer zone – Mesquite, Ironwood, Rabbitbush, Quailbush, Catclaw Acacia, Palo Verde, and Creosote

Source: Pima County Flood Control District, March, 2002

Vegetation under the UPLANDBUFF category transpires at approximately 0.005 ft/day, whereas the same types of vegetation near Riparian areas would transpire at an average rate of 0.016 ft/day. Based on the availability of water in irrigated soil and time of the year, transpiration rate for agricultural crops is 0.02 ft/day on the average (Chow et al., 1988). A rate of 0.02 ft/day was used to estimate evapotranspiration for agricultural crops for an average growing season of 8 months (240 days). Average evapotranspiration rate for vegetation under the SCRUBSHRUB category was estimated at 0.016 ft/day in the active channel. High evapotranspiration rates are likely at locations

where depth to groundwater table is within 25 ft (Robinson, 1958). Constant rate for all years was used in water budget analysis.

Table 6.3 summarizes the water budget analysis for the Rillito River study reach.

Table 6.3 Water budget for the years 1995-2001
(rates are in ac-ft/yr)

Year	**Inflow**		**Outflow**	
	Infiltration*	Reclaimed water	Pumped withdrawal	Evapo-transpiration
1995	2640.00	1236.28	106.32	863.00
1996	2640.00	1352.18	60.60	863.00
1997	2640.00	1172.11	57.43	863.00
1998	2640.00	1098.39	70.57	863.00
1999	2640.00	1292.94	34.40	863.00
2000	2640.00	1433.48	61.58	863.00
2001	-	1380.68	-	-

* Katz (1985), USGS Streamflow Data

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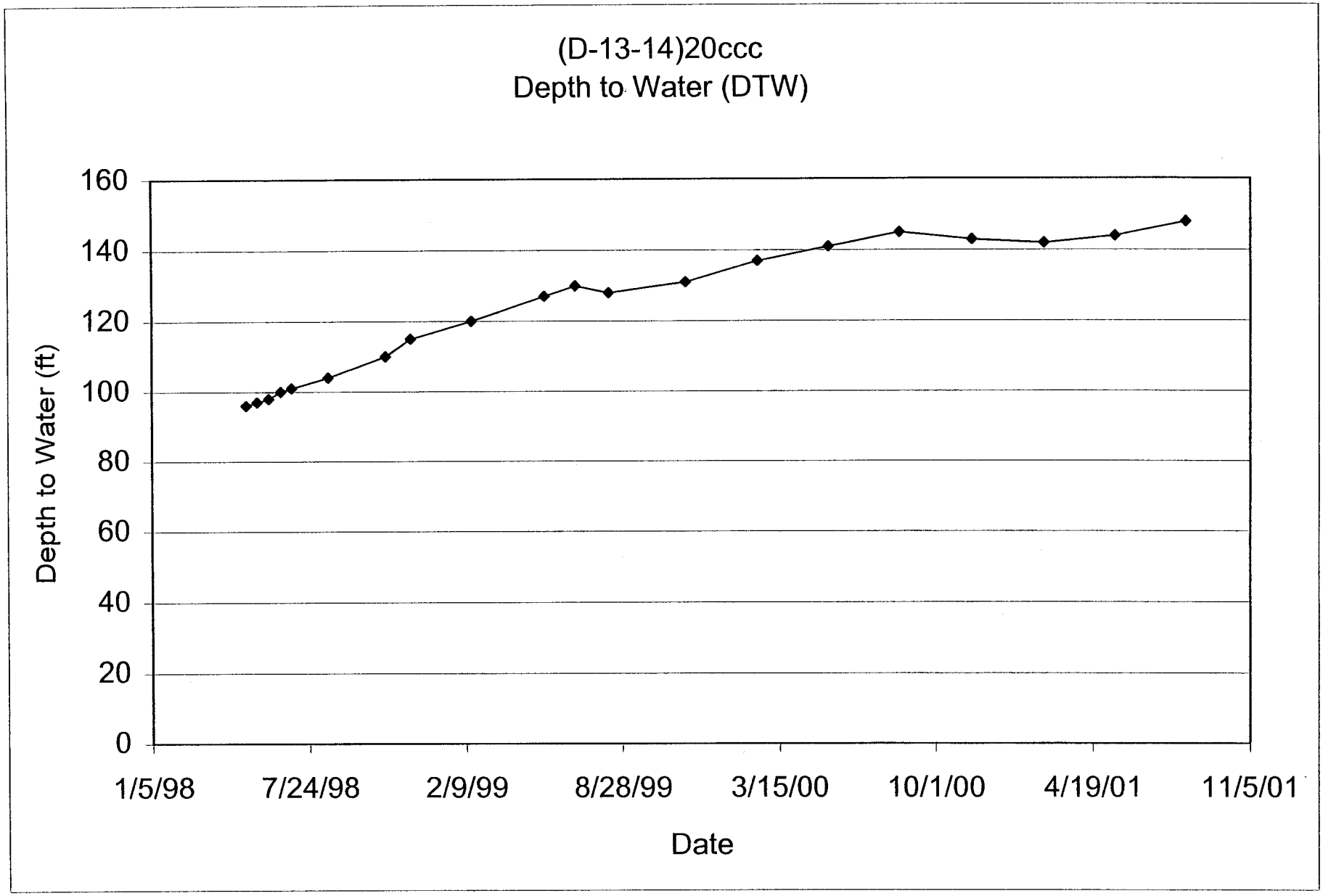
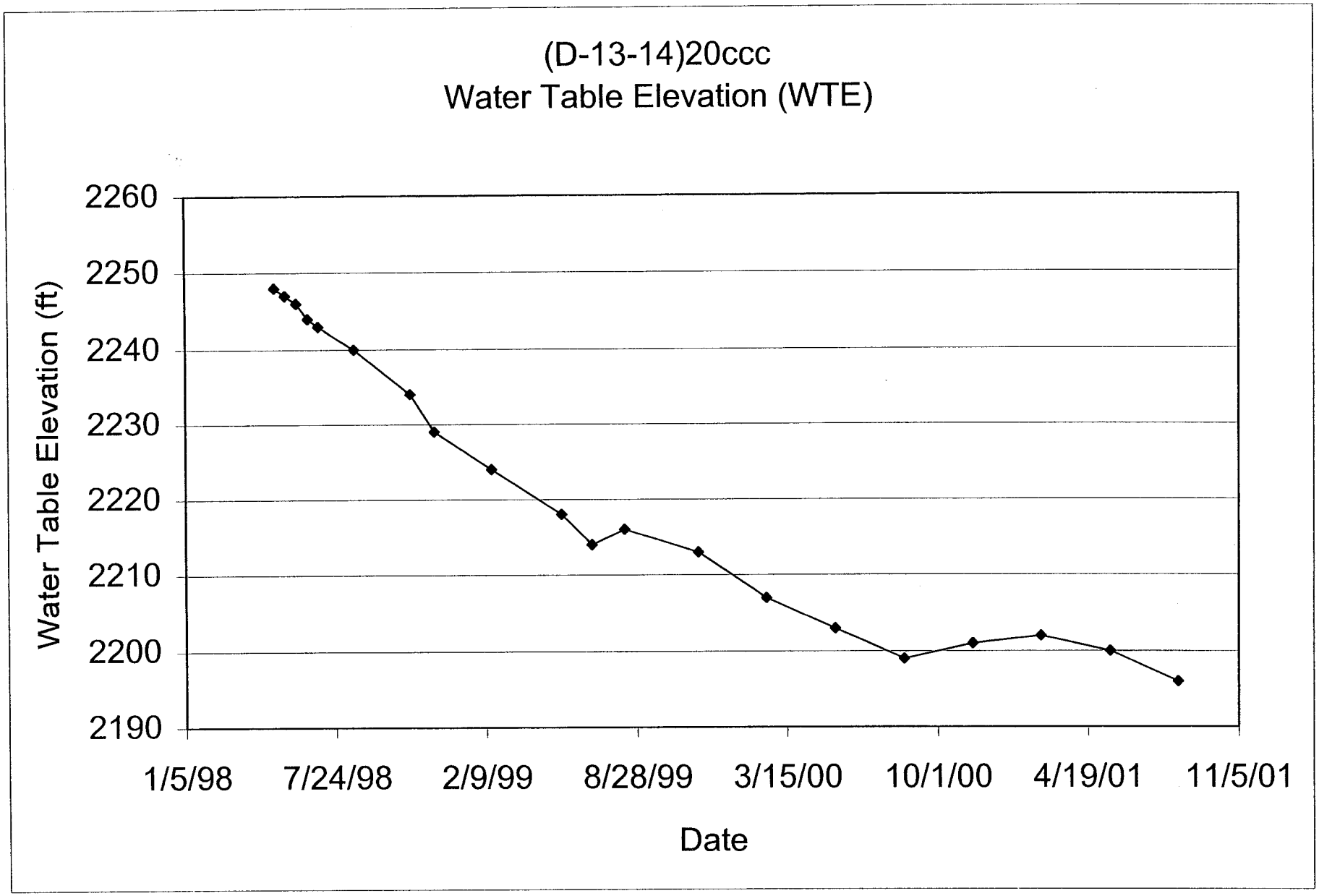
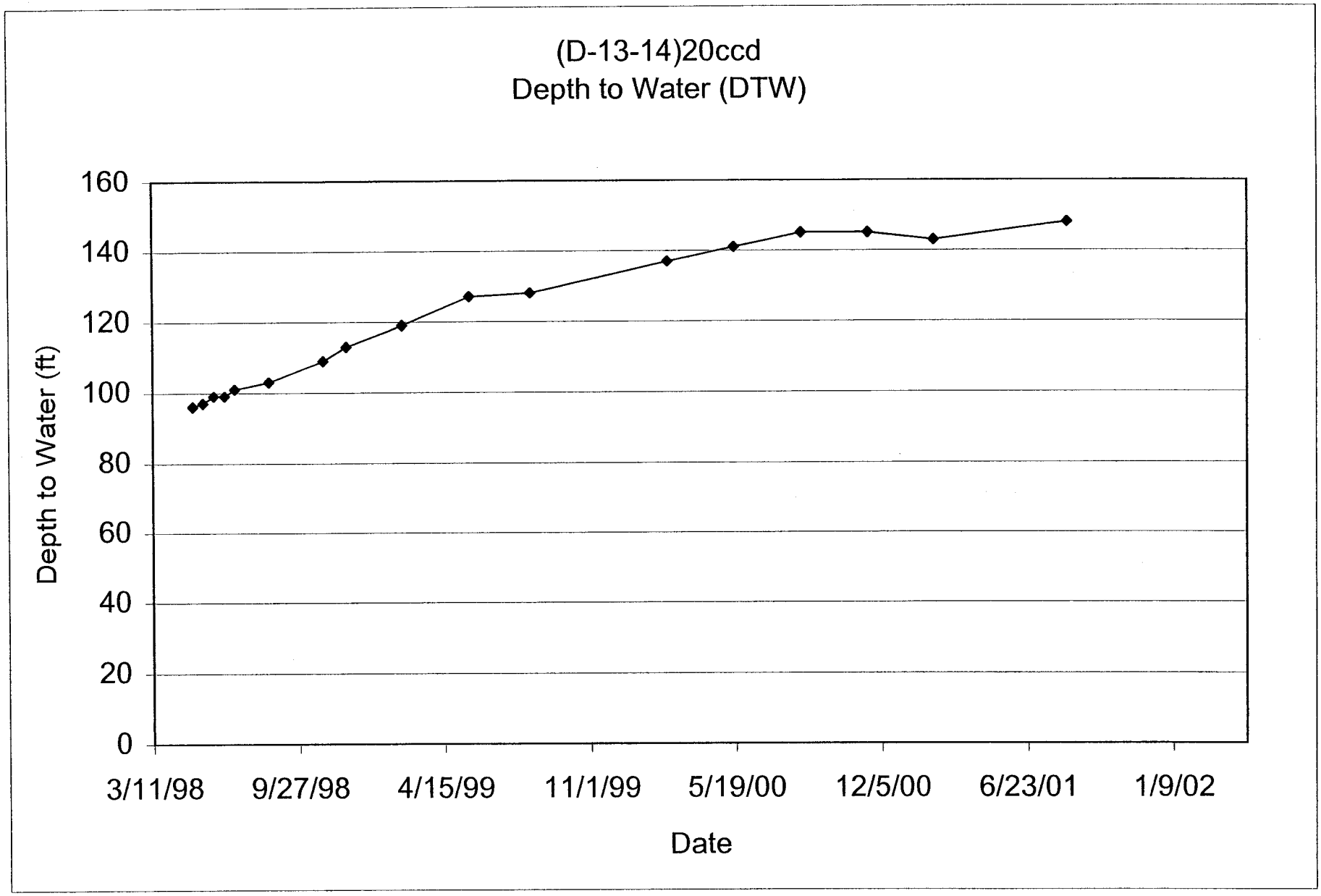
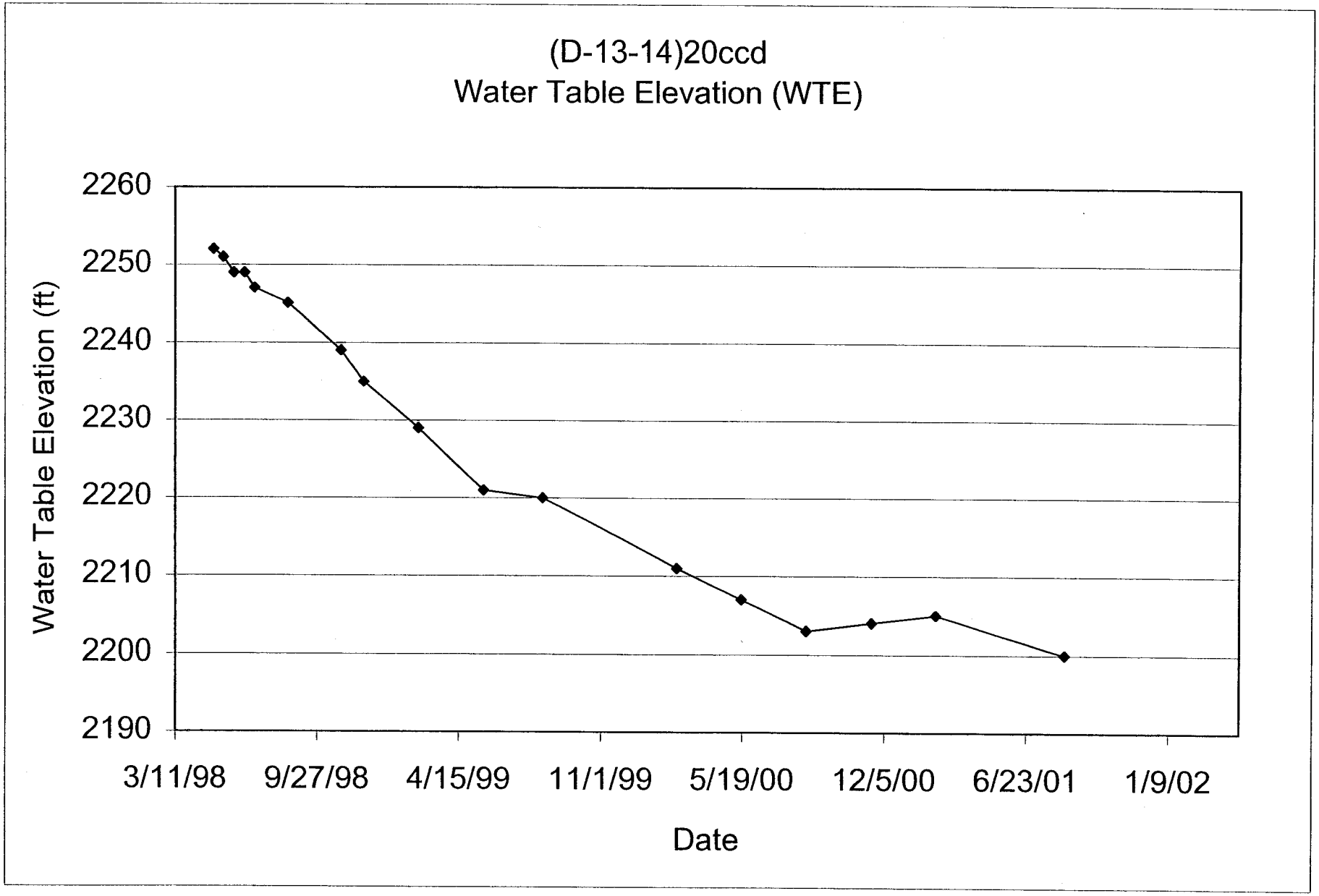
APPENDIX A

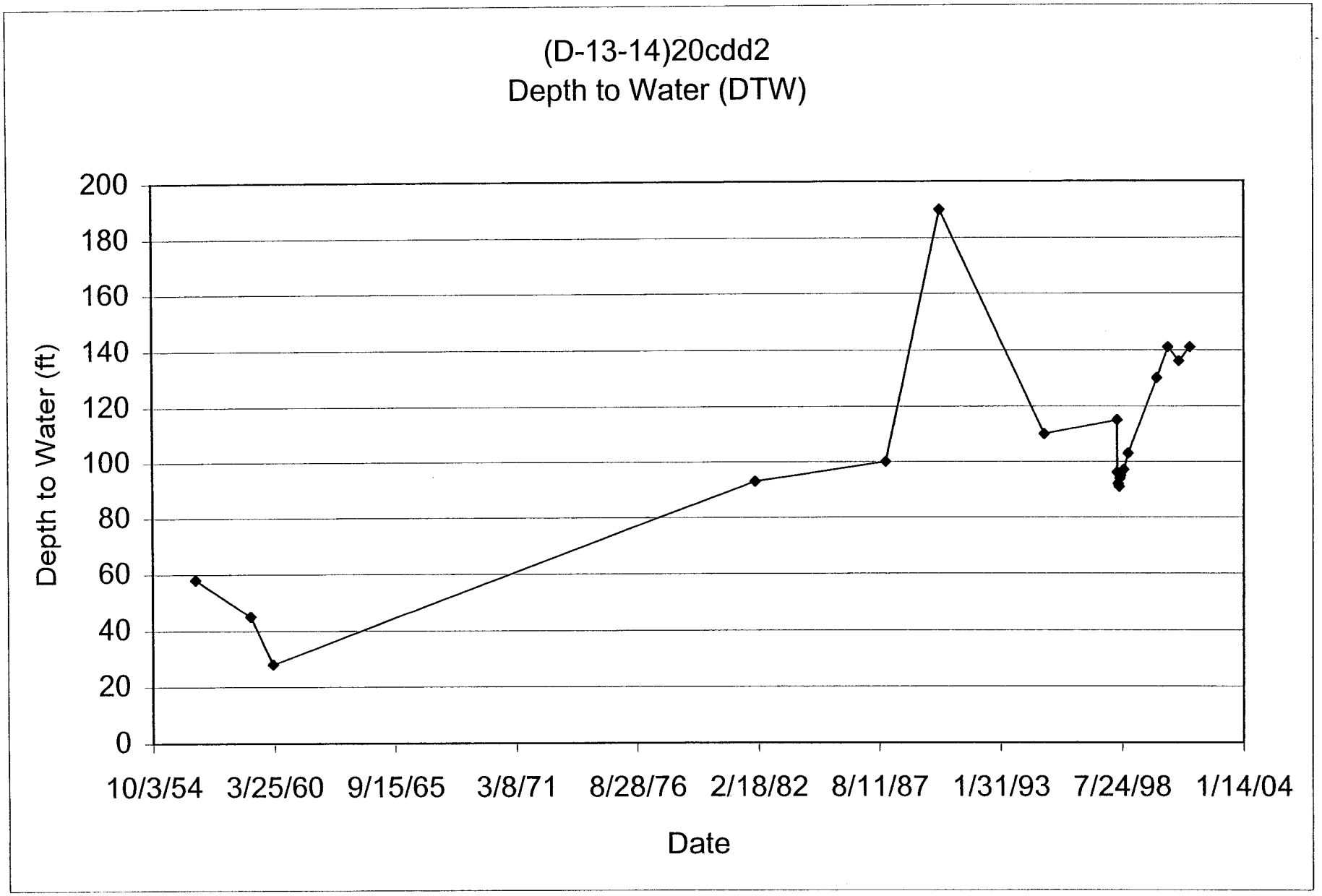
Depth to Water (DTW) and Water Table Elevation (WTE) Plots For ADWR Wells

