KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 95-45c

EFFECTS OF GROUNDWATER PUMPAGE ON
FRESHWATER-SALTWATER TRANSITION ZONE
CHARACTERISTICS, WATER QUALITY AND WATER LEVELS
AT THE SIEFKES INTENSIVE STUDY AREA,
STAFFORD COUNTY, KANSAS

by

D.P. Young

Kansas Geological Survey
1930 Constant Avenue
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A cooperative investigation by

The Kansas Geological Survey and
Big Bend Groundwater Management District No. 5

A primary objective of logging and monitoring efforts, particularly at the Siefkes intensive study site (fig. 1 and table 1) is to monitor the effects of (irrigation) pumping on the freshwater-saltwater interface or transition zone. Observations and interpretations from the limited 1993 irrigation season are discussed by Young et al. (1994). The 1994 season is discussed below.

Water Levels

As of early spring 1995, water levels at the Siefkes site were still recovering from extreme highs in 1993 caused by excessive precipitation in 1992 and 1993. Fluid levels at the Siefkes site are presented in table 2 (which also indicates the dates on which irrigation was occurring) and illustrated in figures 2-4. Although water levels remained high in 1994 (March-April 1994 levels were approximately 4 ft higher than March-April 1993 levels), weather was more normal in 1994 and a fairly typical irrigation season occurred at the Siefkes site. The north half of the field was planted to corn, and milo was double-cropped on the south half.

Figures 2-4 illustrate the rapid drop in water levels when the irrigation well is turned on. Among the shallow wells the response is greatest in the wells closest to the pumping well (figs. 2 and 4). The deep aquifer well shows a greater response to pumping than does the Permian well, in spite of being located at a greater distance from the pumping well. Both deep and shallow aquifer heads drop below Permian head during pumping cycles (see figs. 3 and 4). From March through November, 1994, water levels in all measured wells showed a net drop of 4 to 5 feet; levels dropped about another half foot over winter. Normally in irrigated areas water levels would be expected to rise overwinter as they recover from pumping, however water levels were still recovering (declining) after the extreme highs in 1993.

It is evident that fluid levels in wells at the Siefkes site are affected by other nearby pumping wells, particularly the irrigation well located approximately one-half mile west. On May 16, 1994, the deep aquifer head dropped below the Permian head when the Siefkes irrigation well was not pumping, but when the irrigation well to the west was pumping. The influence of the west irrigation well also is evident in the WOS well, for example, on June 19, 1995 (fig. 2), when the irrigation well to the west was pumping but the Siefkes irrigation well had not yet been run in 1995.