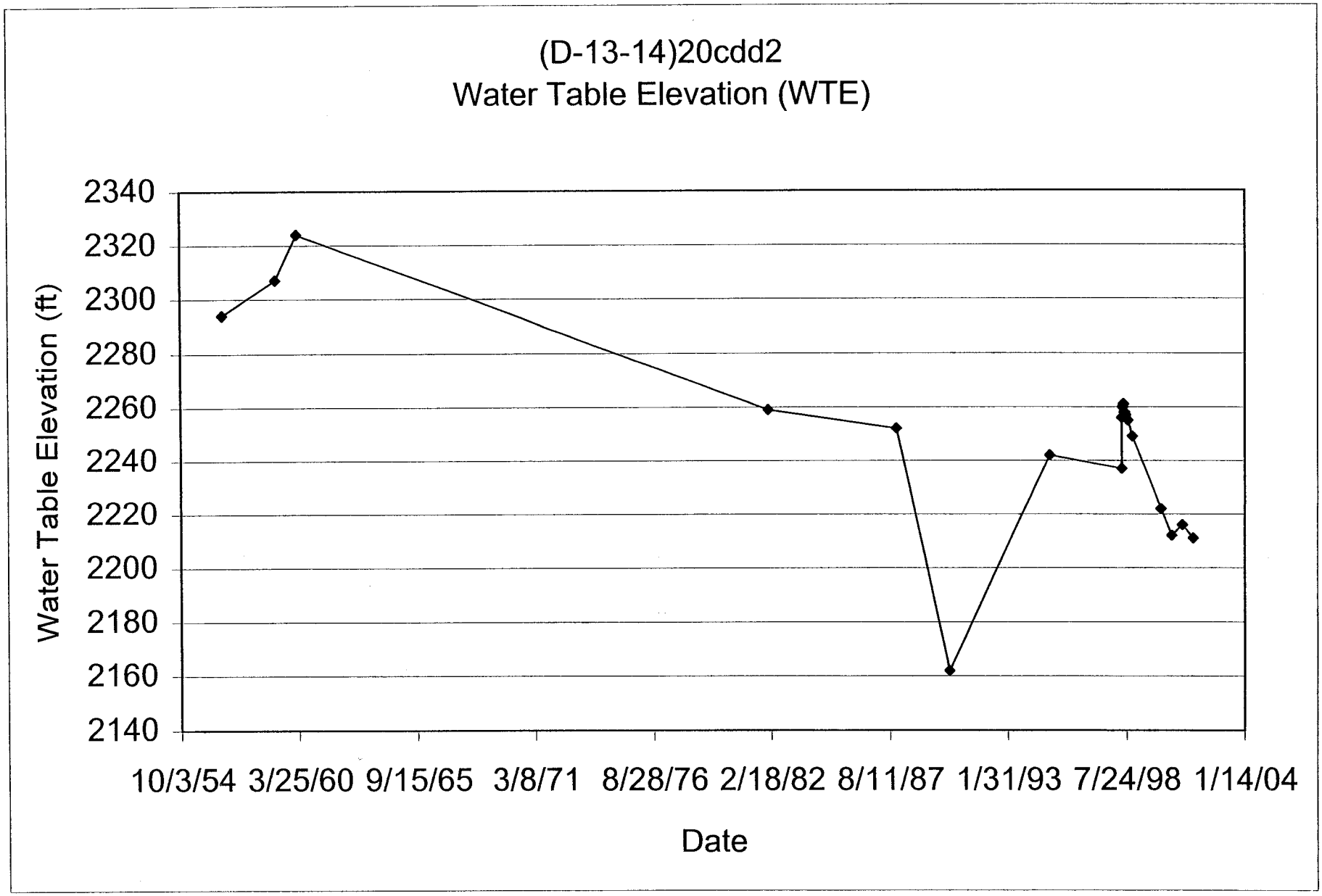

(D-13-14)20ccc
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

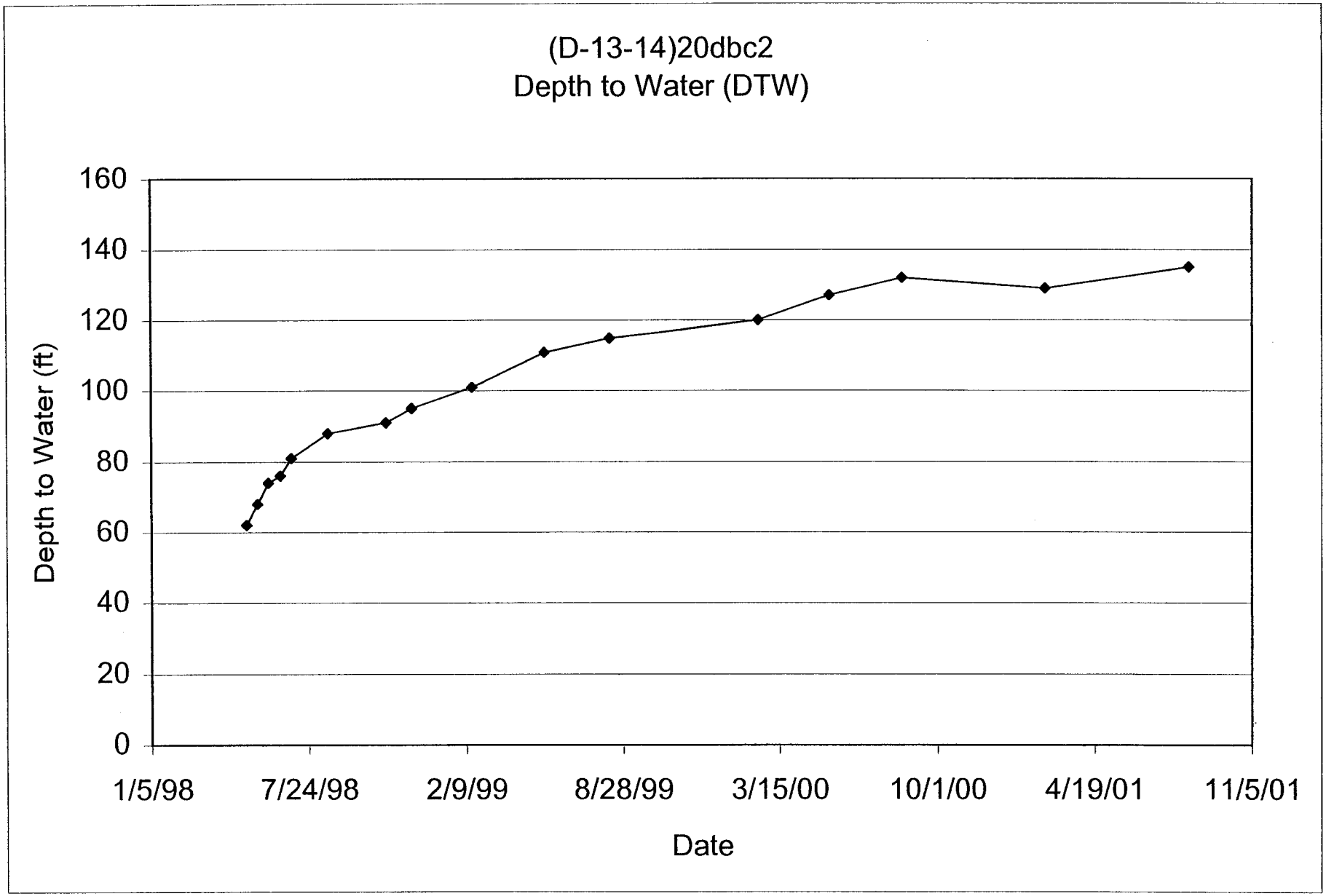

(D-13-14)20ccc
Water Table Elevation (WTE)
Water Table Elevation (ft)
2260
2250
2240
2230
2220
2210
2200
2190
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

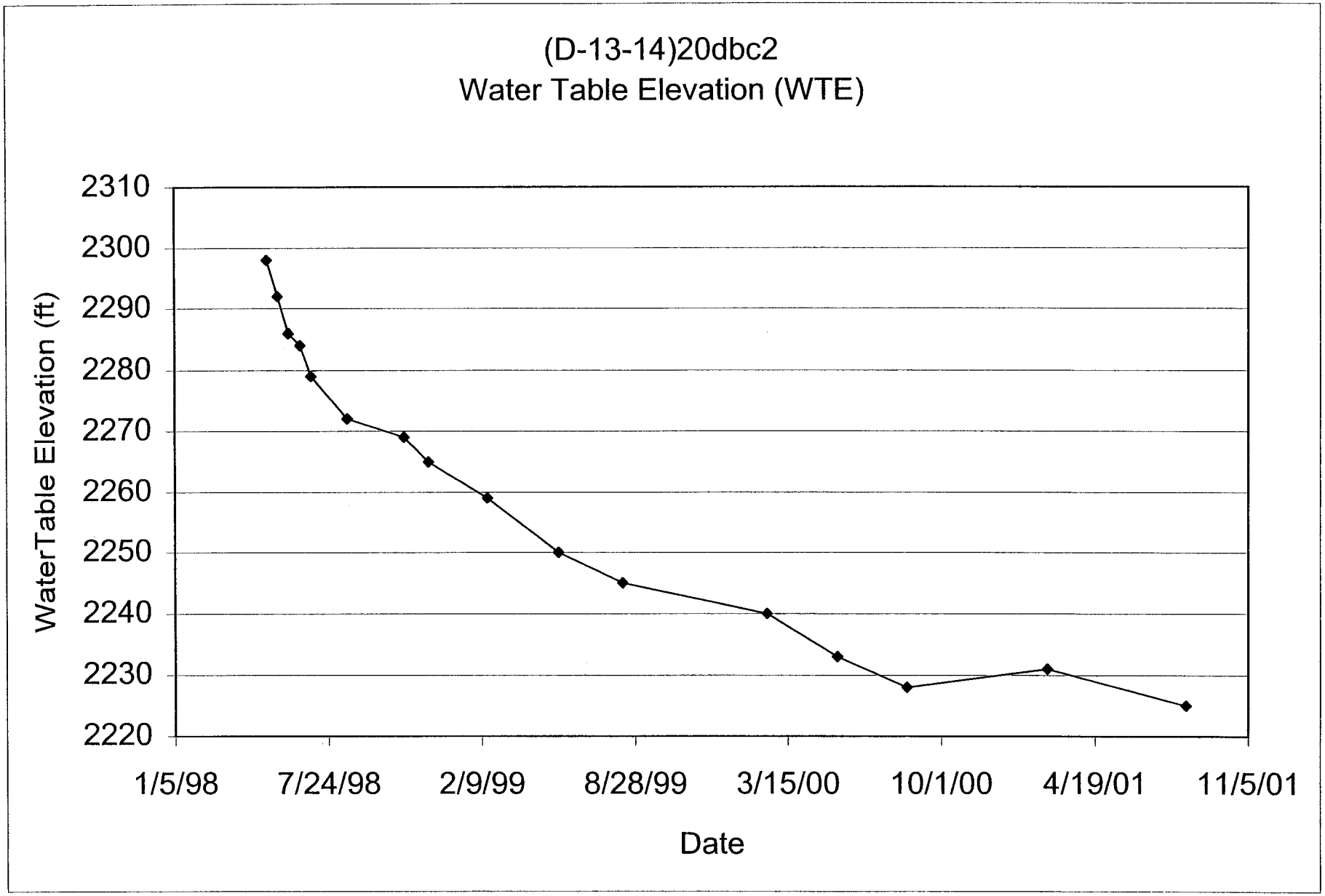

(D-13-14)20ccd
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
3/11/98
9/27/98
4/15/99
11/1/99
5/19/00
12/5/00
6/23/01
1/9/02
Date

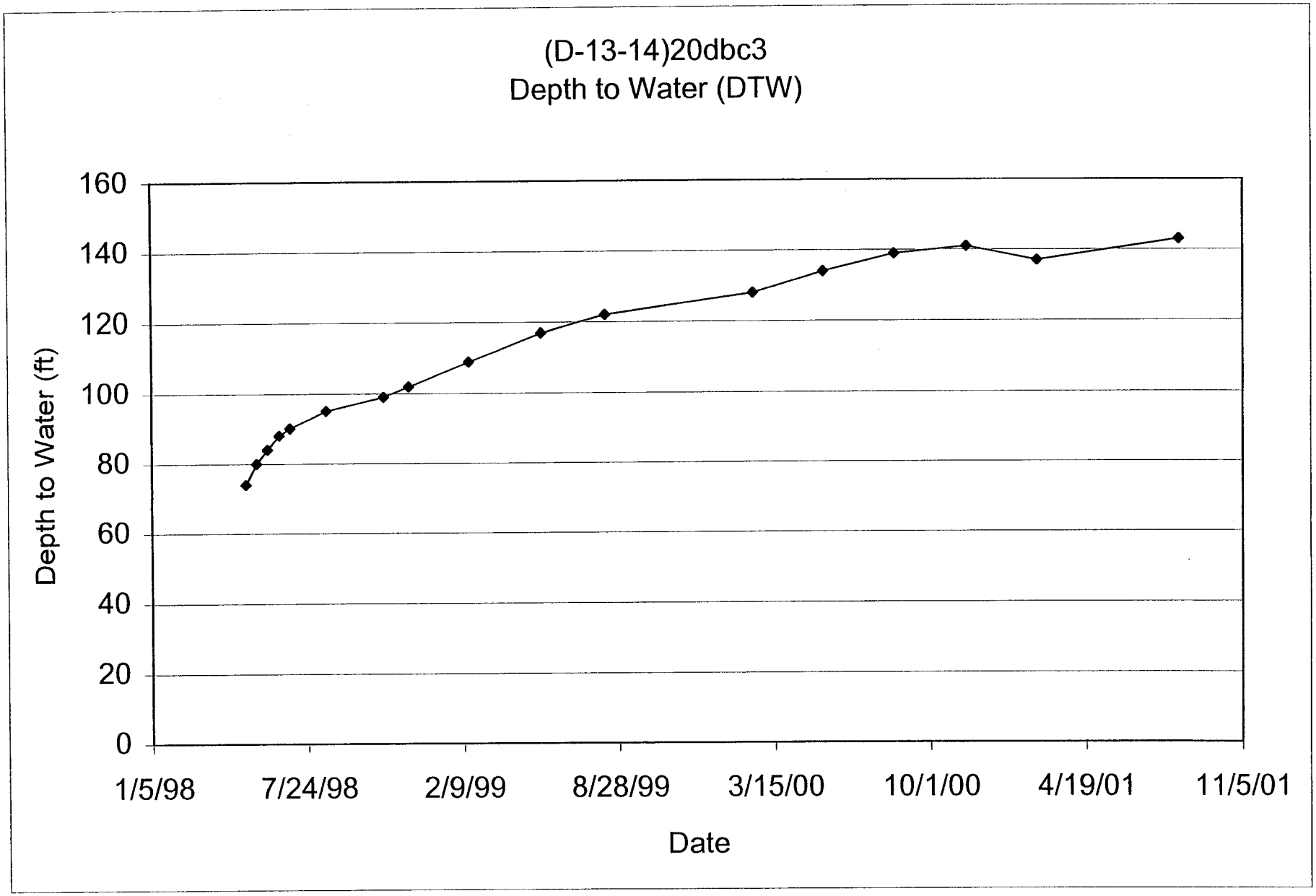

(D-13-14)20ccd
Water Table Elevation (WTE)
Water Table Elevation (ft)
2260
2250
2240
2230
2220
2210
2200
2190
3/11/98
9/27/98
4/15/99
11/1/99
5/19/00
12/5/00
6/23/01
1/9/02
Date

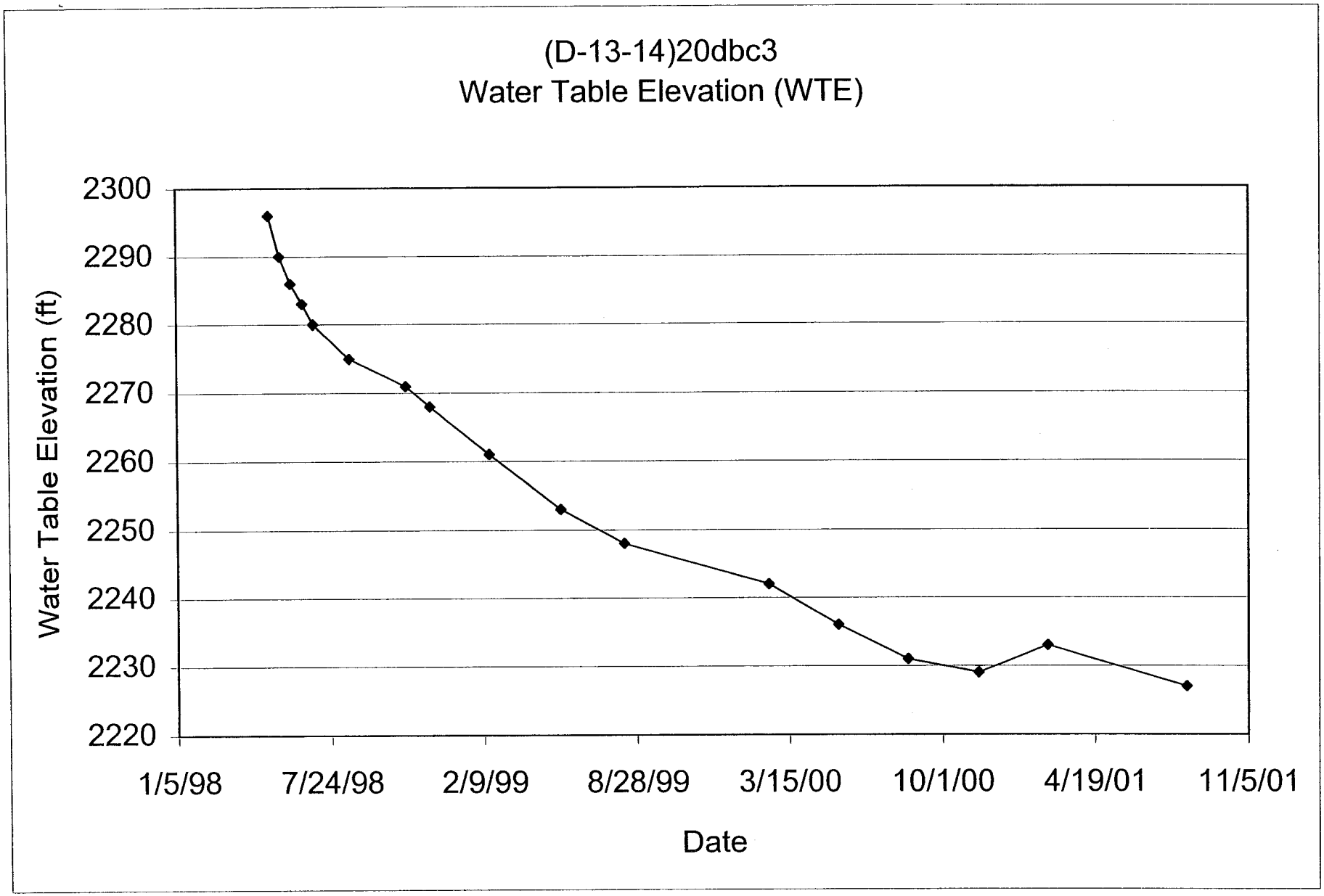

(D-13-14)20cdd2
Depth to Water (DTW)
Depth to Water (ft)
200
180
160
140
120
100
80
60
40
20
0
10/3/54
3/25/60
9/15/65
3/8/71
8/28/76
2/18/82
8/11/87
1/31/93
7/24/98
1/14/04
Date

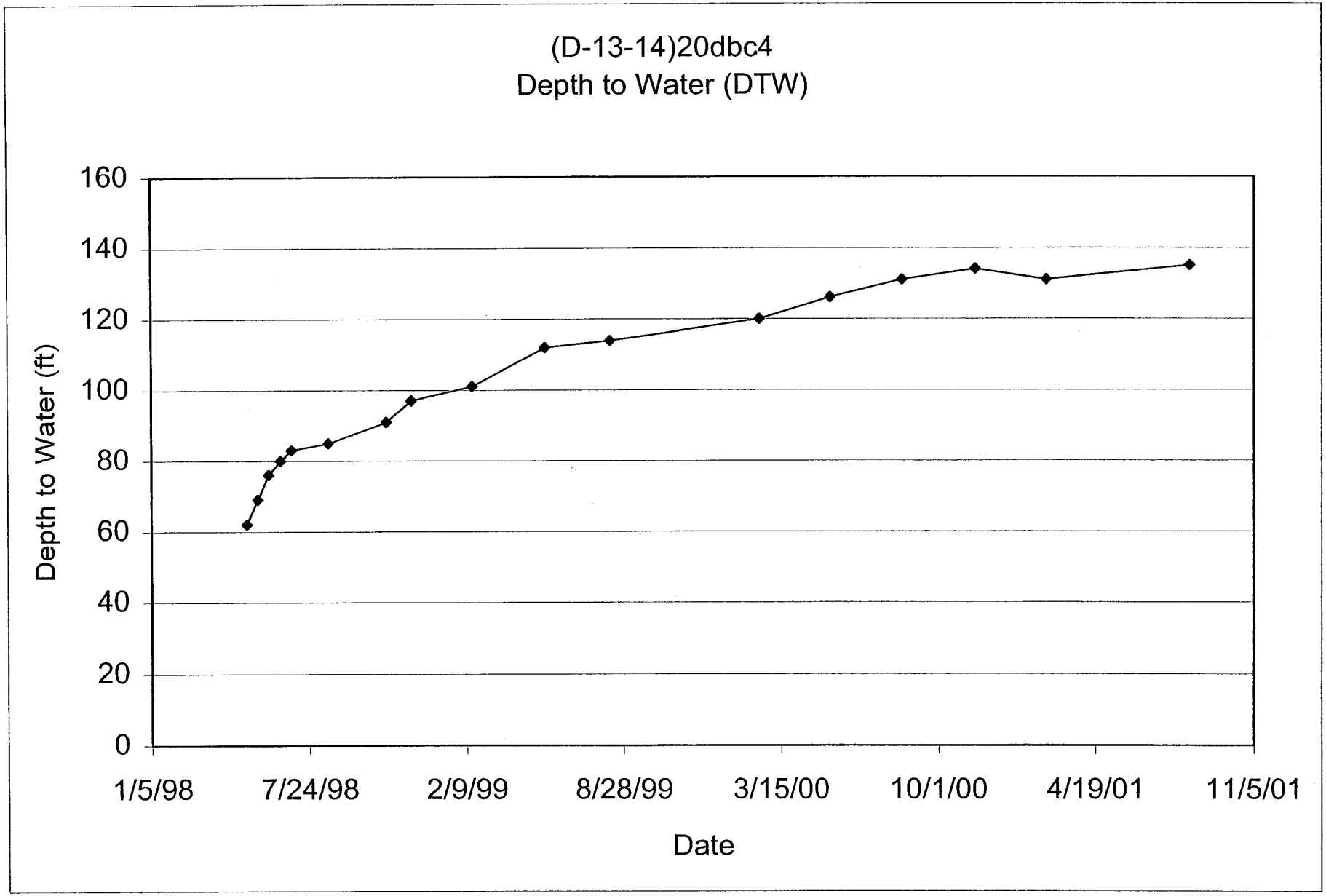

(D-13-14)20cdd2
Water Table Elevation (WTE)
Water Table Elevation (ft)
2340
2320
2300
2280
2260
2240
2220
2200
2180
2160
2140
10/3/54
3/25/60
9/15/65
3/8/71
8/28/76
2/18/82
8/11/87
1/31/93
7/24/98
1/14/04
Date

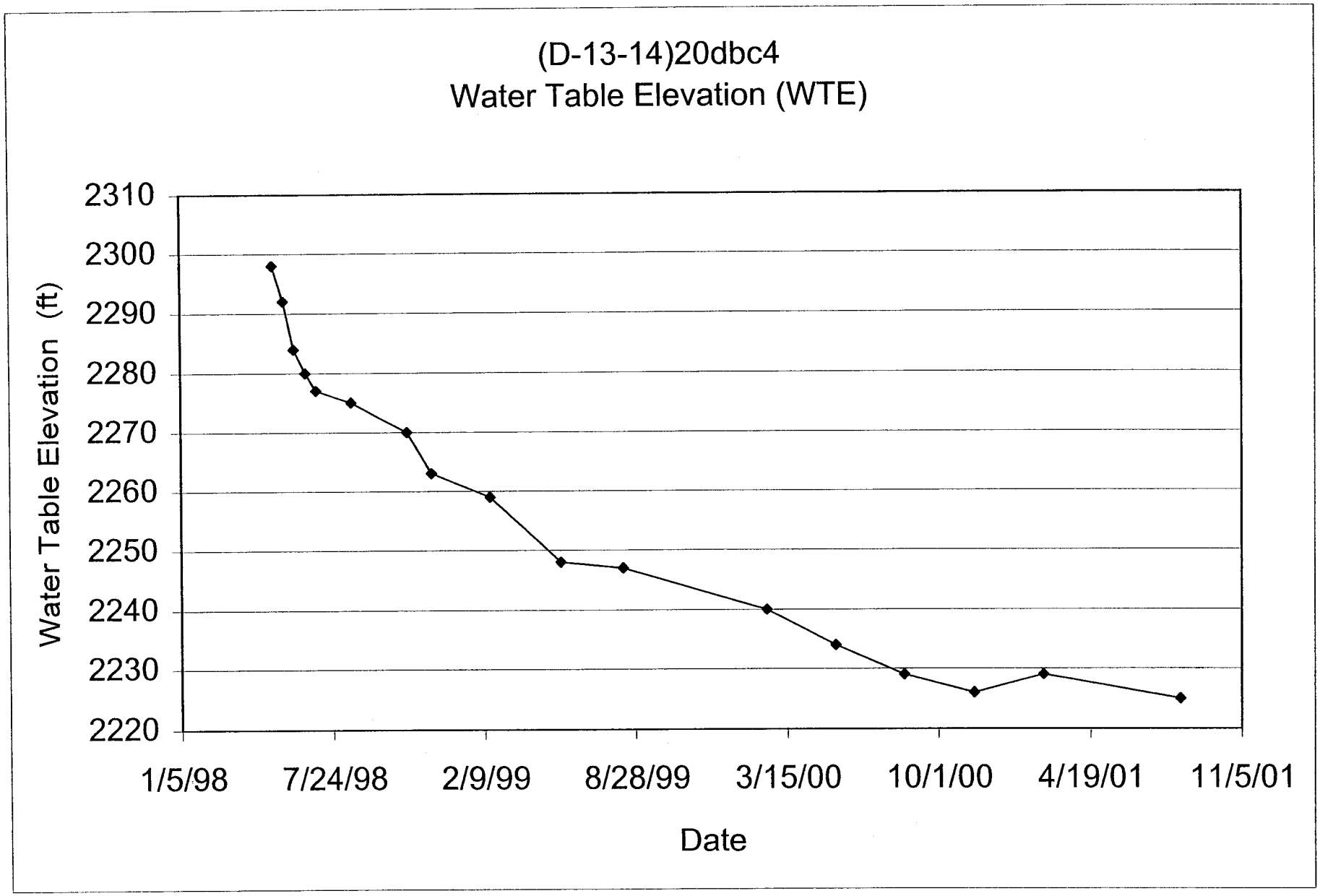

(D-13-14)20dbc2
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

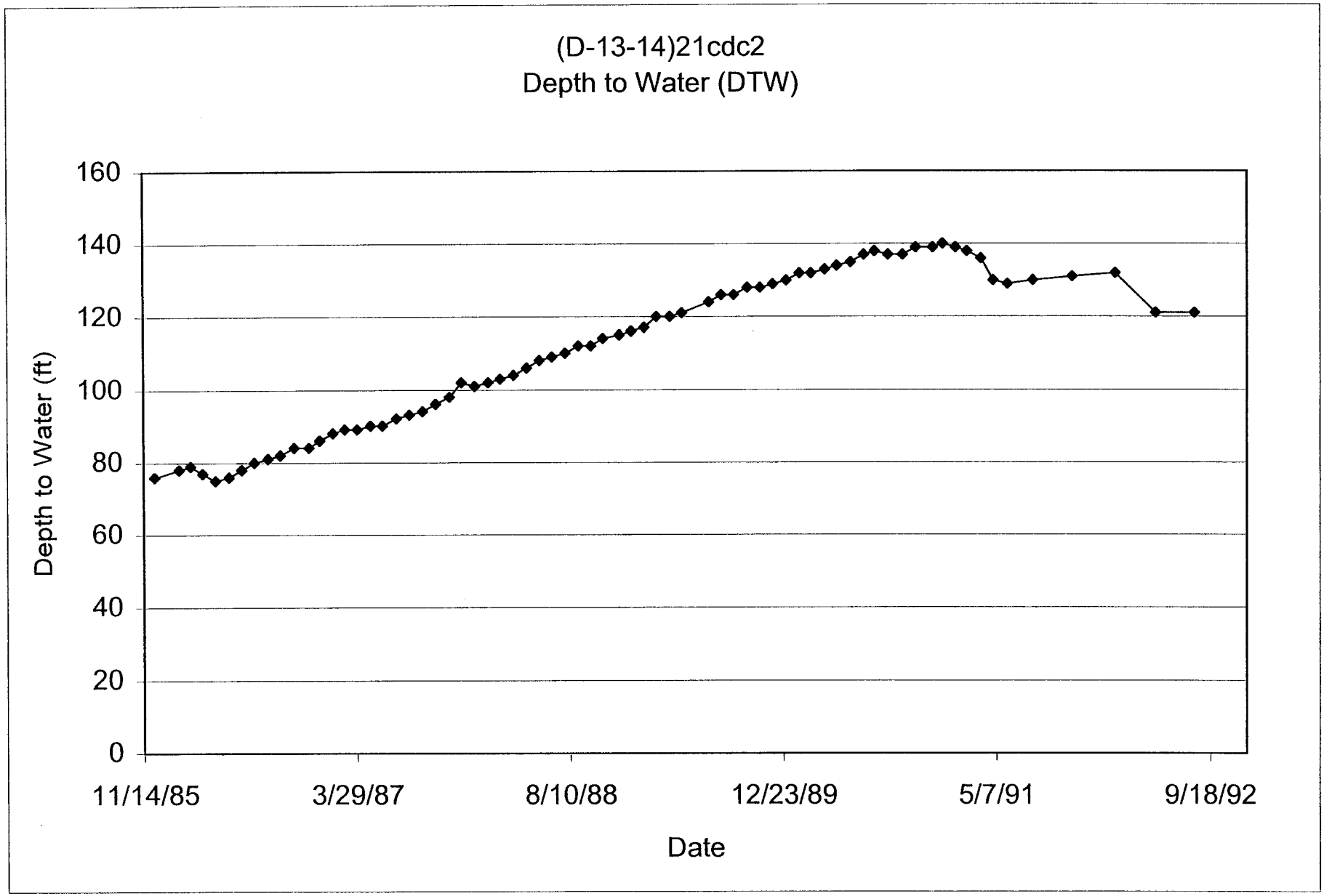

(D-13-14)20dbc2
Water Table Elevation (WTE)
WaterTable Elevation (ft)
2310
2300
2290
2280
2270
2260
2250
2240
2230
2220
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

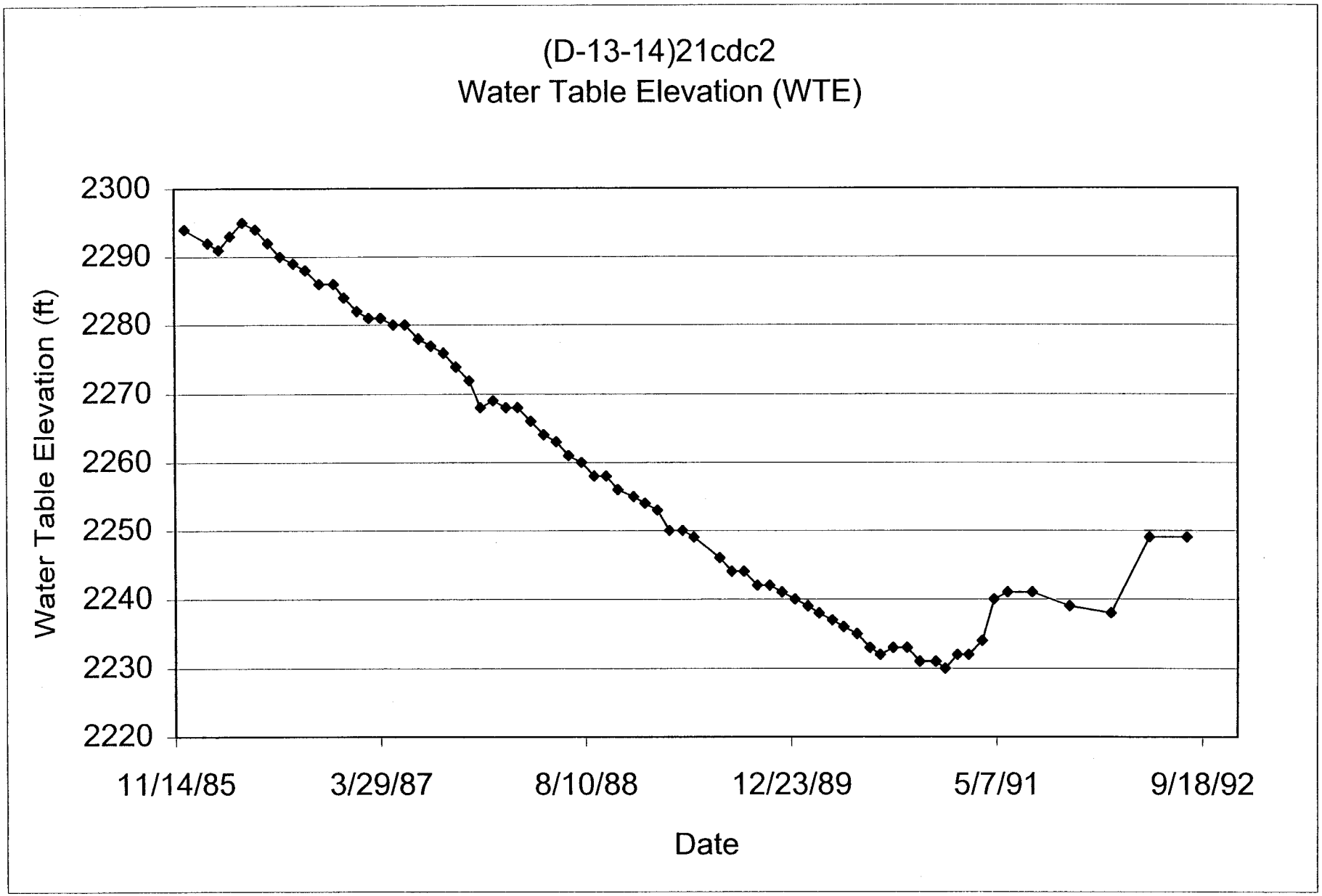

(D-13-14)20dbc3
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

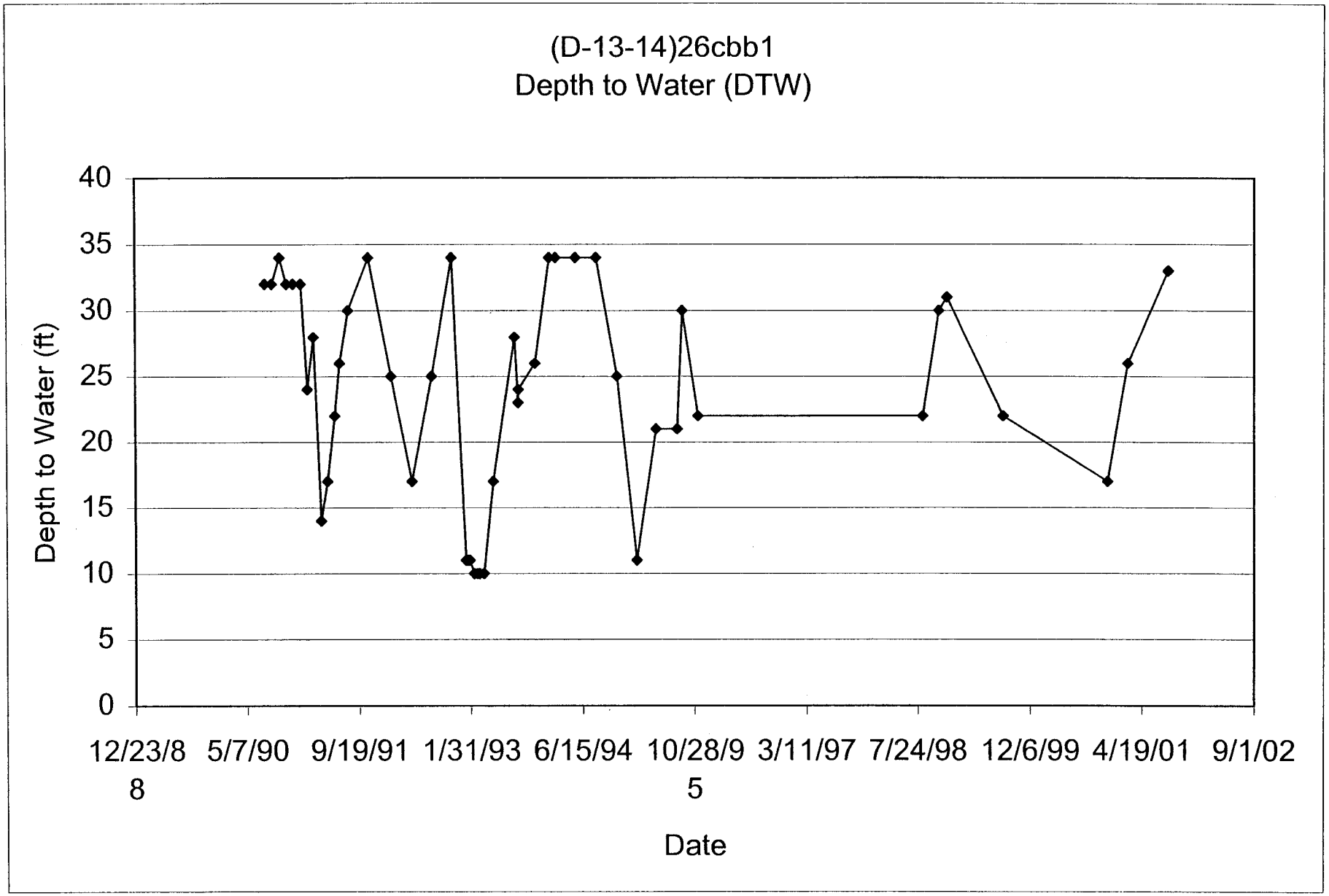

(D-13-14)20dbc3
Water Table Elevation (WTE)
Water Table Elevation (ft)
2300
2290
2280
2270
2260
2250
2240
2230
2220
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date

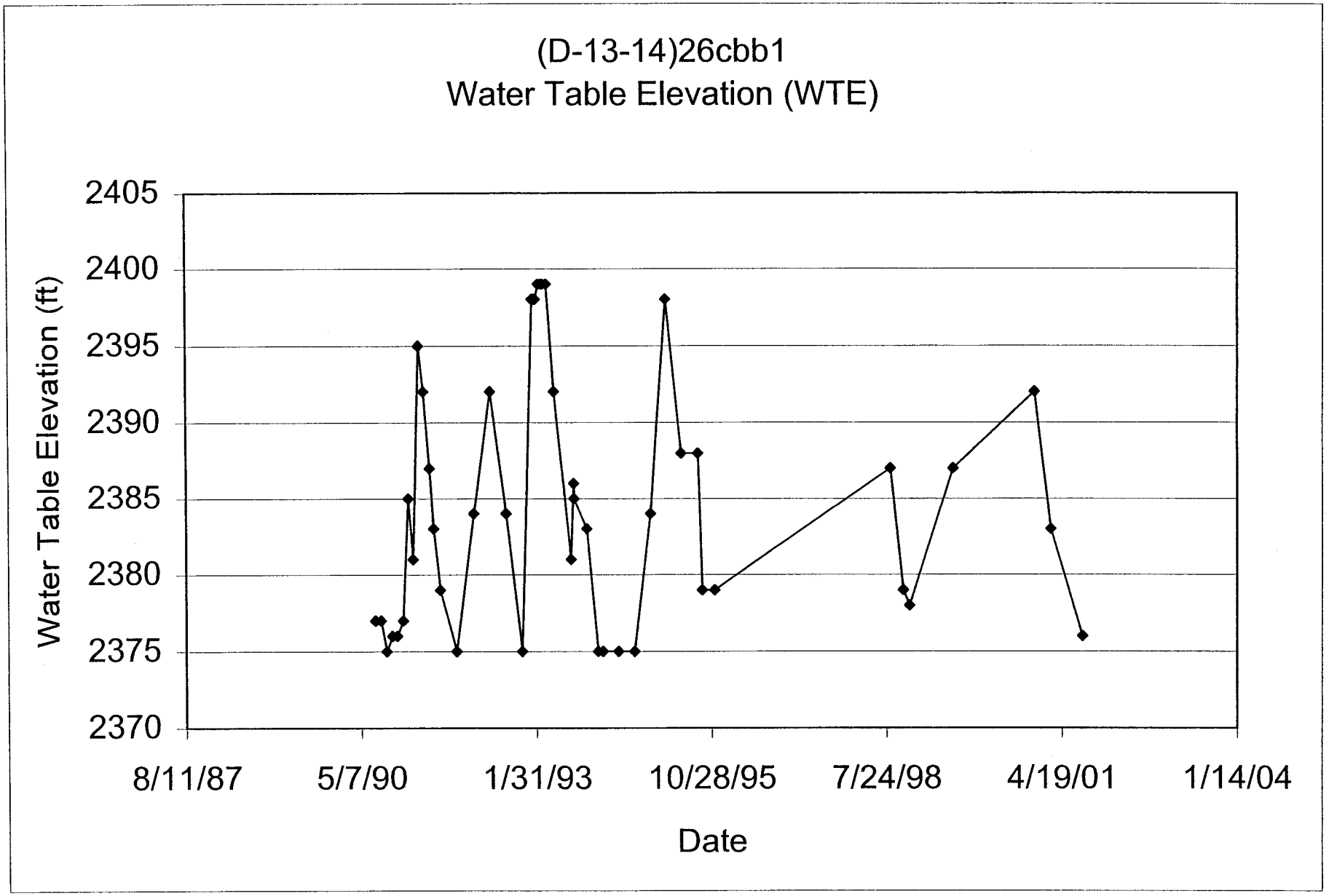

(D-13-14)20dbc4
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date


(D-13-14)20dbc4
Water Table Elevation (WTE)
Water Table Elevation (ft)
2310
2300
2290
2280
2270
2260
2250
2240
2230
2220
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
10/1/00
4/19/01
11/5/01
Date


(D-13-14)21cdc2
Depth to Water (DTW)
Depth to Water (ft)
160
140
120
100
80
60
40
20
0
11/14/85
3/29/87
8/10/88
12/23/89
5/7/91
9/18/92
Date


(D-13-14)21cdc2
Water Table Elevation (WTE)
Water Table Elevation (ft)
2300
2290
2280
2270
2260
2250
2240
2230
2220
11/14/85
3/29/87
8/10/88
12/23/89
5/7/91
9/18/92
Date