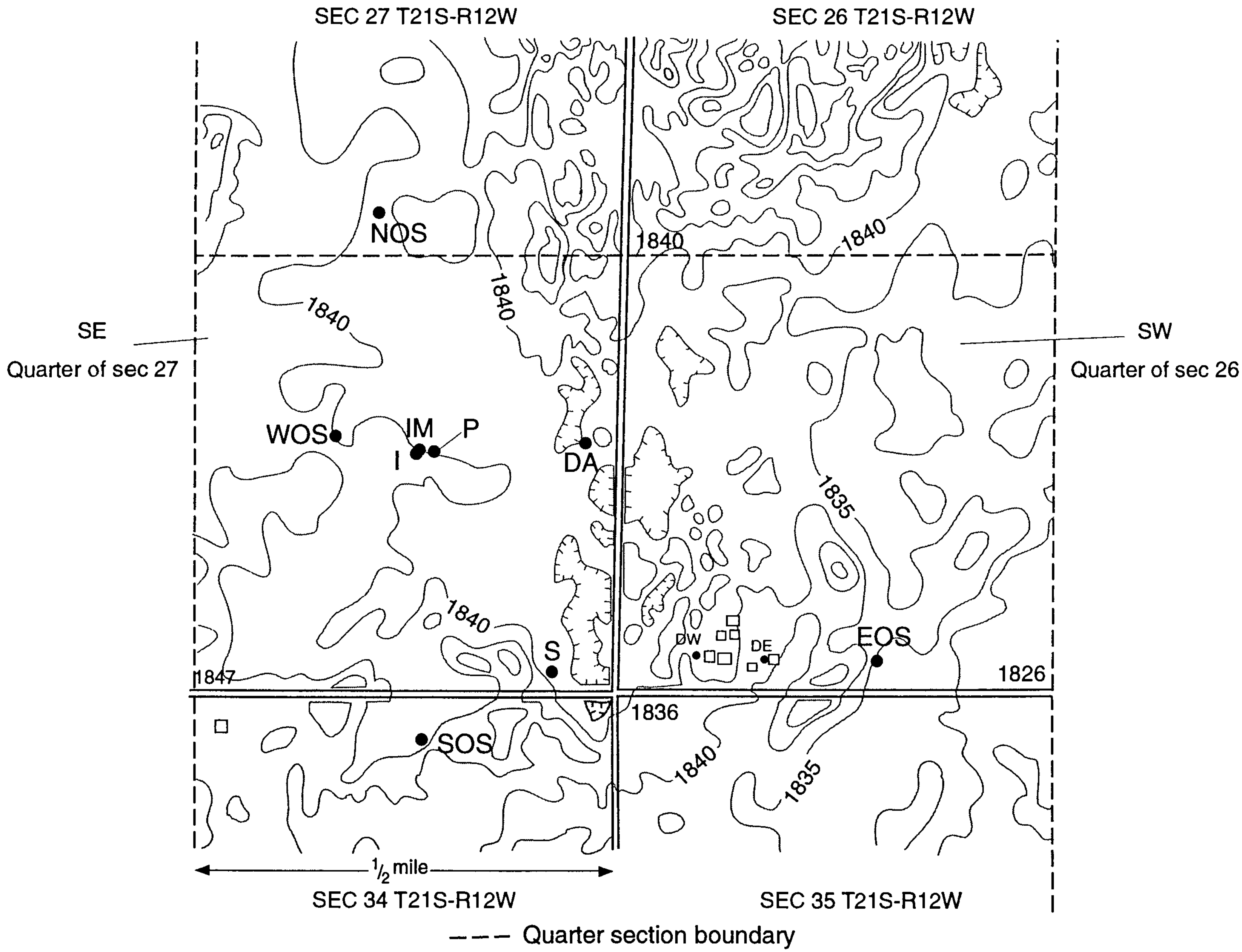

Figure 1. Wells in Siefkes intensive study area. See table 1 for well identification and characteristics, and table 2 for 1993-95 data. Contours indicate approximate elevation of land surface (feet above mean sea level).

Table 1: Information for wells in the Siefkes intensive study area.

Legal location	Well	Description	Screen (bls)	Depth (bls)	Land surface elev.	Elev. top of screen	Elev. bottom of well
21-12-27DACC	I	Irrigation well near center of SE Sec. 27 T21S-R12W	60-80 90-120	120	1840.7	1780.7	1720.7
21-12-27DBDC	WOS	Oil-field supply well west of irrigation well	65-85	85	1839.4	1774.4	1754.4
21-12-27DACC	IM	2" monitoring well near irrigation well	--	60	1840.7	--	1780.7
21-12-27ACDD	NOS	Oil-field supply well north of irrigation well	100-120	120	1839.0	1739.0	1719.0
21-12-27DDDC	S	Stock well southeast of irrigation well	80-90	90	1836.3	1756.3	1746.3
21-12-34AAB	SOS	Oil-field supply well south of irrigation well	80-100	100	1841.0	1761.0	1741.0
21-12-26CDCC	EOS	Oil-field supply well east of irrigation well	80-100	100	1832.9	1752.9	1732.9
21-12-27DACC	P	KGS Permian monitoring well	198-228	228	1839.6	1641.6	1611.6
21-12-27DADD	DA	KGS deep aquifer monitoring well	157-167	167	1839.8	1682.8	1672.8

Table 2A (continued)