(D-13-14)26cbb1
Depth to Water (DTW)
Depth to Water (ft)
40
35
30
25
20
15
10
5
0
12/23/88
5/7/90
9/19/91
1/31/93
6/15/94
10/28/95
3/11/97
7/24/98
12/6/99
4/19/01
9/1/02
Date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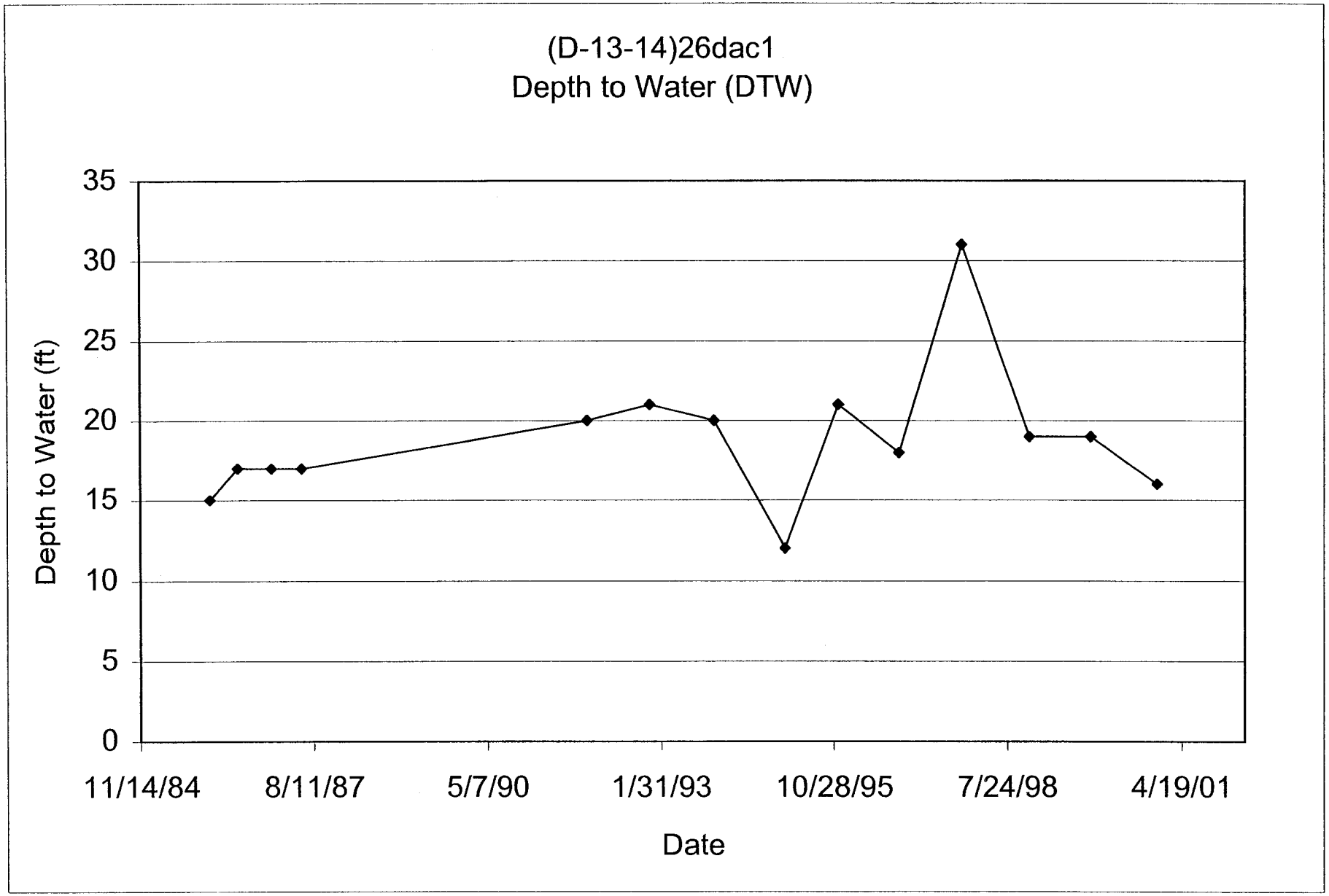
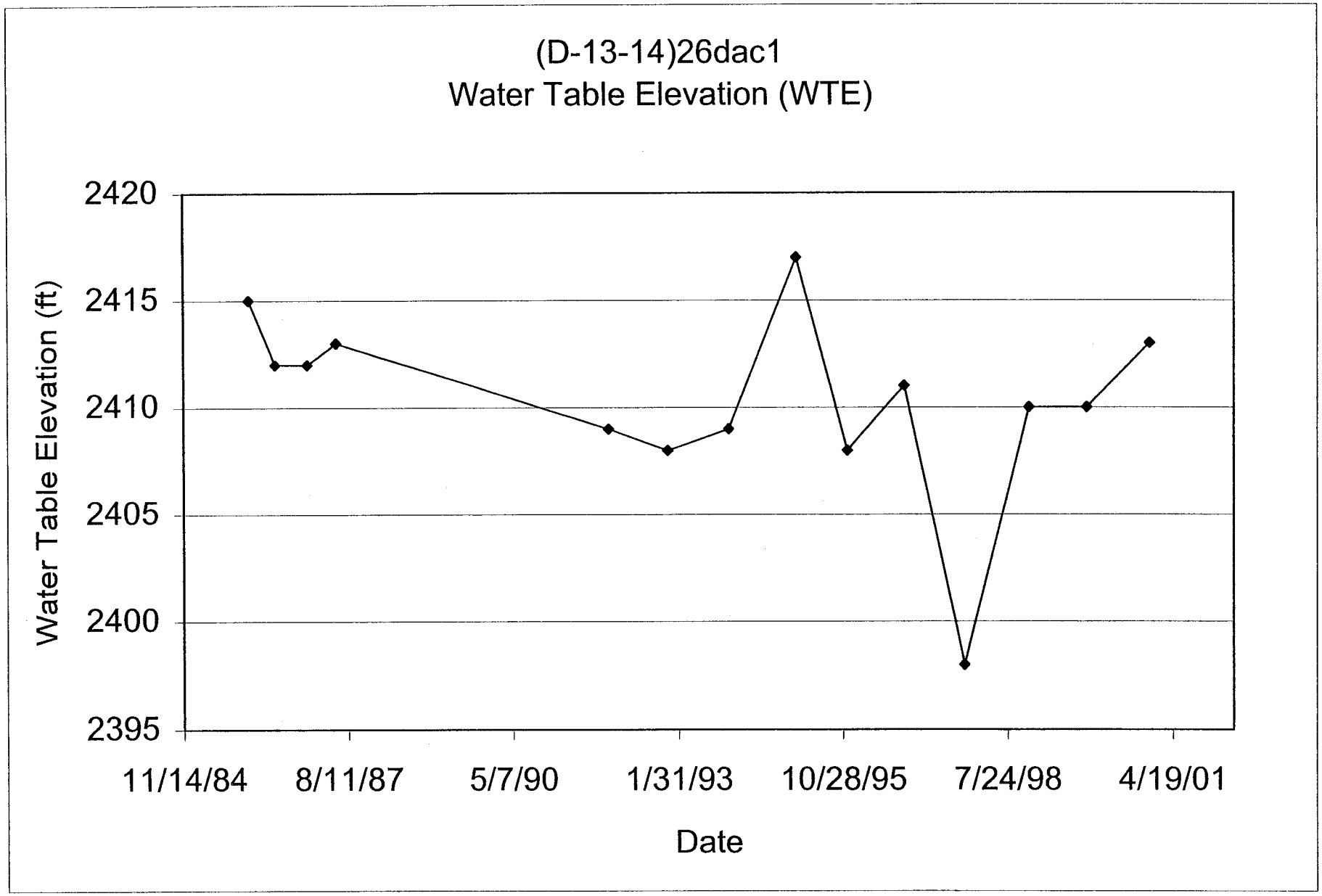
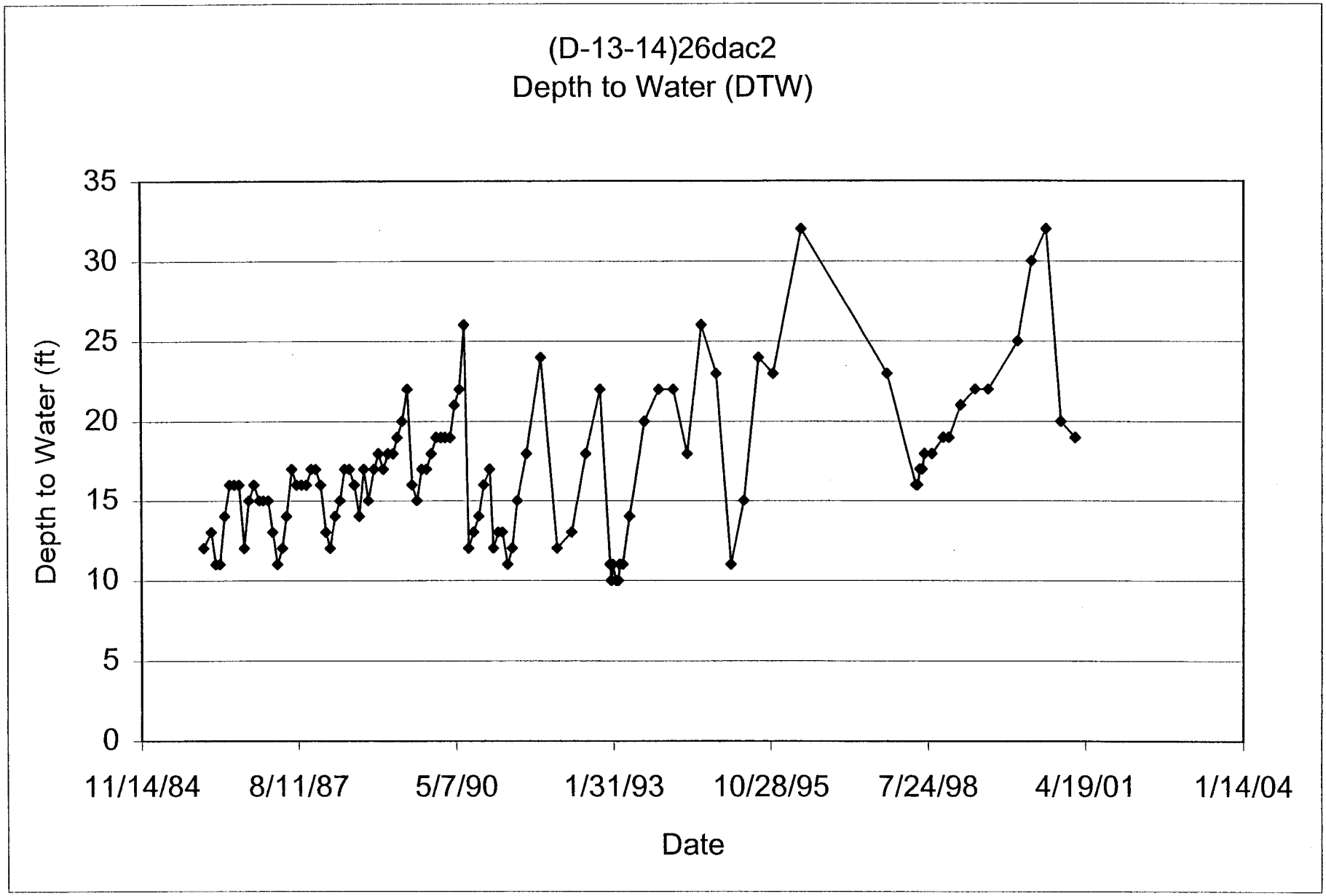
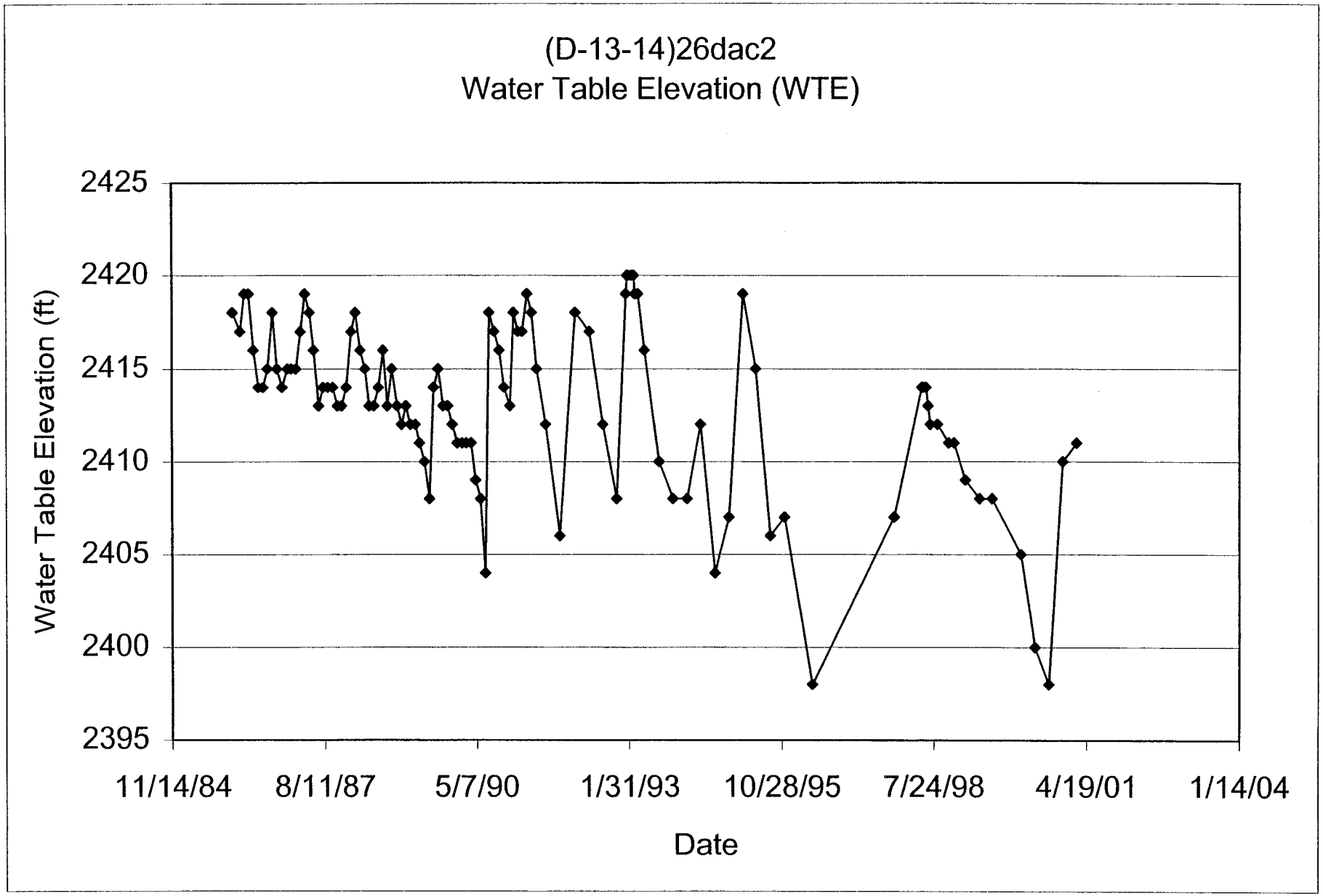
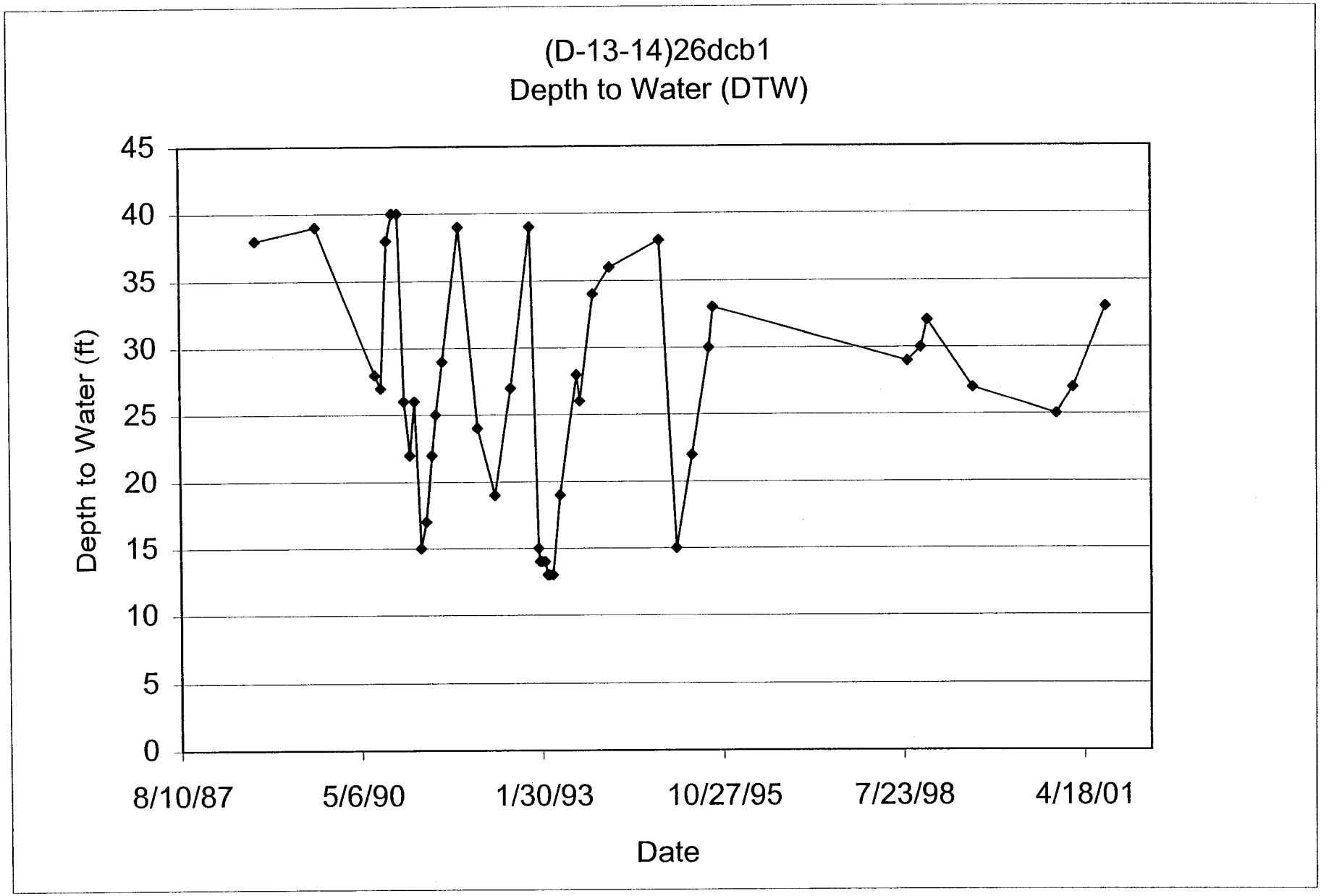
Water Table Elevation (WTE)
Water Table Elevation (ft)
2405
2400
2395
2390
2385
2380
2375
2370
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
Date

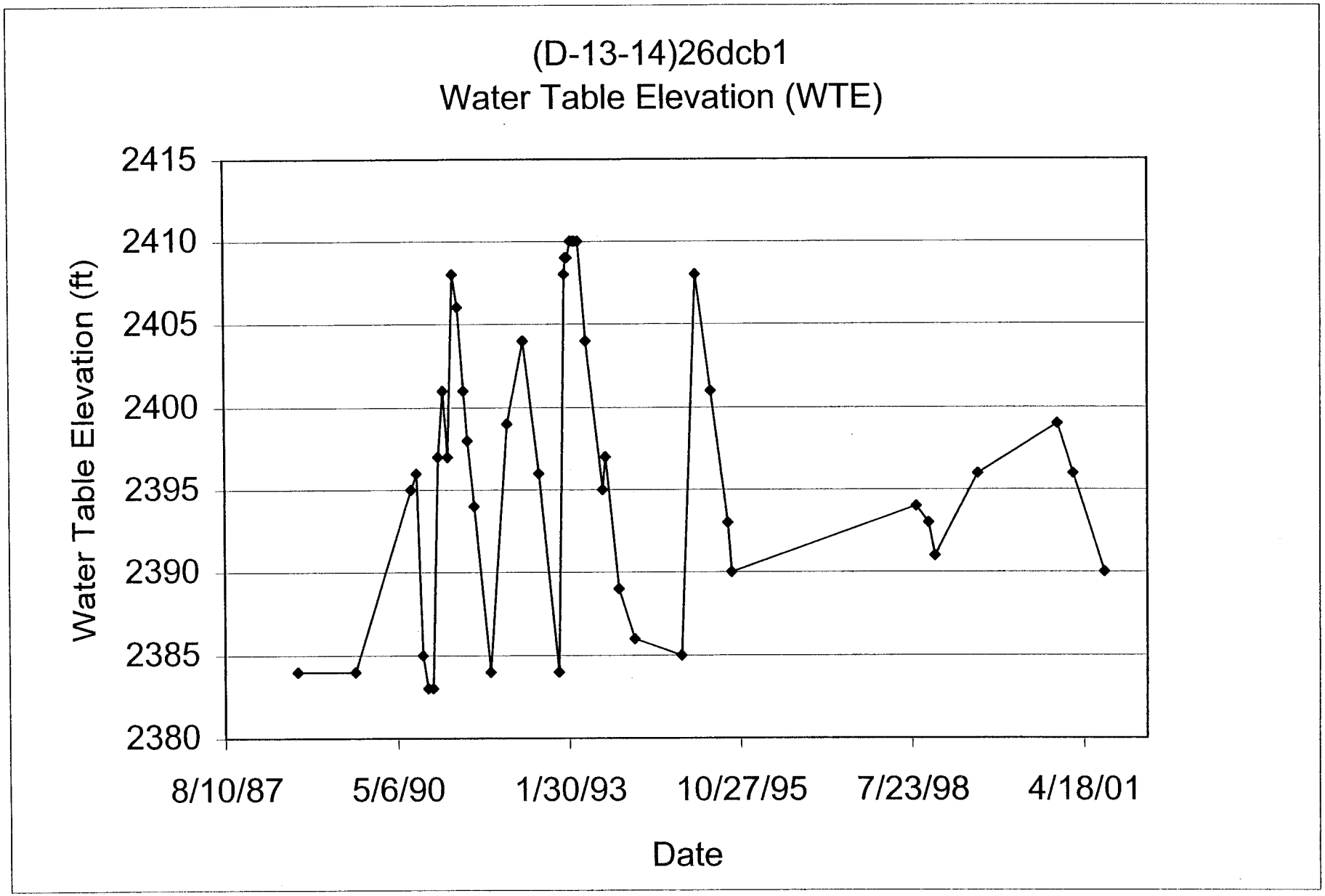

(D-13-14)26dac1
Depth to Water (DTW)
Depth to Water (ft)
35
30
25
20
15
10
5
0
11/14/84
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
Date

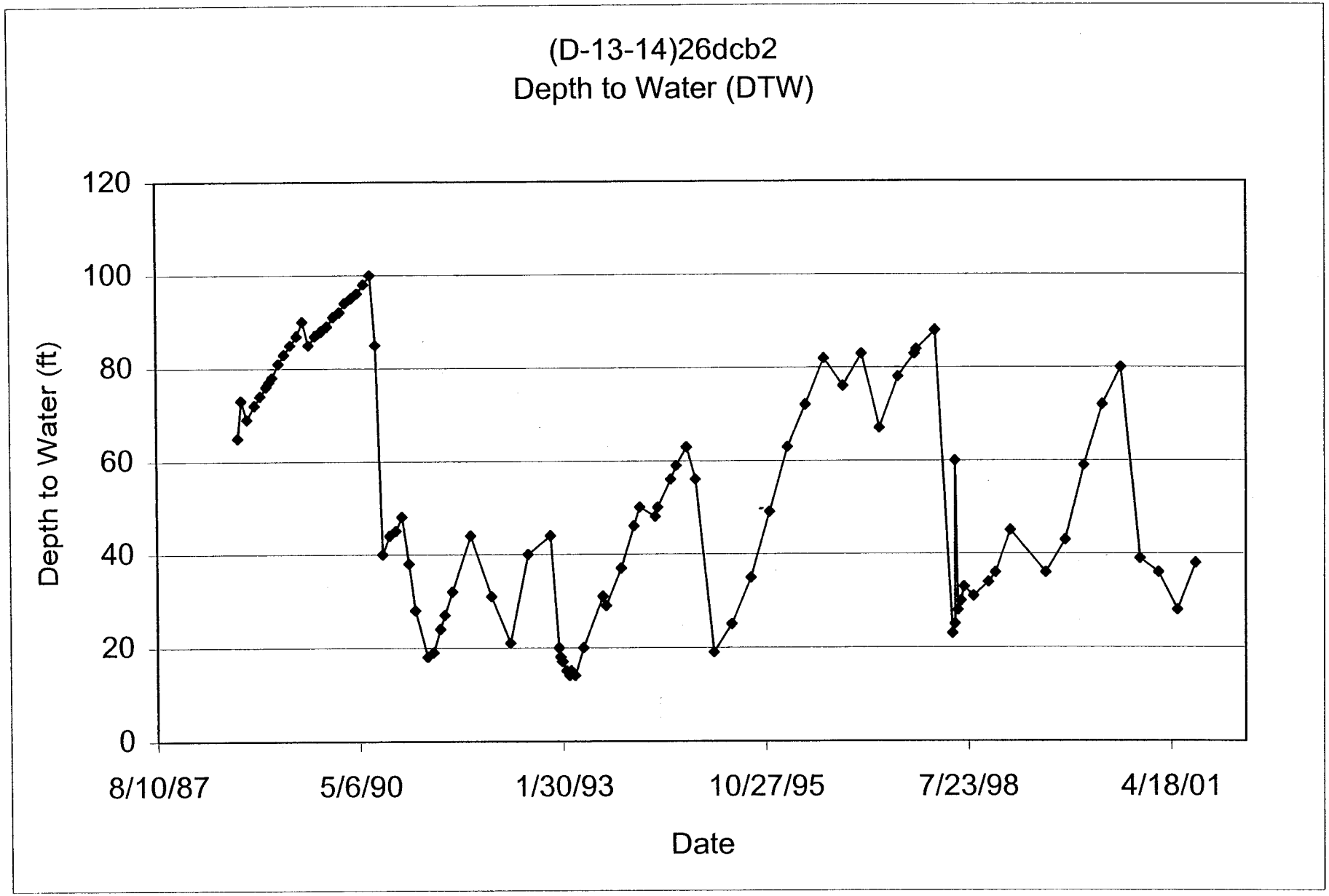

(D-13-14)26dac1
Water Table Elevation (WTE)
Water Table Elevation (ft)
2420
2415
2410
2405
2400
2395
11/14/84
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
Date

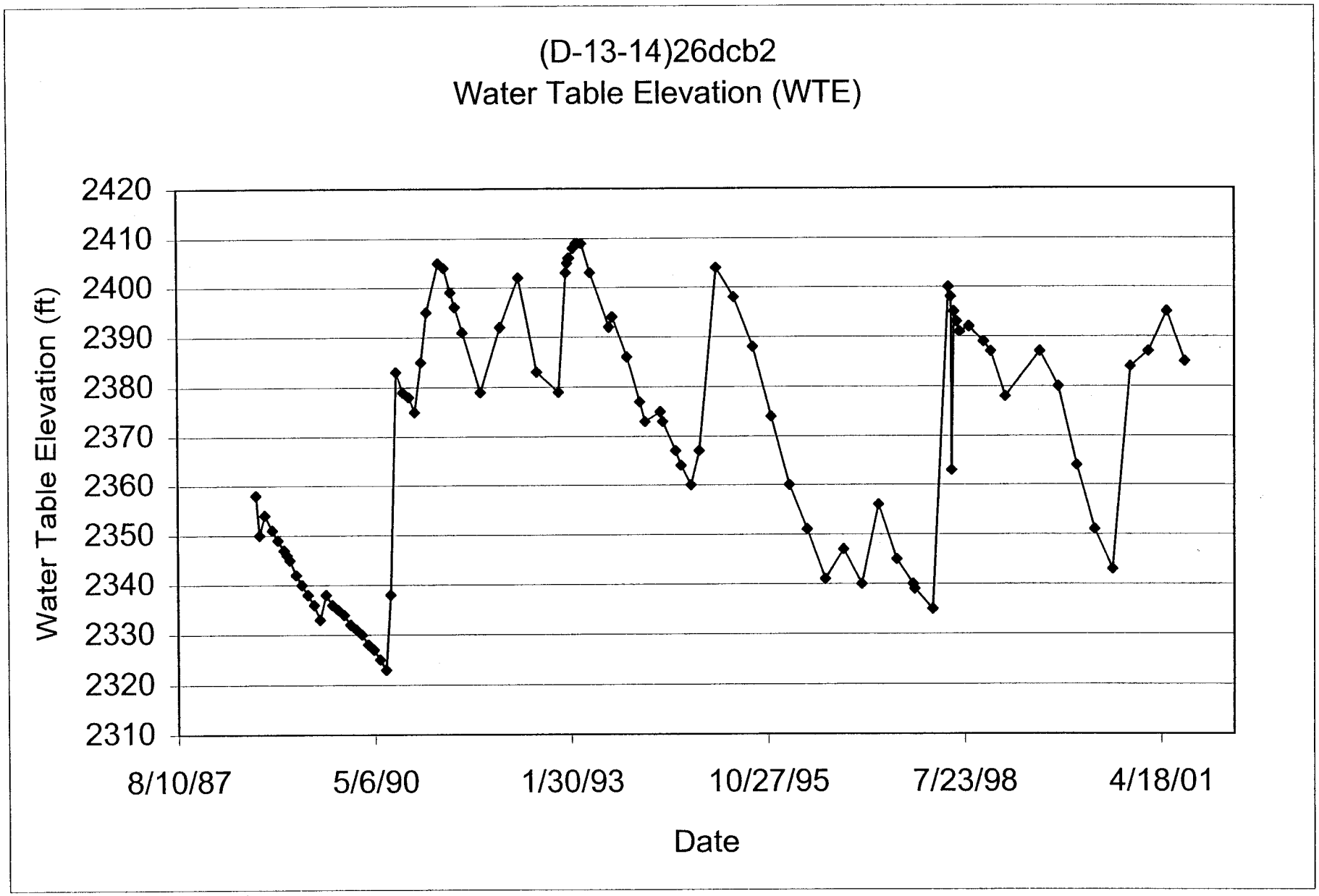

(D-13-14)26dac2
Depth to Water (DTW)
Depth to Water (ft)
35
30
25
20
15
10
5
0
11/14/84
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
Date

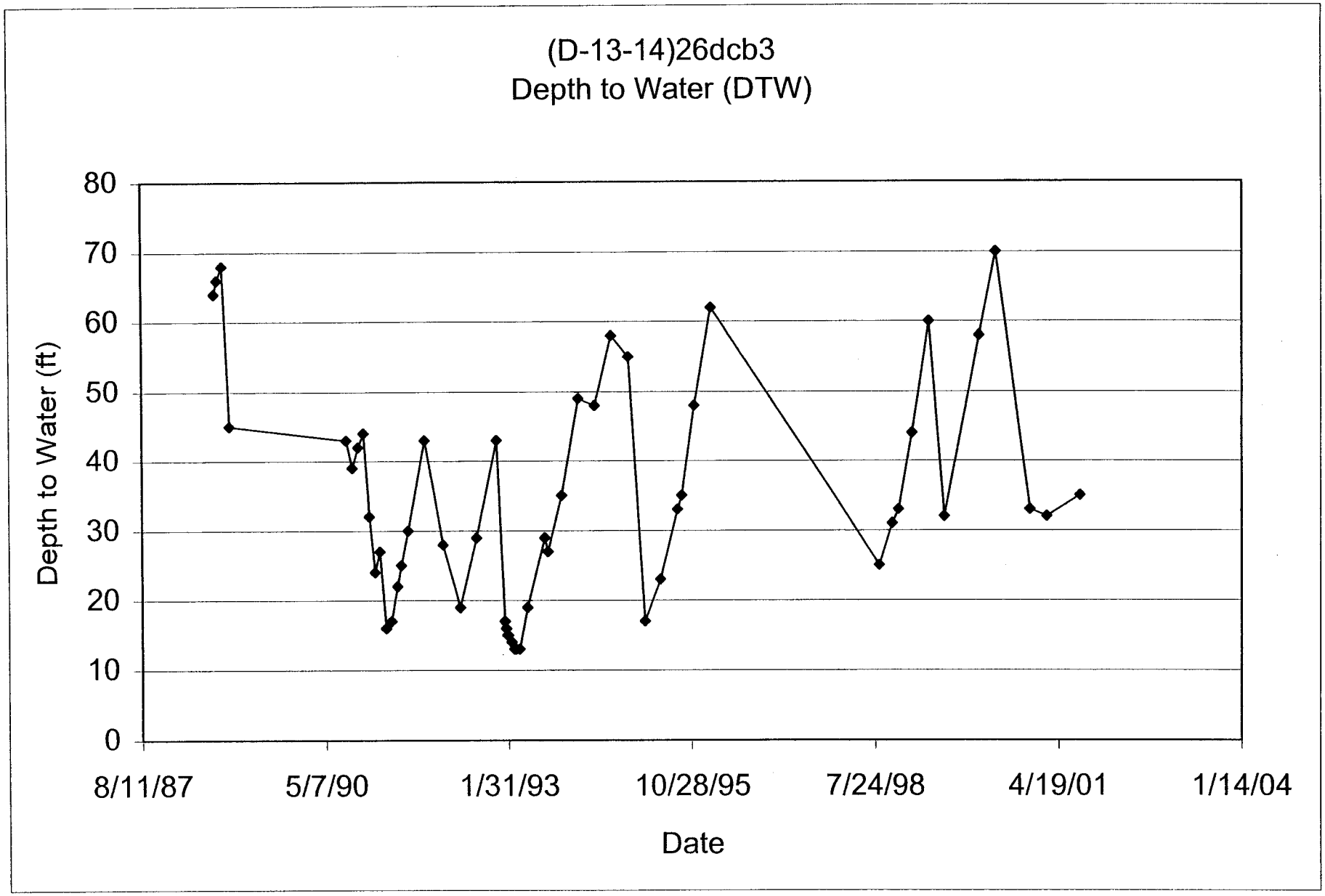

(D-13-14)26dac2
Water Table Elevation (WTE)
Water Table Elevation (ft)
2425
2420
2415
2410
2405
2400
2395
11/14/84
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
Date

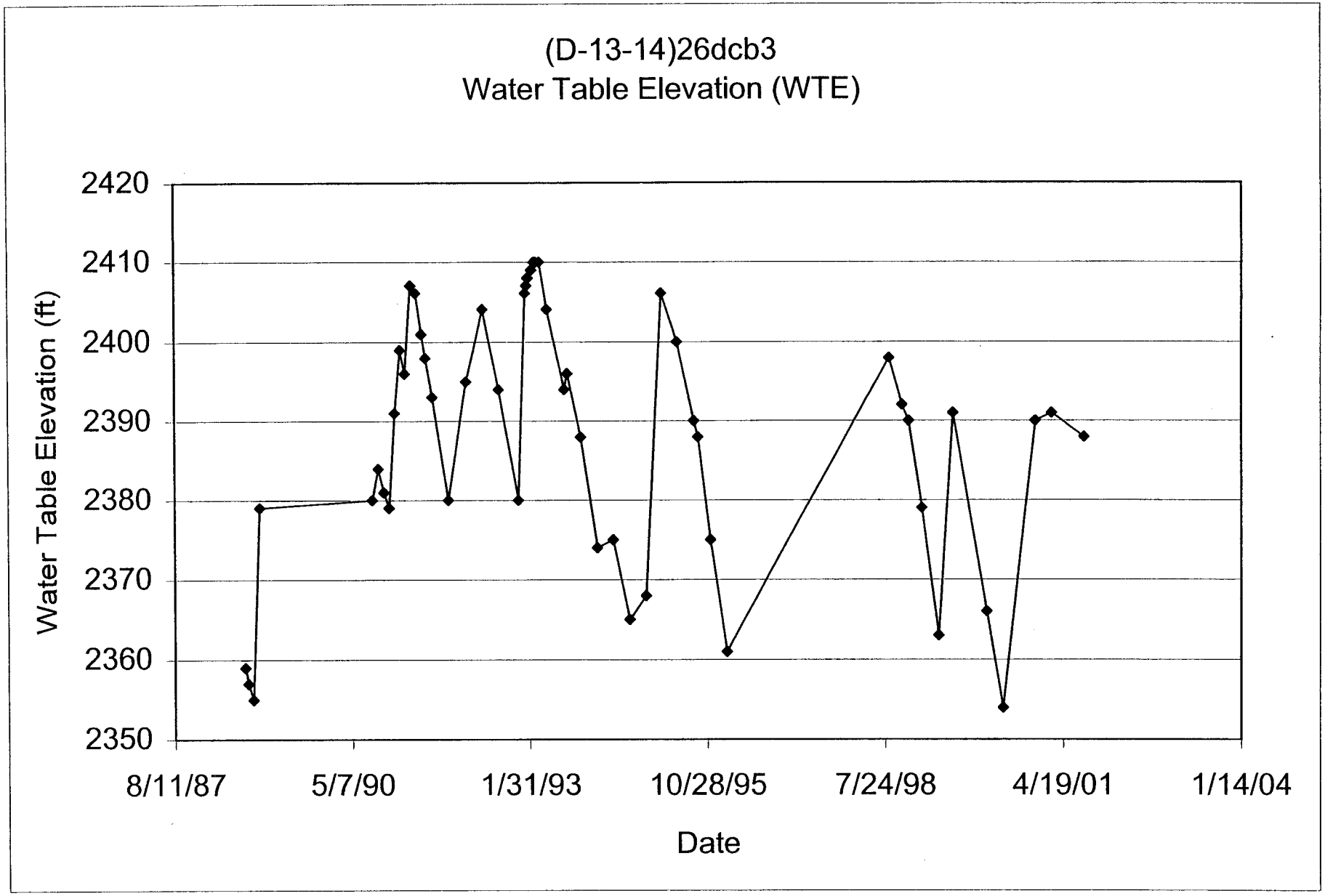

(D-13-14)26dcb1
Depth to Water (DTW)
Depth to Water (ft)
45
40
35
30
25
20
15
10
5
0
8/10/87
5/6/90
1/30/93
10/27/95
7/23/98
4/18/01
Date

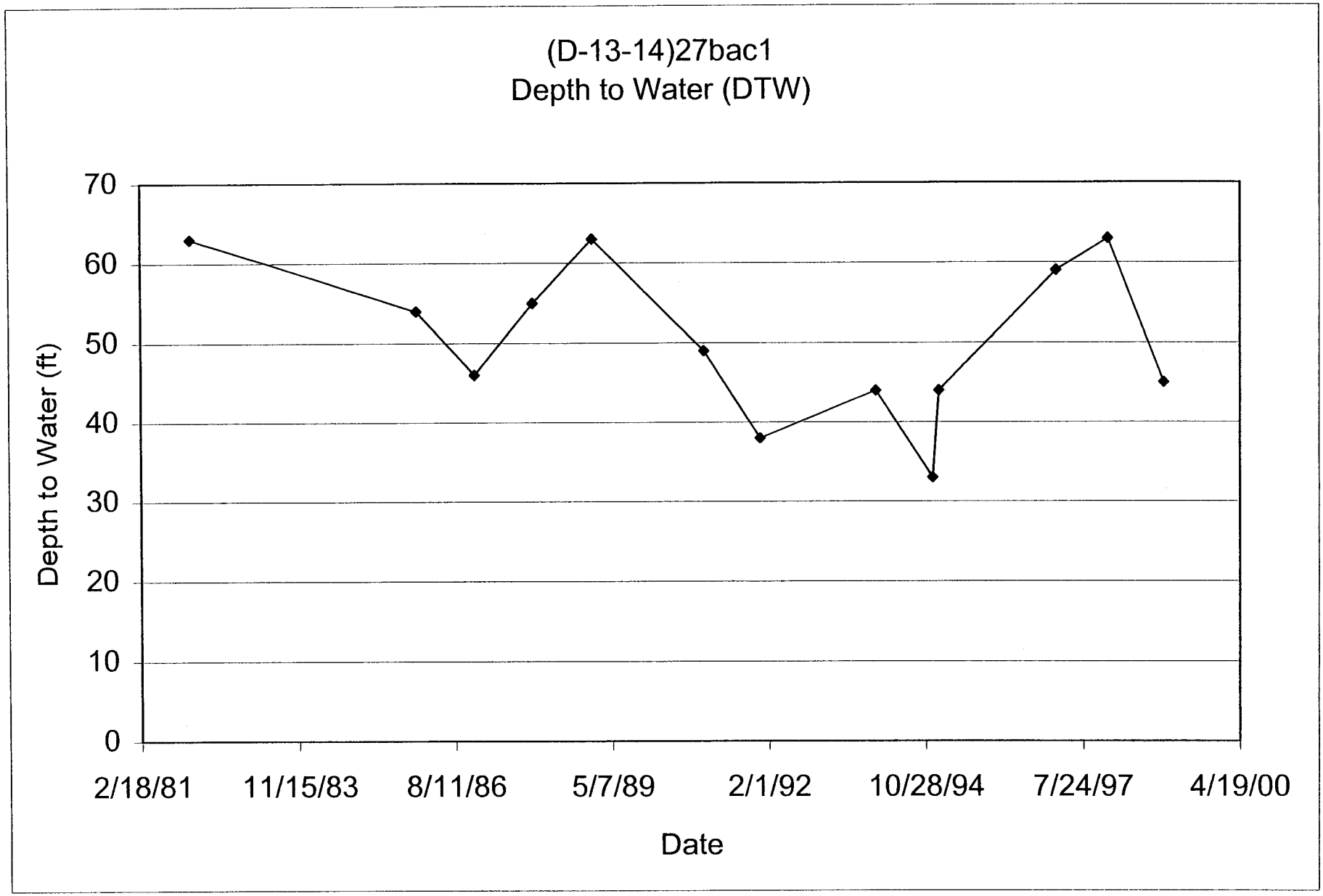

(D-13-14)26dcb1
Water Table Elevation (WTE)
Water Table Elevation (ft)
2415
2410
2405
2400
2395
2390
2385
2380
8/10/87
5/6/90
1/30/93
10/27/95
7/23/98
4/18/01
Date

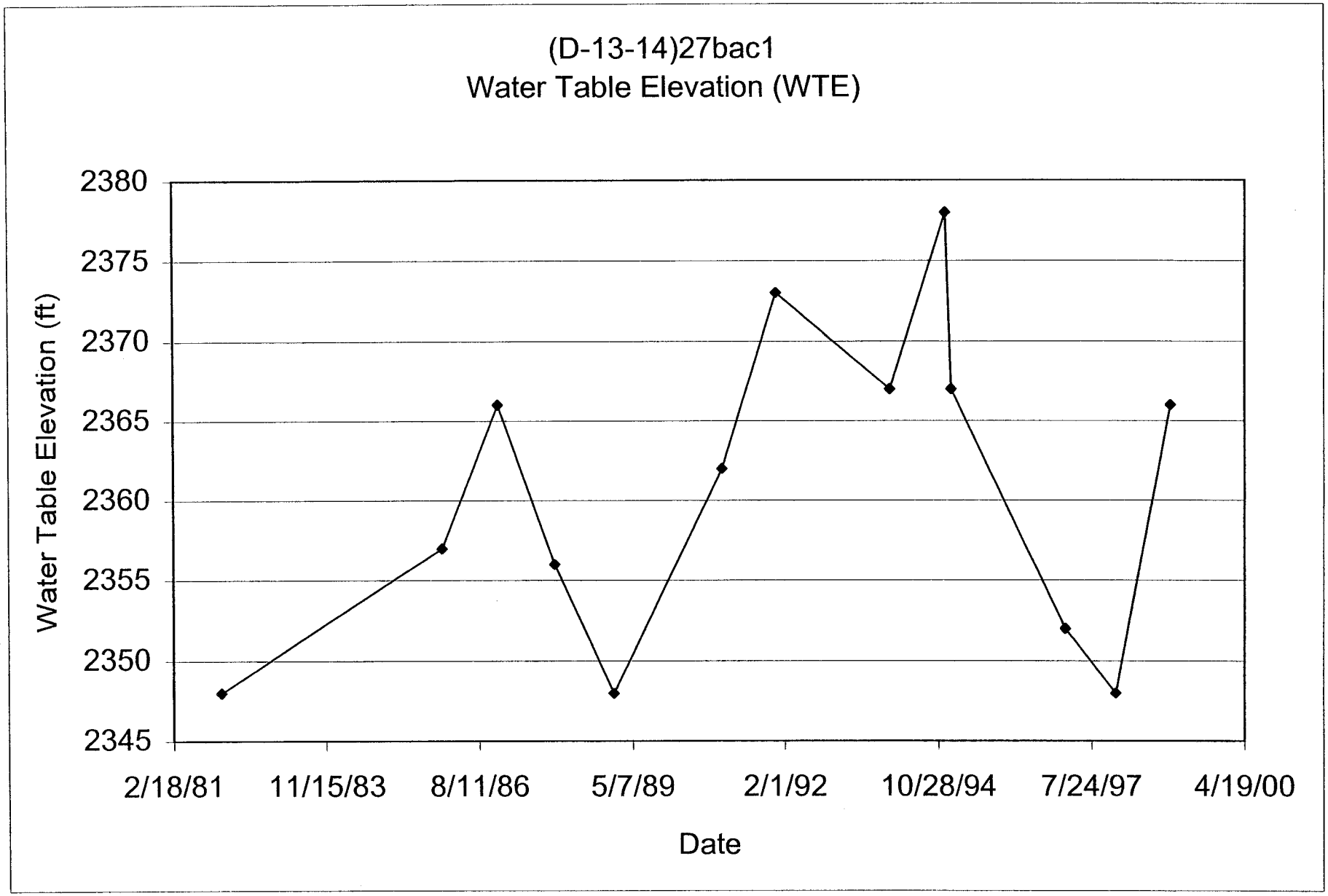

(D-13-14)26dcb2
Depth to Water (DTW)
Depth to Water (ft)
120
100
80
60
40
20
0
8/10/87
5/6/90
1/30/93
10/27/95
7/23/98
4/18/01
Date