DATE	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
8/4/94	x	36078	25.8	28.1	47.4	22.6	20.4	21.1	
8/9/94		39955	27.8	28.2	19.0	17.2	19.8	21.3	
8/10/94	x	40690	26.9	28.5	47.6	23.2	21.0	21.5	
8/12/94	x	41224	25.5	27.2	46.8	21.3	20.7	21.1	
8/17/94		45373	28.6	28.6	21.1	19.8	22.2	22.7	22.8
8/18/94			26.7	24.8		15.0	18.9	20.4	
8/24/94	x	48915	27.0	27.0	47.2			20.3	
9/16/94	x	56063	25.0	26.1	47.2	20.1	19.5	19.7	18.8
10/6/94		58658	23.4	22.3	14.8	12.6	16.1	17.8	15.7
10/13/94		59328	23.8	23.2	15.6				
10/26/94		59328	23.2	22.2	14.8	12.7	16.2	17.8	
11/9/94		59328	23.1	22.2	14.8	12.7	16.3	17.8	15.6
11/16/94		59328	23.0	22.1	14.8				
11/17/94		59328	22.9	22.0	14.7	12.6	16.1	17.6	15.5
	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
3/7/95		0	23.3	22.4	15.2	13.2	16.7	18.0	
3/10/95		0	23.2	22.3	15.2	13.2	16.7	18.0	16.0
3/17/95		0	23.3	22.4	15.3	13.2			
4/6/95		0	23.2	22.4	15.1	13.2			
4/12/95		0	23.4	22.5	15.2	13.3	16.9	18.1	16.2
4/14/95		0	23.3	22.4	15.2	13.2	16.8	18.0	16.1
4/24/95		0	23.4	22.5	15.2	13.2		18.1	
4/26/95		0	23.3	22.4	15.1				
4/28/95		0	23.3	22.4	15.1	13.2	16.9	18.0	16.1
5/1/95		0	23.3	22.4	15.1	13.2			
5/2/95		0	23.3	22.4	15.1	13.2	16.8	18.0	16.1
5/5/95		0	23.4	22.4	15.1	13.2	16.9	18.0	16.2
5/15/95		0	22.7	21.6	13.6	12.0	15.9	17.1	15.2
5/16/95		0	22.4	21.3		11.5			14.4
5/17/95		0			12.6		15.3	16.6	
5/19/95		0	22.3	20.8	12.0	10.7	15.1	16.2	
6/19/95		0	20.4	19.7	11.6	10.8	14.2	14.9	13.5
6/20/95	x	780	20.9	22.0	42.9	16.1	15.6	15.6	14.9
6/21/95	x	1435	21.5	22.0	43.1	16.0	15.6	15.8	

*-- x indicates irrigation well pumping

**-- annual water use in thousands of gallons (no data available for 1993)

Table 2A. 1993-95 water use and water levels in wells at the Siefkes site.