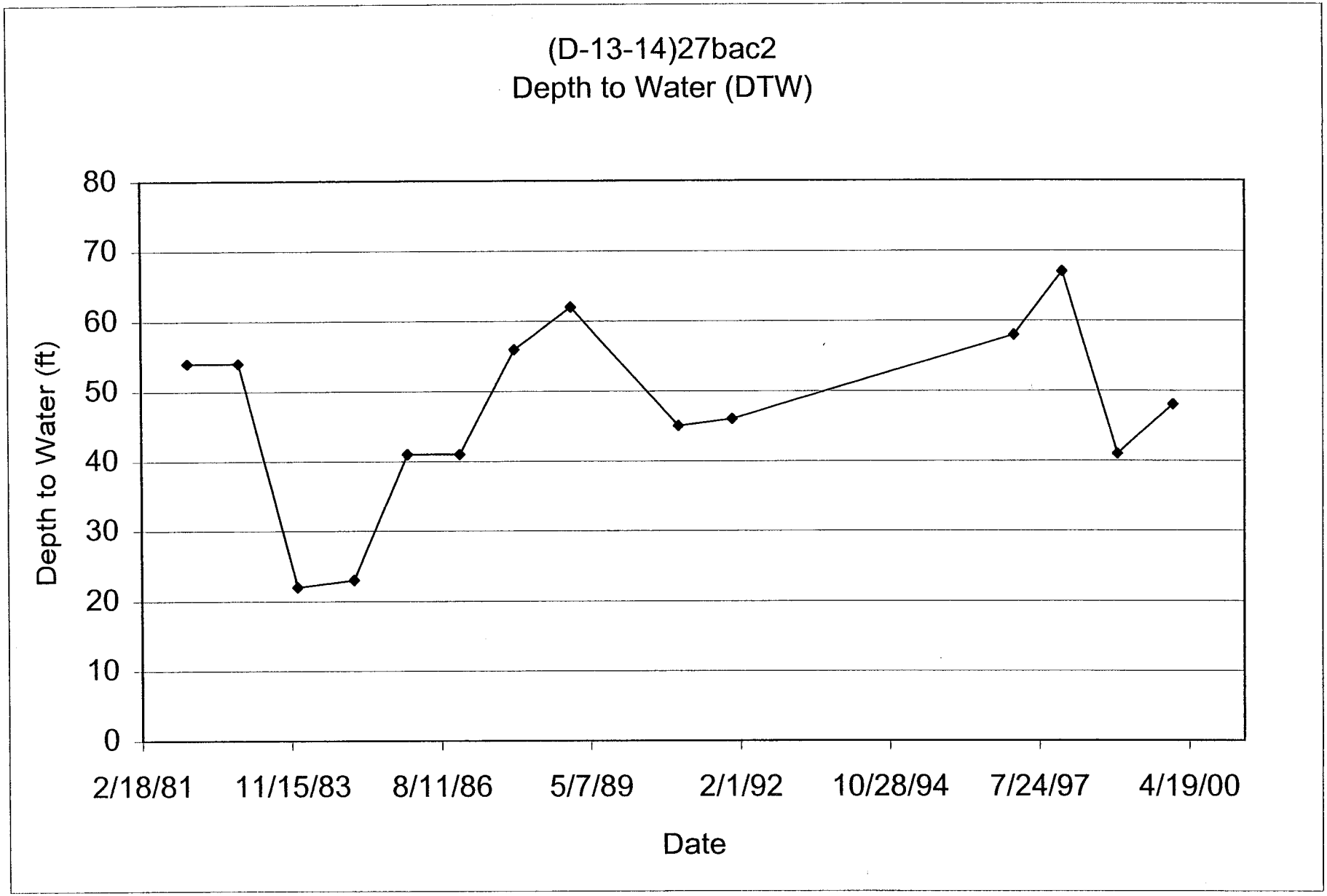

(D-13-14)26dcb2
Water Table Elevation (WTE)
Water Table Elevation (ft)
2420
2410
2400
2390
2380
2370
2360
2350
2340
2330
2320
2310
8/10/87
5/6/90
1/30/93
10/27/95
7/23/98
4/18/01
Date

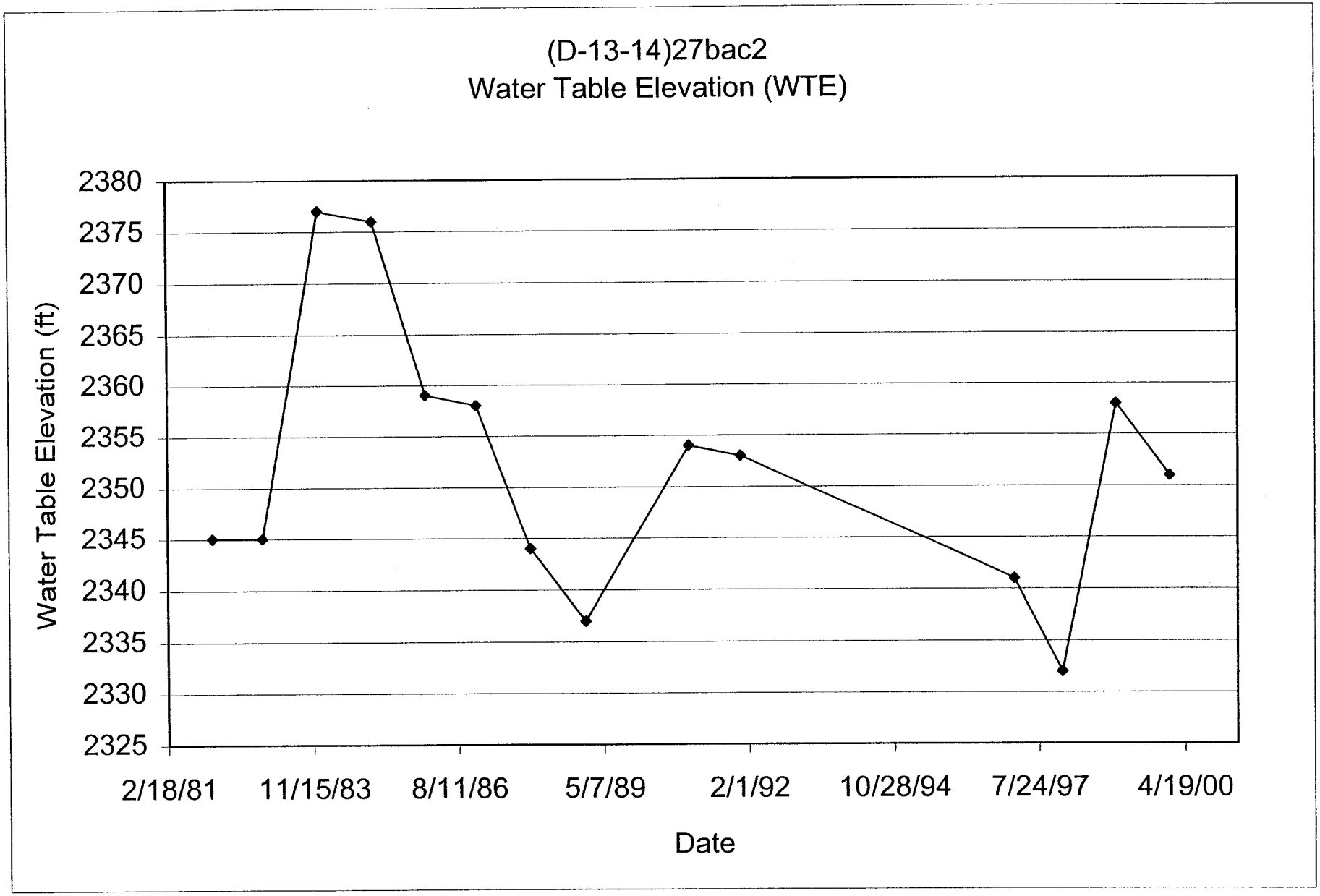

(D-13-14)26dcb3
Depth to Water (DTW)
Depth to Water (ft)
80
70
60
50
40
30
20
10
0
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
Date

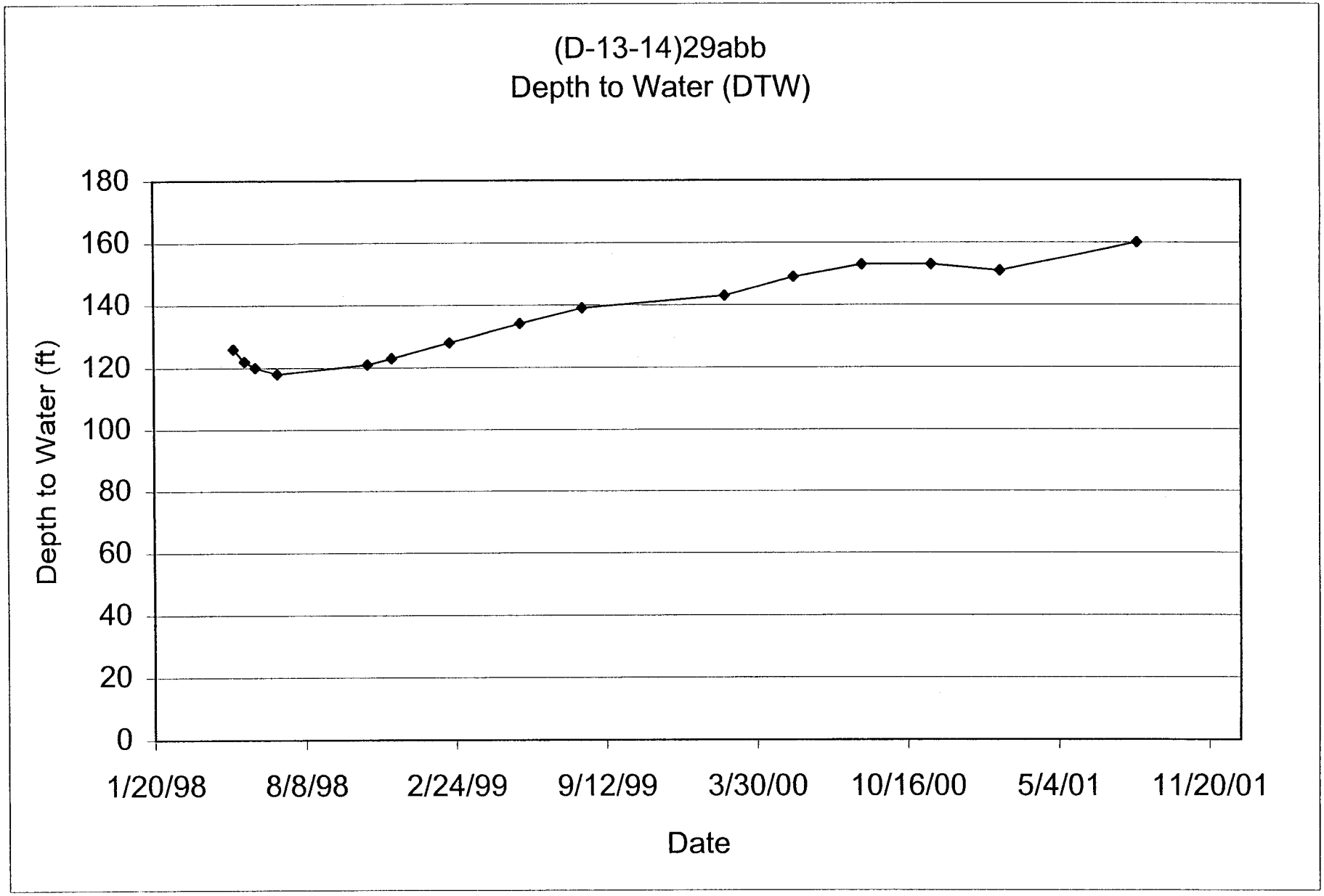

(D-13-14)26dcb3
Water Table Elevation (WTE)
Water Table Elevation (ft)
2420
2410
2400
2390
2380
2370
2360
2350
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
Date

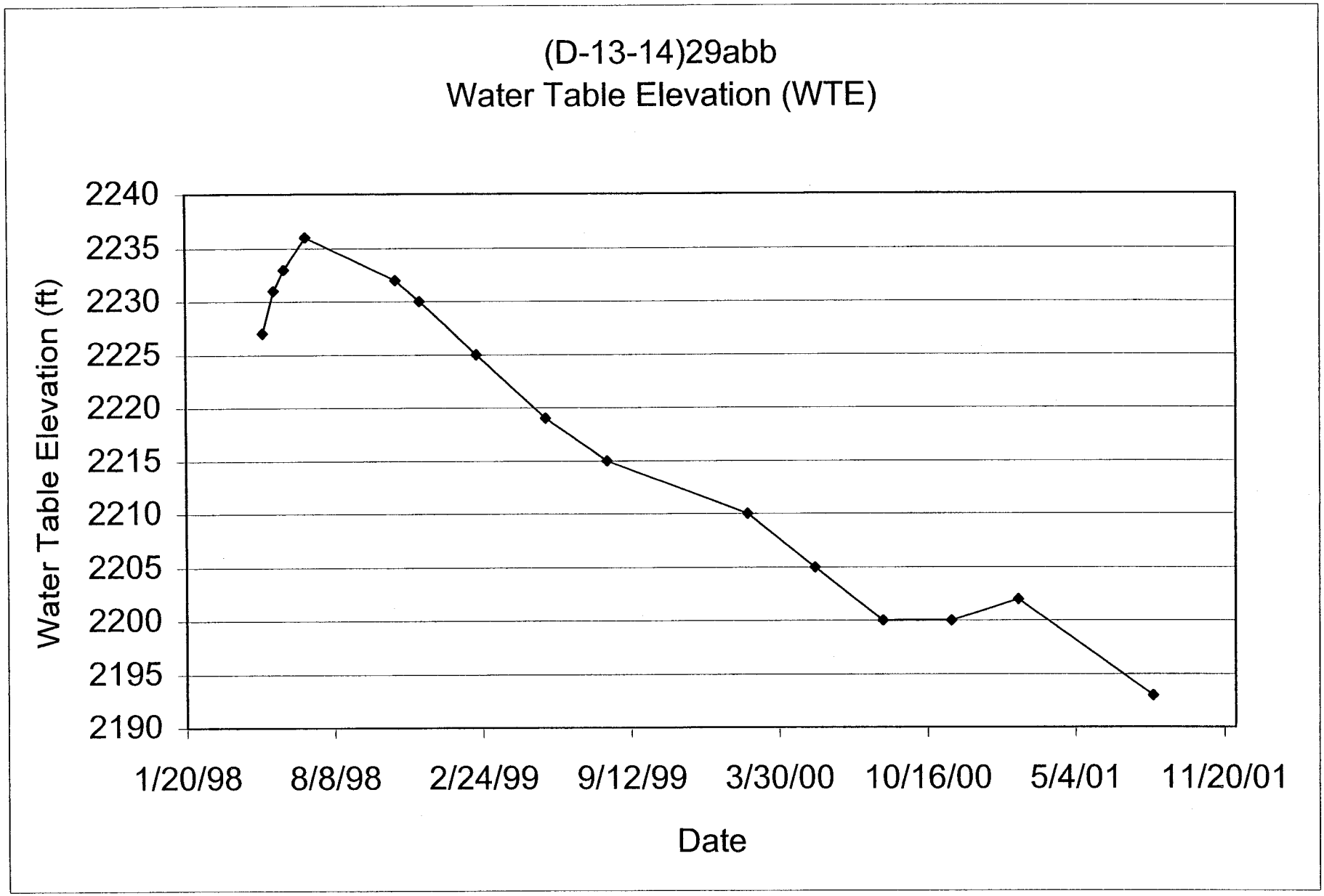

(D-13-14)27bac1
Depth to Water (DTW)
Depth to Water (ft)
70
60
50
40
30
20
10
0
2/18/81
11/15/83
8/11/86
5/7/89
2/1/92
10/28/94
7/24/97
4/19/00
Date


(D-13-14)27bac1
Water Table Elevation (WTE)
Water Table Elevation (ft)
2380
2375
2370
2365
2360
2355
2350
2345
2/18/81
11/15/83
8/11/86
5/7/89
2/1/92
10/28/94
7/24/97
4/19/00
Date


(D-13-14)27bac2
Depth to Water (DTW)
Depth to Water (ft)
80
70
60
50
40
30
20
10
0
2/18/81
11/15/83
8/11/86
5/7/89
2/1/92
10/28/94
7/24/97
4/19/00
Date


(D-13-14)27bac2
Water Table Elevation (WTE)
Water Table Elevation (ft)
2380
2375
2370
2365
2360
2355
2350
2345
2340
2335
2330
2325
2/18/81
11/15/83
8/11/86
5/7/89
2/1/92
10/28/94
7/24/97
4/19/00
Date


(D-13-14)29abb
Depth to Water (DTW)
Depth to Water (ft)
180
160
140
120
100
80
60
40
20
0
1/20/98
8/8/98
2/24/99
9/12/99
3/30/00
10/16/00
5/4/01
11/20/01
Date


(D-13-14)29abb
Water Table Elevation (WTE)
Water Table Elevation (ft)
2240
2235
2230
2225
2220
2215
2210
2205
2200
2195
2190
1/20/98
8/8/98
2/24/99
9/12/99
3/30/00
10/16/00
5/4/01
11/20/01
Date

APPENDIX B

Withdrawal Rates at ADWR Well Locations

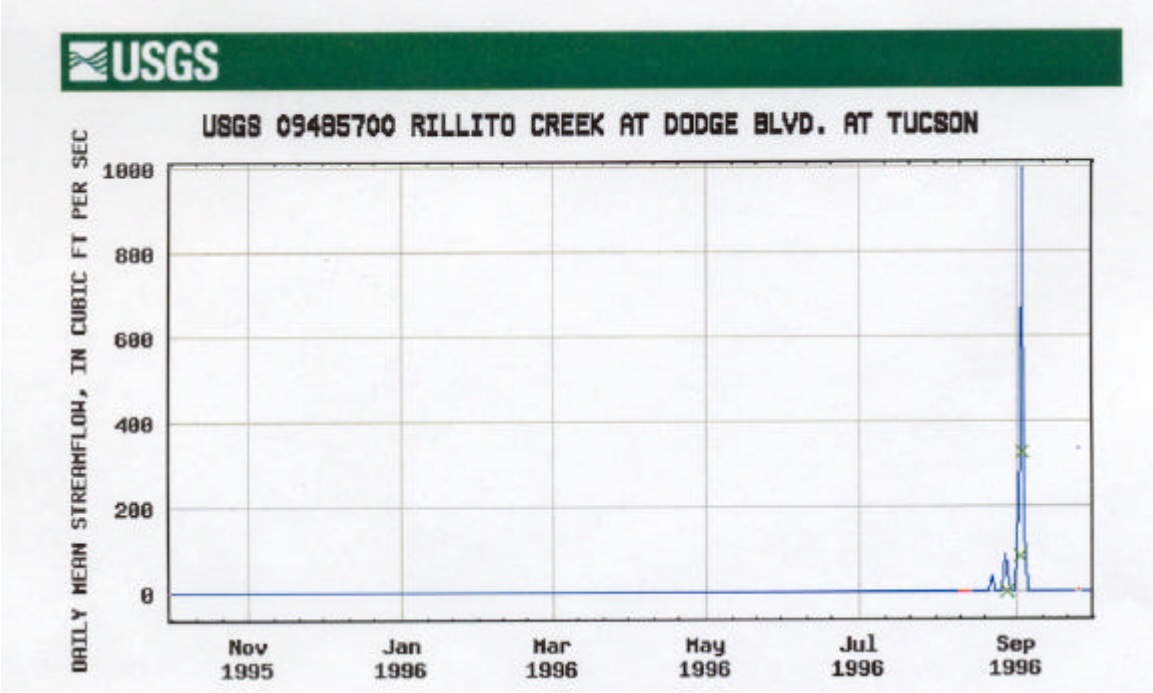
Total withdrawal from DWR wells
(ac-ft/yr)

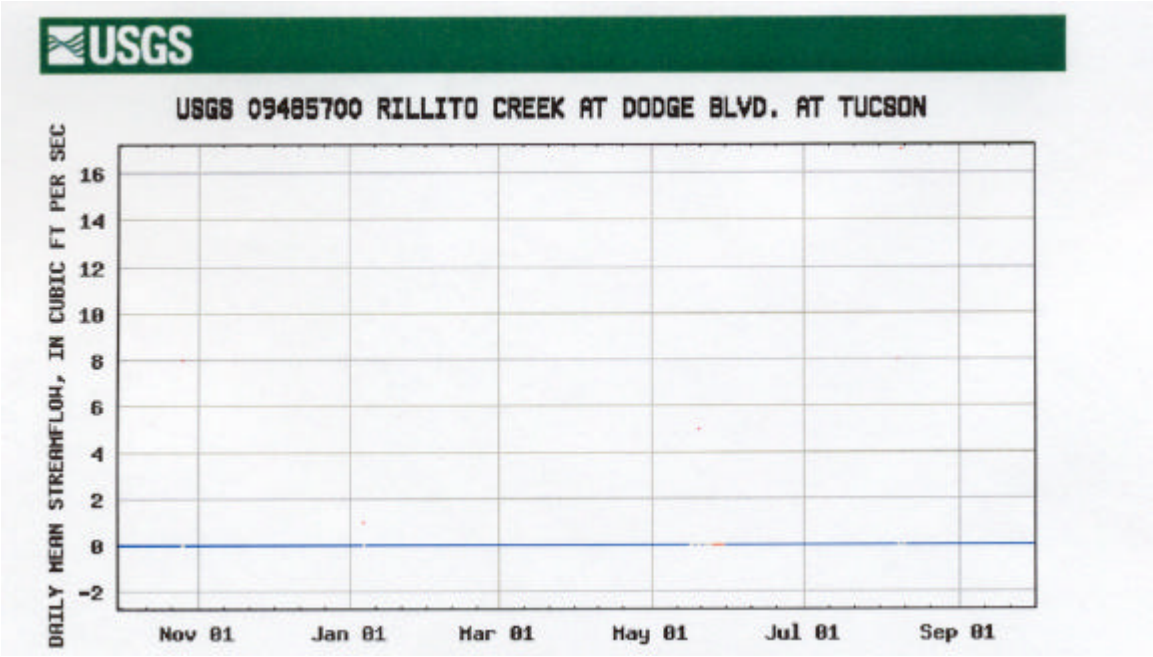
Year	(D-13-14)20cdd	(D-13-14)21cdc	(D-13-14)26dbd	(D-13-14)28abc	(D-13-14)28acc	(D-13-14)28ba0	(D-13-14)28bad	(D-13-14)28bca
	(non-exempt)	(non-exempt)	(non-exempt)	(non-exempt)	(non-exempt)	(non-exempt)	(non-exempt)	(non-exempt)
1995	41.67	9	16.18	2.54	1.42	7	10.06	8
1996	10.91	9	4.06	2.74	1.35	7	7	9
1997	8.51	9	9.92	2.79	1.28	4	4.77	8.5
1998	17.36	9	9.54	2.92	1.187	0	4.621	9
1999	5.35	9	4.38	0	0.404	7	7.23	0
2000	21.6	9	5.18	0	1.92	7	4.76	9

Year	(D-13-14)28bd0	(D-13-14)28bda	(D-13-14)29abb	(D-13-14)29abd	Total
	(non-exempt)	(exempt)	(non-exempt)	(non-exempt)	**(ac-ft/yr)**
1995	1.18	5.54	3.73	0	**106.32**
1996	1.01	5.37	3.16	0	**60.6**
1997	0.2	8.31	0.03	0.12	**57.43**
1998	0.33	10.61	0	6	**70.57**
1999	0.83	0	0.03	0.18	**34.4**
2000	0.09	0	2.43	0.6	**61.58**

APPENDIX C

USGS Streamflow Plots


USGS
USGS 09485700 RILLITO CREEK AT DODGE BLVD. AT TUCSON
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
1000
800
600
400
200
0
Nov 1995
Jan 1996
Mar 1996
May 1996
Jul 1996
Sep 1996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DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
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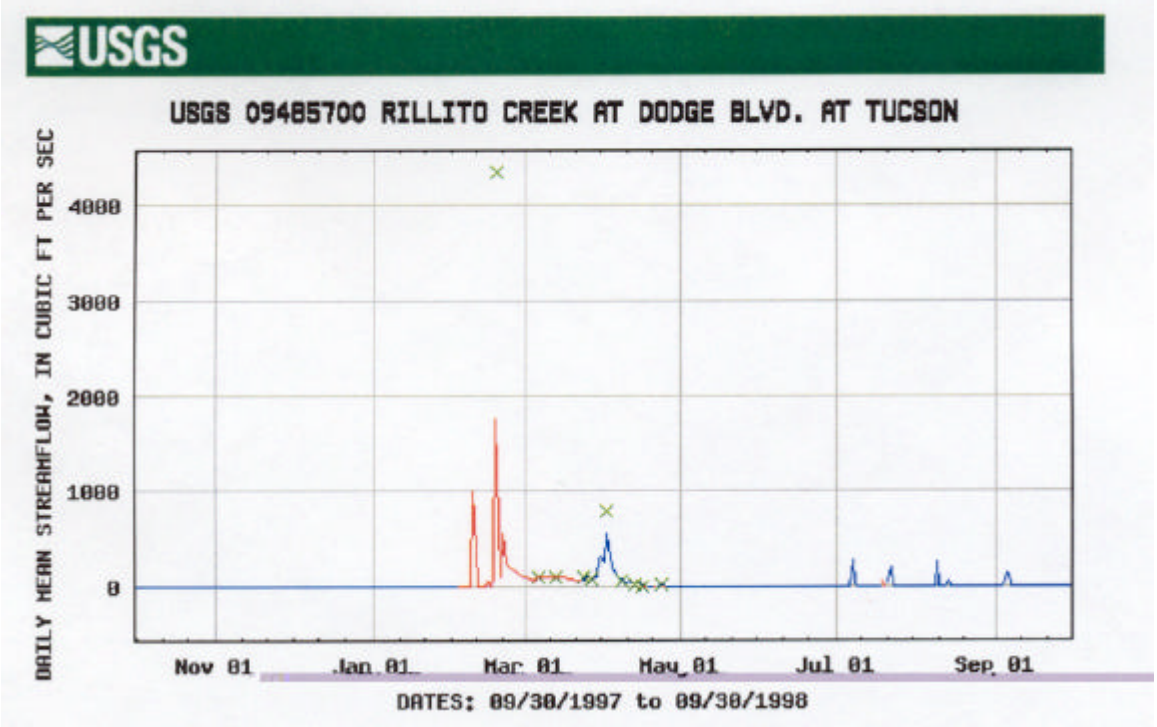
10
8
6
4
2
0
-2
Nov 01
Jan 01
Mar 01
May 01
Jul 01
Sep 01


USGS
USGS 09485700 RILLITO CREEK AT DODGE BLVD. AT TUCSON
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
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3000
2000
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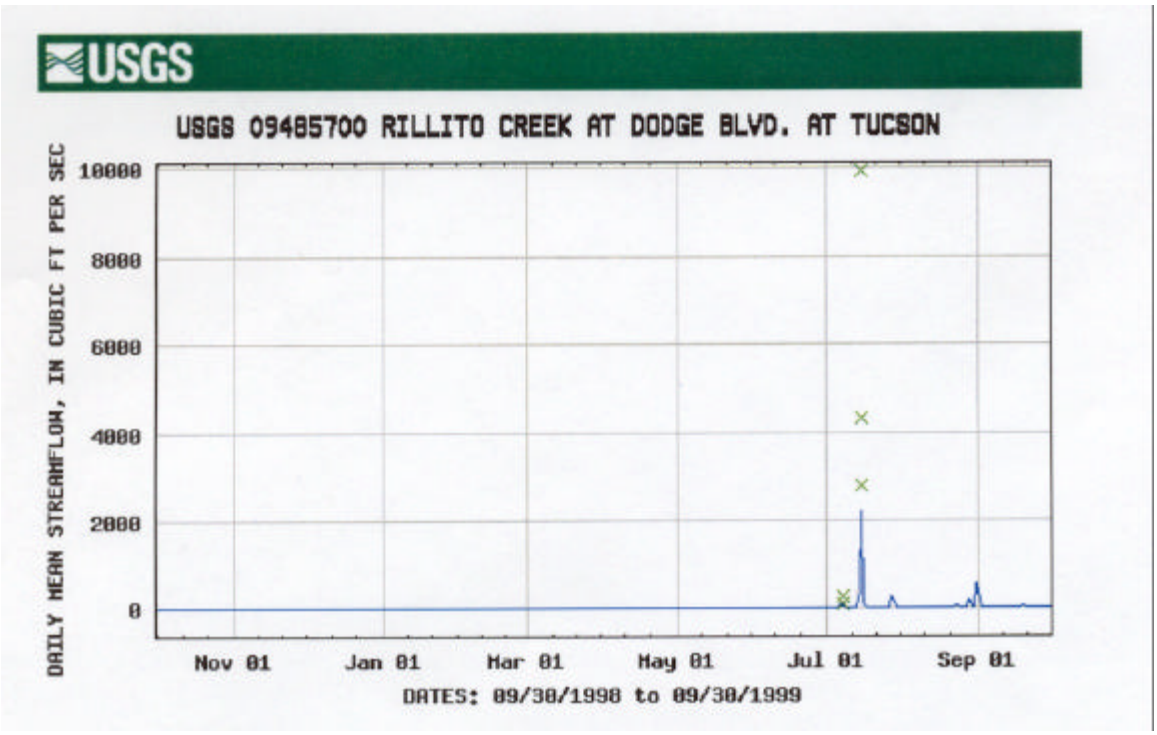
May 01
Jul 01
Sep 01
DATES: 09/30/1997 to 09/30/1998


USGS
USGS 09485700 RILLITO CREEK AT DODGE BLVD. AT TUCSON
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
10000
8000
6000
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2000
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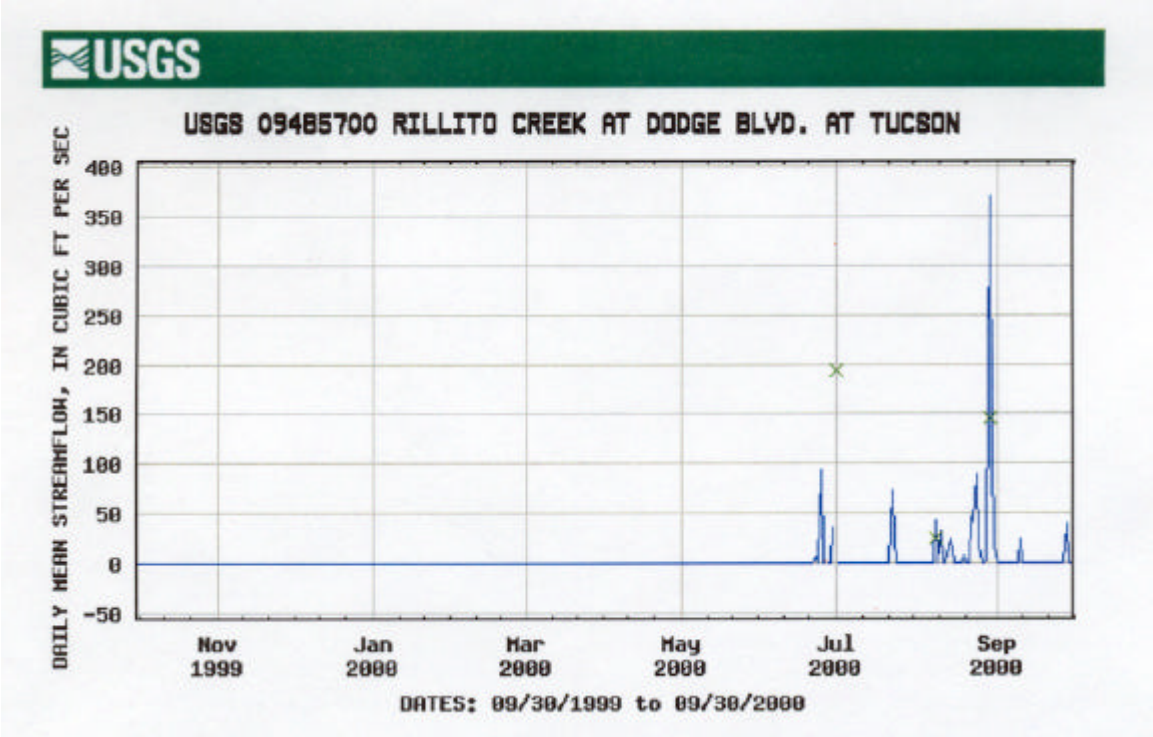
Mar 01
May 01
Jul 01
Sep 01
DATES: 09/30/1998 to 09/30/1999


USGS
USGS 09485700 RILLITO CREEK AT DODGE BLVD. AT TUCSON
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
400
350
300
250
200
150
100
50
0
-50
Nov 1999
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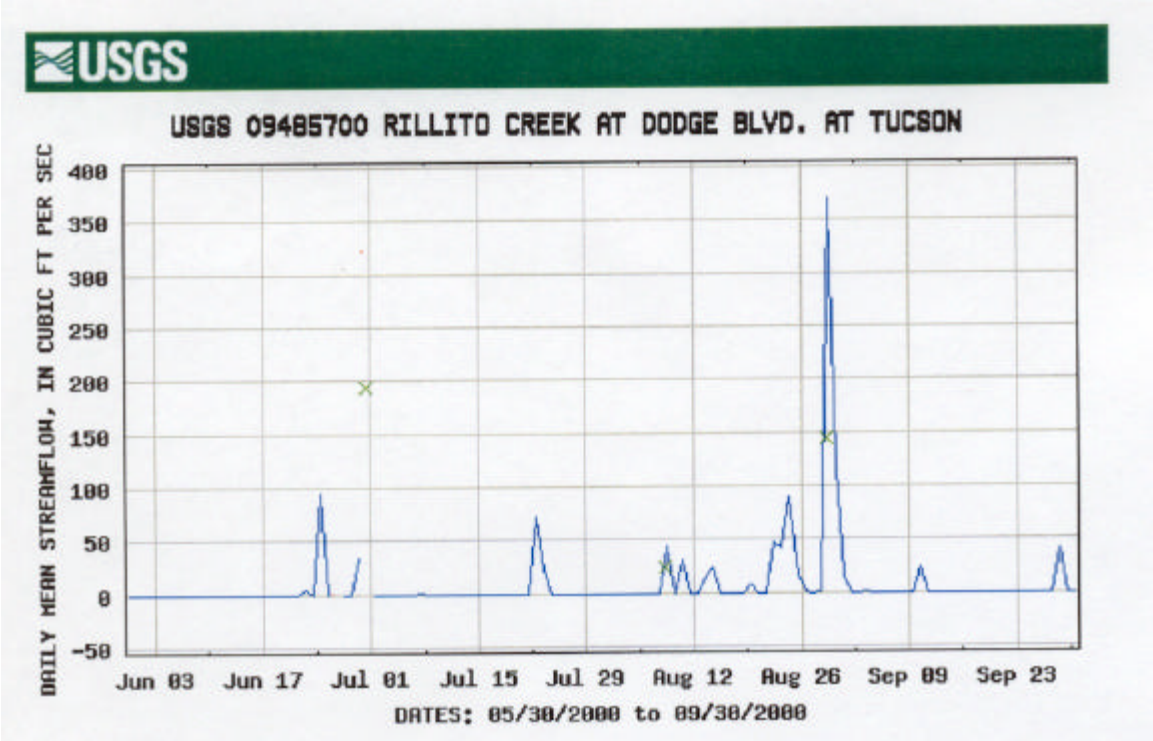
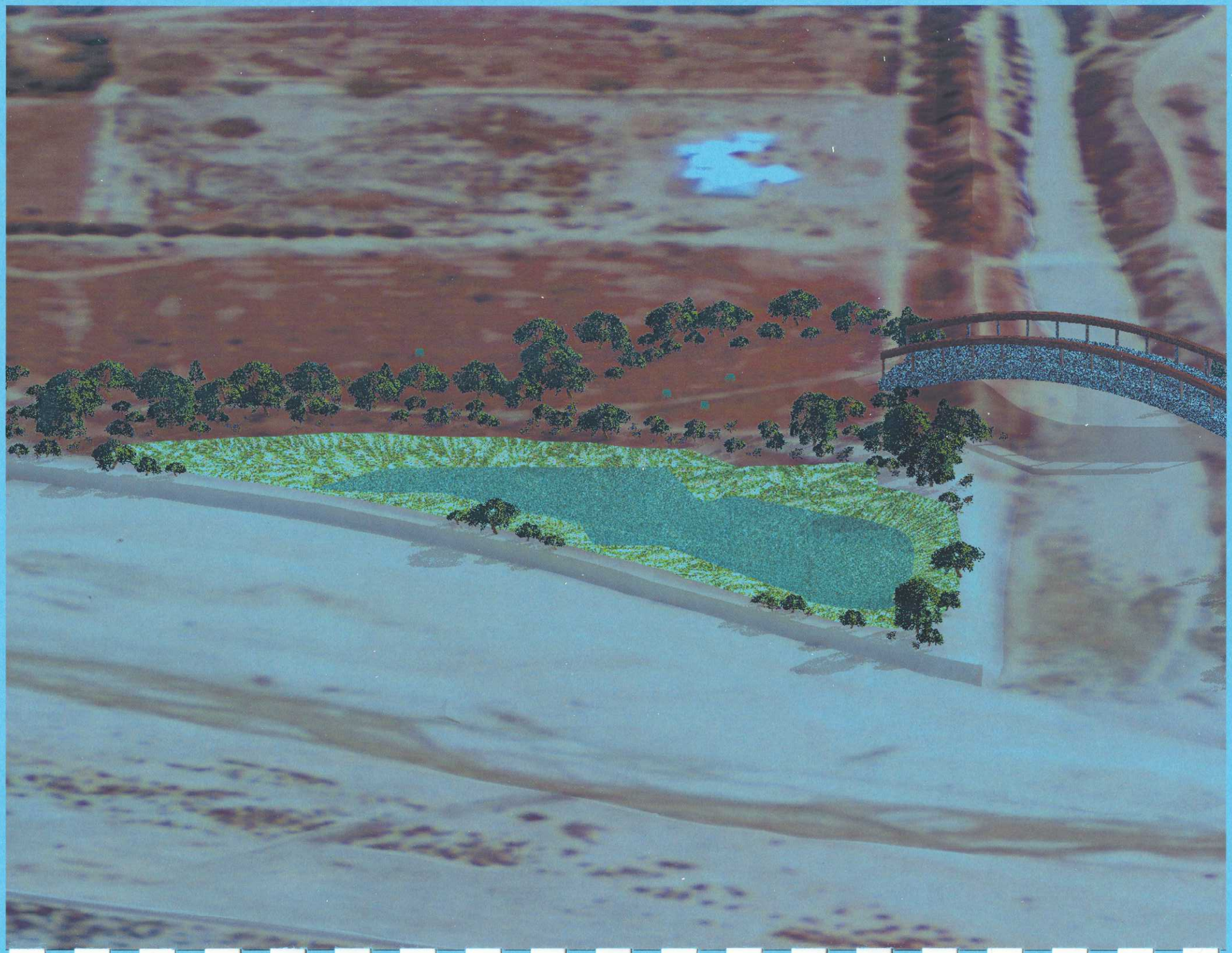
Mar 2000
May 2000
Jul 2000
Sep 2000
DATES: 09/30/1999 to 09/30/2000


USGS
USGS 09485700 RILLITO CREEK AT DODGE BLVD. AT TUCSON
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
400
350
300
250
200
150
100
50
0
-50
Jun 03
Jun 17
Jul 01
Jul 15
Jul 29
Aug 12
Aug 26
Sep 09
Sep 23
DATES: 05/30/2000 to 09/30/2000



El Rio Antiguo
Rillito River Environmental Restoration

ADDENDUM TO
DOCUMENTATION FOR HYDROLOGY & HYDRAULIC STUDIES

U.S. Army Corps of Engineers
Los Angeles District

Pima County Department of Transportation and Flood Control District
201 N. Stone Avenue
Tucson, Arizona 85701
May 9, 2002

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I. INTRODUCTION

This addendum presents results of additional analyses for Hydrology and Hydraulic Studies being performed in support of the feasibility study for the Rillito River Environmental Restoration (El Rio Antiguo) Project. The following sections describe the procedures and estimates of average annual and monthly streamflows for the Rillito River and tributaries joining the north and south bank, average annual groundwater inflow/outflow, and capacities of the storm drains entering the Rillito. These results will be used for the water budget analysis of this environmental restoration project.

II. AVERAGE ANNUAL/MONTHLY STREAMFLOW FOR RILLITO

The United States Geological Survey (USGS) currently operates streamflow gaging stations at two locations along the Rillito - at Dodge Boulevard (#9485700) since 1988, and near La Cholla Boulevard (#9486055) since 1990. However, USGS previously maintained since 1915 (until 1984) gaging a station (#9486000) near Pima Wash confluence between Oracle Road and Flowing Wells Road. Available long record (1915-1984) from this gaging station (#9486000) is used to estimate average monthly and annual flows for the Rillito and summarized in Table 1. It should be noted here that the variability of monthly flows are large, and for a given month, average monthly flow varies from a minimum of zero to several hundred cubic feet per second. Maximum, minimum and standard deviation of monthly flows are also listed in Table 1 to indicate this large variability. Note that standard deviations of monthly flows typically vary from about two times to eight times of corresponding mean values.

Table 1

Average Monthly Flows for the Rillito

Month	Maximum (cfs)	Minimum (cfs)	Standard Deviation (cfs)	Mean		
				(cfs)	(acre-ft)	% of annual
January	603	0	80	18	1105	10.9
February	203	0	46	21	1277	12.6
March	183	0	37	17	1044	10.3
April	13	0	2.8	0.89	51	0.5
May	69	0	8.8	1.1	71	0.7
June	9.7	0	1.9	0.54	30	0.3
July	500	0	84	29	1794	17.7
August	263	0	49	37	2301	22.7
September	302	0	44	17	1024	10.1
October	116	0	15	2.8	172	1.7
November	40	0	7.5	2.0	122	1.2
December	556	0	77	18	1135	11.2

Data source: Water Resources Investigations Report 98-4225, U.S. G. S., 1998, Ref. 3.

The average annual flow for the Rillito is 14 cfs or 10,135 acre-ft, with a standard deviation of 17 cfs or 12,307 acre-ft. The average annual flow has lower standard deviation and therefore is a more reliable estimate, compared to its monthly distribution which is subject to greater uncertainty.

III. AVERAGE ANNUAL/MONTHLY STREAMFLOW FOR TRIBUTARIES

III. 1. General

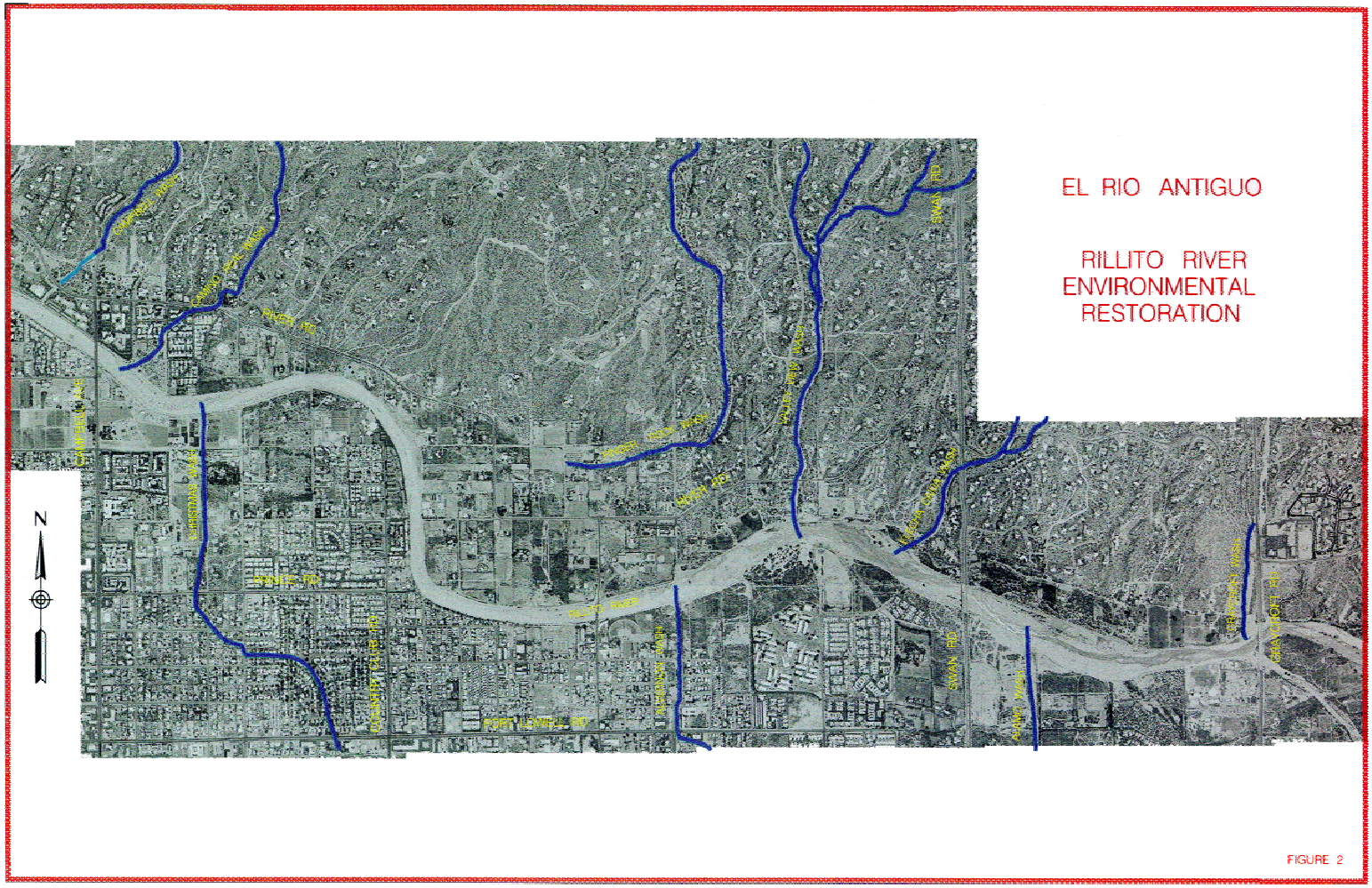
There are nine major tributaries joining the Rillito River in the study reach from Craycroft Road to Campbell Avenue. Six tributaries – Craycroft Wash, Flecha Caida Wash, Valley View Wash, Finger Rock Wash, Camino Real Wash and Campbell Wash – join the north bank, while three tributaries – Alamo Wash, Alvernon Wash and Christmas Wash – join the south bank of the Rillito. Locations of these tributaries are shown in Figure 1. Streamflow data are not available for any of these tributaries, except for a limited recorded data for the Alamo Wash (which comprises of annual peak discharge data only and therefore not suitable for the present analysis). As a result, available streamflow data from gaged watersheds with similar characteristics are analyzed to provide estimates of average monthly and annual runoff volumes for the nine tributaries shown in Figure 1.