					Depth to water (ft)				
DATE	I*		P	DA	IM	WOS	SOS	EOS	NOS
3/24/93					15.2	14.2			16.8
3/26/93								18.6	
4/17/93			23.0	22.6					
5/20/93			22.2	20.9					
5/25/93			22.0	20.7	12.8	11.2	14.8	16.0	13.8
7/7/93			21.7	19.5	11.4	9.5	13.4	15.0	12.5
7/8/93			20.9	18.8	10.8	8.9	12.7	14.4	11.8
7/27/93			19.1	18.5	10.0	8.1	11.5	13.5	
7/29/93	x		21.2	23.0	43.9	16.9	16.2	16.3	
8/17/93	x		21.1	21.6	45.0	17.1	15.8	16.5	15.6
8/23/93					13.4		15.4	16.4	
8/24/93	x		22.4	23.4	45.9	17.8	17.3	17.2	
8/25/93			22.5	22.2	44.4	17.4	16.4	16.5	
9/10/93			18.7	17.4	10.2	8.7	11.8	13.1	
9/18/93			18.1	16.4	9.0	7.0	10.7	12.5	
10/12/93	x		18.4	19.6	42.2	13.9	13.1	14.0	
10/13/93			19.1	17.5	10.4	8.2	11.9	13.5	10.7
10/14/93			18.0	17.0					
10/21/93			17.3	16.6	9.8	7.5	11.2	12.9	10.0
	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
3/4/94		0		17.5	10.8		12.2	13.8	11.1
3/5/94		0	17.9		10.8	8.6			
3/23/94		0				8.8			11.4
3/24/94		0	18.4	18.3	11.4	9.2	12.7	14.4	
3/30/94		0	18.4	18.0	11.3	9.0	12.6	14.2	11.5
3/31/94	x	0	18.1	19.2	37.9	13.0	13.3	14.4	12.6
4/1/94	x	680	18.8	20.4	42.4	15.0	14.2	15.0	13.3
4/8/94		3476				9.6			
4/13/94		4050	18.4	17.9	11.4	9.0	12.6	14.1	11.4
4/19/94		4050	18.6	18.4	11.7	9.3	12.8	14.5	12.0
4/21/94	x	4426	18.9	21.4	42.6		14.9	15.8	
4/22/94	x	5183	20.4	22.8	44.7	17.3	17.2	17.0	
5/16/94		5772	18.6	18.1	11.4			14.3	11.6
5/19/94			19.4	19.8	13.0	11.3	14.2	15.5	13.8
5/26/94		9293	20.2	19.8	12.8			15.8	
6/21/94		16236	25.9	26.9	20.1	17.8	20.5	21.3	20.4
6/23/94			24.3	25.0	17.2		19.0	20.0	
7/5/94		21775	22.0	21.5	14.7	13.0	16.1	17.2	15.6
7/8/94	x	21842	22.8	25.6	45.0		19.1	19.6	19.0
7/19/94		27488	21.6	20.5	13.4	11.2	14.7	16.4	14.4
7/20/94		27488	21.5	20.5	13.4			16.4	
7/21/94	x	27545	21.0	23.3	44.1	16.8	17.0	17.8	
8/3/94		35398	25.3	25.3	17.5	16.1	19.5	20.4	

Table 2B. 1993-95 water use and water levels in wells at the Siefkes site.									
				Water level elevations (ft above mean sea level)					
DATE	I*		P	DA	IM	WOS	SOS	EOS	NOS
3/24/93					1825.5	1825.2			1822.2
3/26/93								1814.3	
4/17/93			1816.6	1817.2					
5/20/93			1817.4	1818.9					
5/25/93			1817.6	1819.1	1827.9	1828.2	1826.2	1816.9	1825.2
7/7/93			1817.9	1820.3	1829.3	1829.9	1827.6	1817.9	1826.5
7/8/93			1818.7	1821.0	1829.9	1830.5	1828.3	1818.5	1827.2
7/27/93			1820.5	1821.3	1830.7	1831.3	1829.5	1819.4	
7/29/93	x		1818.4	1816.8	1796.8	1822.5	1824.8	1816.6	
8/17/93	x		1818.5	1818.2	1795.7	1822.3	1825.2	1816.4	1823.4
8/23/93					1827.3		1825.6	1816.5	
8/24/93	x		1817.2	1816.4	1794.8	1821.6	1823.7	1815.7	
8/25/93			1817.1	1817.6	1796.3	1822.0	1824.6	1816.4	
9/10/93			1820.9	1822.4	1830.5	1830.7	1829.2	1819.8	
9/18/93			1821.5	1823.4	1831.7	1832.4	1830.3	1820.4	
10/12/93	x		1821.2	1820.2	1798.5	1825.5	1827.9	1818.9	
10/13/93			1820.5	1822.3	1830.3	1831.2	1829.1	1819.4	1828.3
10/14/93			1821.6	1822.8					
10/21/93			1822.3	1823.2	1830.9	1831.9	1829.8	1820.0	1829.0
	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
3/4/94		0		1822.3	1829.9		1828.8	1819.1	1827.9
3/5/94		0	1821.7		1829.9	1830.8			
3/23/94		0				1830.6			1827.6
3/24/94		0	1821.2	1821.5	1829.3	1830.2	1828.3	1818.5	
3/30/94		0	1821.2	1821.8	1829.4	1830.4	1828.4	1818.7	1827.5
3/31/94	x	0	1821.5	1820.6	1802.8	1826.4	1827.7	1818.5	1826.4
4/1/94	x	680	1820.8	1819.4	1798.3	1824.4	1826.8	1817.9	1825.7
4/8/94		3476				1829.8			
4/13/94		4050	1821.2	1821.9	1829.3	1830.4	1828.4	1818.8	1827.6
4/19/94		4050	1821.0	1821.4	1829.0	1830.1	1828.2	1818.4	1827.0
4/21/94	x	4426	1820.7	1818.4	1798.1		1826.1	1817.1	
4/22/94	x	5183	1819.2	1817.0	1796.0	1822.1	1823.8	1815.9	
5/16/94		5772	1821.0	1821.7	1829.3			1818.6	1827.4
5/19/94			1820.2	1820.0	1827.7	1828.1	1826.8	1817.4	1825.2
5/26/94		9293	1819.4	1820.0	1827.9			1817.1	
6/21/94		16236	1813.7	1812.9	1820.6	1821.6	1820.5	1811.6	1818.6
6/23/94			1815.3	1814.8	1823.5		1822.0	1812.9	
7/5/94		21775	1817.6	1818.3	1826.1	1826.4	1824.9	1815.7	1823.4
7/8/94	x	21842	1816.8	1814.2	1795.7		1821.9	1813.3	1820.0
7/19/94		27488	1818.0	1819.3	1827.3	1828.2	1826.3	1816.5	1824.6
7/20/94		27488	1818.1	1819.3	1827.3			1816.5	
7/21/94	x	27545	1818.6	1816.5	1796.6	1822.6	1824.0	1815.1	
8/3/94		35398	1814.3	1814.5	1823.2	1823.3	1821.5	1812.5	