As described in the "Hydrologic Documentation" (March, 2002), watersheds of tributaries joining the south bank are highly urbanized, while north bank tributaries have relatively natural watersheds. Because of this difference in characteristics, two groups of similar watersheds are selected and available streamflow data are analyzed to develop two different relations for average annual runoff volumes.

III. 2. Average Annual Runoff Volume

For the urbanized tributaries on the south bank, stream flow data from the following six gaged watersheds in Tucson area with similar physical characteristics are utilized: Airport Wash, Railroad Wash, Tucson Arroyo, High School Wash, Arcadia Wash and Atterbury Wash. Table 2 summarizes physical characteristics and runoff data for these six watersheds. Available streamflow data from these watersheds are analyzed to develop a regression relation between the average annual runoff volume and independent variables representing physical characteristics for the watersheds.

Figure 2


EL RIO ANTIGUO
RILLITO RIVER
ENVIRONMENTAL
RESTORATION
N
FIGURE 2

From a sensitivity analysis, it was found that drainage area alone was not a good indicator, but drainage area combined with impervious area (in fraction) were the most important explanatory variables. Based on this consideration, the following relation for urban watersheds were obtained from multiple regression analysis:

$$AAR_u = 67.29 + 87.56\,(IA) + 17.30\,(IA)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where AAR_u = Average annual runoff for urban watersheds in acre-ft

A = Drainage area, in sq. miles

I = Impervious area, in fraction

Eq. (1) has a correlation coefficient of 0.985 and a standard deviation of 43.47. Average annual runoff volumes for the three south bank tributaries are estimated using Eq. (1) and summarized in Table 3.

Table 2

Watershed Characteristics

Watershed/Station	Drainage Area (sq. mile)	Mean Basin Elevation (ft)	Forested Area (%)	Impervious Area (%)	Mean Annual Rainfall (in)	Mean Annual Runoff			
						cfs	Inch	Acre-ft	Percent of Rainfall
Airport Wash (9482400)	23.0	2700	1.1	9.1	10.8	0.43	0.25	311.3	2.3
Railroad Wash (9482950)	2.3	2490	0.0	51.6	11.0	0.21	1.24	152.0	11.3
Tucson Arroyo (at Vine Ave) (9483000)	8.2	2510	0.0	45.5	11.0	0.88	1.46	637.1	13.3
High School Wash (9483010)	0.95	2460	0.0	38.5	11.0	0.11	1.57	79.6	14.3
Arcadia Wash at Tucson (9485550)	2.72	2560	0.0	49.8	11.0	0.36	1.80	260.7	16.4
Atterbury Wash at Tucson (9485390)	4.97	-	-	13.3	11.0	0.23	0.63	166.5	5.7
Tanque Verde Creek near Tucson ((9483100)	43.0	4780	21.0	-	17.0	8.90	2.81	6,443.3	16.5
Sabino Creek near Tucson (9484000)	35.5	6300	85.0	-	22.6	14.0	5.35	10,135.5	23.7
Bear Creek near Tucson (9484200)	16.3	5860	82.0	-	20.6	4.7	3.91	3,402.6	19.0
Tanque Verde Creek at Tucson (9484500)	219.0	4340	36.0	-	16.7	33.0	2.04	23,890.9	12.2
Rincon Creek near Tucson (9485550)	44.8	4850	57.0	-	19.2	7.0	2.12	5,067.8	11.0

Table 3
Average Annual Runoff for South Bank Tributaries

Watershed	Drainage Area (sq. miles)	Impervious Area (%)	Average Annual Runoff (acre-ft)
Alamo Wash	9.90	46.8	844.3
Alvernon Wash	3.32	53.7	278.4
Christmas Wash	3.32	45.1	237.2

For North bank tributaries which have relatively natural or rural watersheds, stream flow data from the following five gaged watersheds in Tucson area having similar physical characteristics are utilized:

Tanque Verde Creek near Tucson, Sabino Creek near Tucson, Bear Creek near Tucson, Tanque Verde Creek at Tucson and Rincon Creek near Tucson. Physical and runoff characteristics for these watersheds are summarized in Table 2. It was found that drainage area and mean basin rainfall were the most important independent variables for estimating average annual runoff for these watersheds. Based on this consideration, the following relation is developed for north bank tributaries using multiple regression analysis:

$$AAR_n = 0.252\ A^{0.924}\ P^{2.291} \quad \ldots\ldots \quad (2)$$

where AAR_n = Average annual runoff for natural watersheds, in acre-ft.

A = Drainage area, in sq. miles

P = Mean basin annual rainfall, in inches

Eq. (2) has correlation coefficient of 0.954. Average annual runoff for the six north bank tributaries are estimated using Eq. (2) and summarized in Table 4. Basin rainfalls for the tributaries in Table 4 are estimated as average value of the annual rainfall recorded at two stations: # 2160 (Sabino Creek at Dam) and # 2170 (Ventana Wash at Skyline). These two stations are the nearest to the tributary watersheds and are part of the Pima County ALERT network.

Table 4

Average Annual Runoff for North Bank Tributaries

Watershed	Drainage Area (sq. mile)	Basin Rainfall (inch)	Average Annual Runoff (acre-ft)
Craycroft Wash	3.07	12.73	241.4
Flecha Caida Wash	1.47	12.73	122.2
Valley View Wash	4.11	12.73	316.0
Finger Rock Wash	6.09	12.73	454.5
Camino Real Wash	1.86	12.73	151.9
Campbell Wash	2.50	12.73	199.6

III. 3. Average Monthly Runoff Volume

A review of the average monthly flows for the Rillito and the gaged watersheds used in the analysis in Section III. 2, indicates that variability of monthly flows are very large. As an example, this can be seen from Table 1, which shows that standard deviations of monthly flows are two to eight times the corresponding mean values. Consequently, any attempt to develop relations for monthly flows similar to Eq. (1) or Eq. (2) is likely to yield unreliable estimates. An alternative approach involves estimating monthly distributions as percent of annual runoff volumes from the available records for the gaged watershed analyzed in Section III. 2, and then apply them to get monthly values from the annual values estimated in Section III.2. This approach, though approximate but relatively more reliable, will be utilized in the following analysis.

From the available stream flow record, average monthly runoff values expressed as percent of average annual runoff are summarized in Table 5 for the six urban watersheds used in Section III.2 for developing Eq. (1). Similarly, Table 6 summarizes the corresponding values for the five natural watersheds. Average values indicated for each month at the bottom row of Tables 5 and 6 are combined with average annual runoff values given in Tables 3 and 4, respectively, to estimate average monthly values for each of the eleven watersheds, and the results are summarized in Table 7.

Table 5

Average Monthly Runoff as Percent of Average Annual Runoff for Urban Watersheds

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Airport Wash*	1.7	2.6	1.2	0.4	0.1	0.2	38.0	16.0	23.5	10.6	2.0	3.7	100.0
Railroad Wash**	13.3	7.7	3.7	0.4	0.36	2.0	15.4	15.4	20.7	10.9	3.7	7.7	100.0
Tucson Arroyo*	5.4	4.8	3.5	0.8	0.7	1.0	26.4	27.8	10.2	7 .8	4.2	7.5	100.0
High School Wash*	9.5	5.6	7.1	1.2	1.4	1.5	17.8	20.9	17.4	8 .0	4.0	5.7	100.0
Arcadia Wash**	10.1	14.9	9.2	0.3	1.9	2.0	9.7	23.3	18.7	2.6	3.0	4.0	100.0
Atterbury Wash**	12.2	7.0	7.4	0.11	1.6	1.0	11.1	17.0	32.2	2.4	2.1	5.2	100.0
Average	8.7	7.1	5.4	0.5	1.0	1.3	19.7	20.1	20.5	7.1	3.2	5.6	100.0

* Data from Water Resources Investigations Report 98-4225, U.S.G.S., 1998, Ref. 3.

** Data from U.S.G.S. web site: http://waterdata.usgs.gov/az/nwis/monthly/

Table 6

Average Monthly Runoff as Percent of Average Annual Runoff for Natural Watersheds

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Tanque Verde Creek (near Tucson)	13.8	19.8	14.0	3.2	0.3	0.1	3.0	7.7	9.0	4.3	1.9	23.1	100.0
Sabino Creek	16.5	17.4	21.6	7.7	1.3	0.3	3.6	8.4	6.0	2.7	2.6	11.9	100.0
Baer Creek	18.0	21.8	15.6	3.7	0.4	0.0	1.2	3.2	6.4	5.6	1.8	22.4	100.0
Tanque Verde Creek (at Tucson	42.0	17.0	21.0	4.0	0.27	0.0	0.37	0.78	0.12	0.03	1.0	13.0	100.0
Rincon Creek	23.9	18.2	16.1	3.7	0.2	0.1	4.3	13.6	4.0	1.9	1.3	12.7	100.0
Average	22.8	18.8	17.7	4.5	0.5	0.1	2.5	6.7	5.1	2.9	1.7	16.6	100.0

Data source: Water Resources Investigations Report 98-4225, U.S.G.S., 1998, Ref. 3.

Table 7

Average Monthly Runoff (Acre-ft) for Tributaries

Watershed	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North Bank:													
Craycroft Wash	55.0	45.4	42.7	10.9	1.2	0.2	6.0	16.2	12.3	7.0	4.1	40.0	241.4
Flecha Caida Wash	27.9	23.0	21.6	5.5	0.6	0.1	3.1	8.2	6.2	3.5	2.1	20.3	122.2
Valley View Wash	72.0	59.4	55.9	14.2	1.6	0.3	7.9	21.2	16.1	9.2	5.4	52.4	316.0
Finger Rock Wash	103.6	85.4	80.4	20.4	2.3	0.5	11.4	30.4	23.2	13.2	7.7	75.4	454.5
Camino Real Wash	34.6	28.5	26.9	6.8	0.8	0.2	3.8	10.2	7.7	4.4	2.6	25.2	151.9
Campbell Wash	45.5	37.5	35.3	9.0	1.0	0.2	5.0	13.4	10.2	5.8	3.4	33.1	199.6
South Bank:													
Alamo Wash	73.4	59.9	45.6	4.2	8.4	11.0	166.3	169.7	173.1	59.9	27.0	47.3	844.3
Alvernon Wash	24.2	19.8	15.0	1.4	2.8	3.6	54.8	55.9	57.1	19.8	8.9	15.6	278.4
Christmas Wash	20.6	16.8	12.8	1.2	2.4	3.1	46.7	47.7	48.6	16.8	7.6	13.3	237.2

IV. SURFACE WATER INFLOW/OUTFLOW ALONG RILLITO

Based on average annual runoff volumes given in Sections II and III, surface water inflow/outflow volumes (annual) along the Rillito are estimated. The following analysis is based on three assumptions: (i) Rillito river inflows at Craycroft Road are equal to the values given in Table 1; (ii) Rillito flow increases downstream by addition of each tributary flow along the study reach; and (iii) no transmission loss from river bed is considered.

Average annual runoff along Rillito:

At Craycroft Road

Average Annual Runoff (AAR) = 10,135 acre-ft.

At Craycroft Wash (Inflow = 241 acre-ft)

AAR (upstream) = 10,135 acre-ft.
AAR (downstream) = 10,376 acre-ft.

At Alamo Wash (Inflow = 844 acre-ft)

AAR (upstream) = 10,376 acre-ft.
AAR (downstream) = 11,220 acre-ft.

At Flecha Caida Wash (Inflow = 122 acre-ft)

AAR (upstream) = 11,220 acre-ft.
AAR (downstream) = 11,342 acre-ft.

At Valley View Wash (Inflow = 316 acre-ft)

AAR (upstream) =11,342 acre-ft.
AAR (downstream) = 11,658 acre-ft.

At Alvernon Wash (Inflow = 278 acre-ft)

AAR (upstream) = 11,658 acre-ft.
AAR (downstream) = 11,936 acre-ft.

At Finger Rock Wash (Inflow = 454 acre-ft)

AAR (upstream) = 11,936 acre-ft.
AAR (downstream) = 12,390 acre-ft.

At Christmas Wash (Inflow = 237 acre-ft)

AAR (upstream) = 12,390 acre-ft.
AAR (downstream) = 12,627 acre-ft.

At Camino Real Wash (Inflow = 152 acre-ft)

AAR (upstream) = 12,627 acre-ft.
AAR (downstream) = 12, 779 acre-ft.

At Campbell Wash (Inflow = 200 acre-ft)

AAR (upstream) = 12,779 acre-ft.
AAR (downstream) = 12,979 acre-ft.

From the above calculations, the total contribution from the nine tributaries in the study reach, on an average annual basis, is 2,844 acre-ft, while Rillito River inflow at the upstream end (Craycroft Road) is 10,135 acre-ft.

V. AVERAGE ANNUAL GROUNDWATER INFLOW/OUTFLOW

Groundwater table elevations in the study reach are shown in Figure 2. It is seen from Figure 2 that groundwater flow direction is approximately perpendicular to the Rillito River alignment (or in the south-southwest direction). Groundwater flow in this direction across the southern boundary of the study reach is estimated using Darcy's Law and geohydrologic data given in the U.S. Geological Survey (USGS) Water Resources Investigations Report 97-4125 (1997, Ref. 2) and USGS Water Supply Paper 1939-E (1973, Ref. 4). The USGS report (Ref. 2) provided estimates of groundwater flow across the Rillito River reach from Craycroft Road to Country Club Road. From Fig. 2, groundwater table gradient is estimated as 0.0379 sq./ft. From Ref. 2 and Ref. 4, saturated aquifer thickness (Fort Lowell Formation) is estimated as 50 feet, with average hydraulic conductivity of 57 ft./day. Using these data, annual groundwater flow across the study reach (4.1 miles) of the Rillito River is estimated as 6,900 acre-ft. This value is consistent with the estimated groundwater flow of 4,400 acre-ft. for the Rillito River reach from Craycroft to Country Club Road, as given in Ref. 2, for the period from December 1992 to January 1993. According to Ref. 2, groundwater inflow from the north of the Rillito River reach is negligible because of low permeability of the underlying aquifer (Tinaja beds) north of the study reach. With this assumption (i.e., groundwater inflow is negligible), an average annual net groundwater outflow of 6,900 acre-ft. is estimated for the study reach. As an approximation, average monthly groundwater outflow of 575

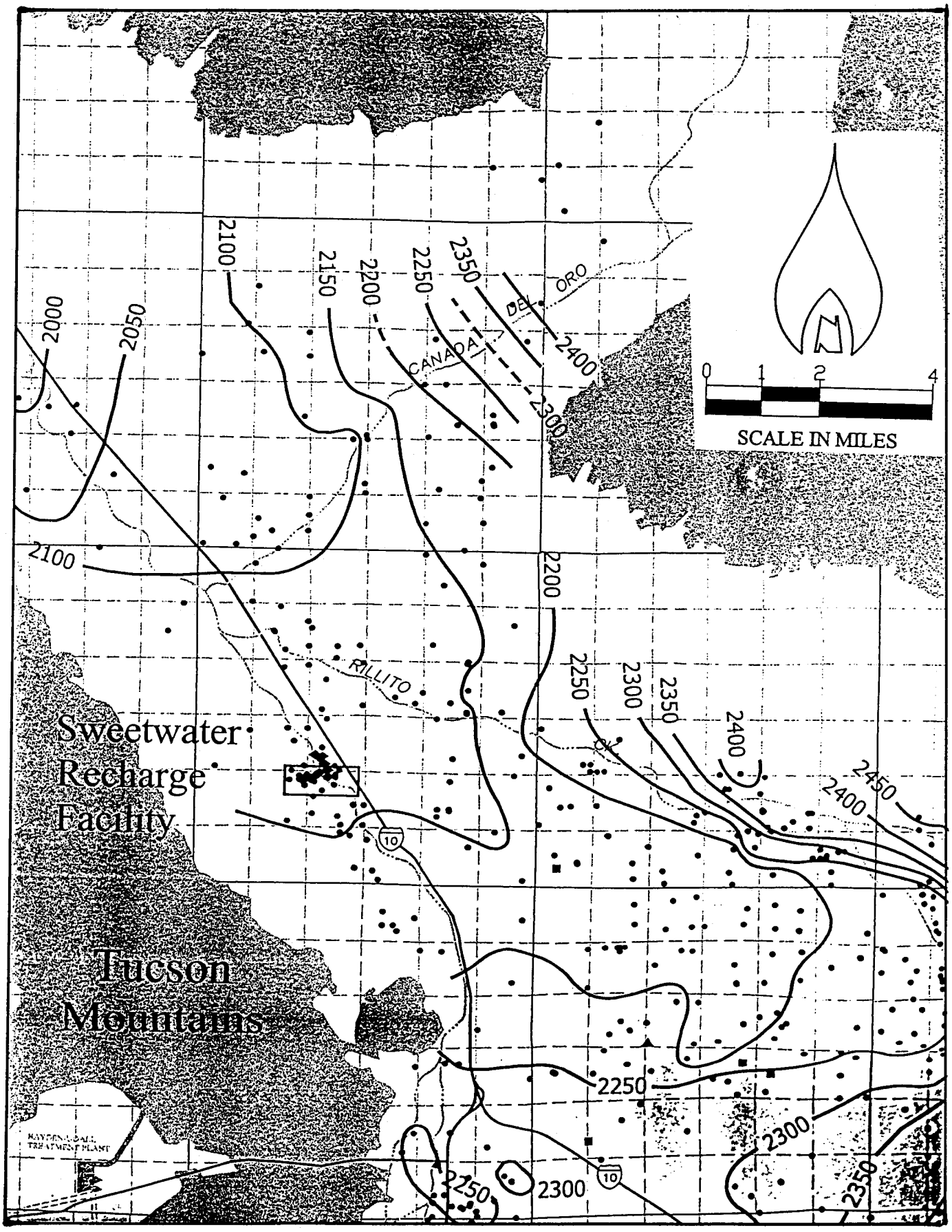


Figure 2. Groundwater Table Elevations

Source: Plate 2 of Reference 1

acre-ft./month may be used. There is no available data to estimate any variation in monthly groundwater outflows over the year.

VI. STORM DRAINS ENTERING RILLITO

There are 13 existing storm drains of various sizes which discharge into the study reach of the Rillito River. Maps obtained from the City of Tucson show locations and plans/profiles, but no data is available on design discharges for these storm drains. As an alternative, capacities of the existing storm drains are estimated and summarized below along with their locations (south bank) and sizes.

<u>At Craycroft Road</u>

66" RCP, Capacity = 127 cfs

54" RCP, Capacity = 78 cfs

Total Capacity = 205 cfs

<u>At Swan Road</u>

48" RCP, Capacity = 73 cfs

30" RCP, Capacity = 22 cfs

24" RCP, Capacity = 24 cfs

Total Capacity = 119 cfs

<u>At Dodge Blvd.</u>

72" RCP, Capacity = 315 cfs

42" RCP, Capacity = 63 cfs

Total Capacity = 378 cfs

At Kelvin Blvd.

42" CMP, Capacity = 75 cfs

48" RCP, Capacity = 140 cfs

Total Capacity = 215 cfs

At Prince Road

48" CMP, Capacity = 45 cfs

60" RCP, Capacity = 201 cfs

Total Capacity = 246 cfs

East of Campbell Avenue

50" x 31" CMP, Capacity = 47 cfs

At Campbell Avenue

72" RCP, Capacity = 201 cfs

Total estimated capacity for all 13 existing storm drains on south bank is 1411 cfs.

In addition to the existing storm drains mentioned above, storn runoffs from the planned subdivision at Christopher City will discharge (in future) into the Rillito River at Columbus Blvd. through two storm drains with combined design discharge (Q100) of 600 cfs.

VII. REFERENCES

1. Tucson Water, 2000. "Annual Static Water Level Basic Data Report, Tucson Basin and Avra Valley, Pima County, Arizona, 1998," City of Tucson, Planning and Engineering Division, December 2000.

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5. Pima County Department of Transportation and Flood Control District, 2002. "El Rio Antiguo, Rillito River Environmental Restoration, Documentation for Hydrologic Studies," Tucson, Arizona, March 2002.