Table 2B (continued)									
DATE	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
8/4/94	x	36078	1813.8	1811.7	1793.3	1816.8	1820.6	1811.8	
8/9/94		39955	1811.8	1811.6	1821.7	1822.2	1821.2	1811.6	
8/10/94	x	40690	1812.7	1811.3	1793.1	1816.2	1820.0	1811.4	
8/12/94	x	41224	1814.1	1812.6	1793.9	1818.1	1820.3	1811.8	
8/17/94		45373	1811.0	1811.2	1819.6	1819.6	1818.8	1810.2	1816.2
8/18/94			1812.9	1815.0		1824.4	1822.1	1812.5	
8/24/94	x	48915	1812.6	1812.8	1793.5			1812.6	
9/16/94	x	56063	1814.6	1813.7	1793.5	1819.3	1821.5	1813.2	1820.2
10/6/94		58658	1816.2	1817.5	1825.9	1826.8	1824.9	1815.1	1823.3
10/13/94		59328	1815.8	1816.6	1825.1				
10/26/94		59328	1816.4	1817.6	1825.9	1826.7	1824.8	1815.1	
11/9/94		59328	1816.5	1817.6	1825.9	1826.7	1824.7	1815.1	1823.4
11/16/94		59328	1816.6	1817.7	1825.9				
11/17/94		59328	1816.7	1817.8	1826.0	1826.8	1824.9	1815.3	1823.5
	I*	USE**	P	DA	IM	WOS	SOS	EOS	NOS
3/7/95		0	1816.3	1817.4	1825.5	1826.2	1824.3	1814.9	
3/10/95		0	1816.4	1817.5	1825.5	1826.2	1824.3	1814.9	1823.0
3/17/95		0	1816.3	1817.4	1825.4	1826.2		1832.9	
4/6/95		0	1816.4	1817.4	1825.6	1826.2			
4/12/95		0	1816.2	1817.3	1825.5	1826.1	1824.1	1814.8	1822.8
4/14/95		0	1816.3	1817.4	1825.5	1826.2	1824.2	1814.9	1822.9
4/24/95		0	1816.2	1817.3	1825.5	1826.2		1814.8	
4/26/95		0	1816.3	1817.4	1825.6				
4/28/95		0	1816.3	1817.4	1825.6	1826.2	1824.1	1814.9	1822.9
5/1/95		0	1816.3	1817.4	1825.6	1826.2			
5/2/95		0	1816.3	1817.4	1825.6	1826.2	1824.2	1814.9	1822.9
5/5/95		0	1816.2	1817.4	1825.6	1826.2	1824.1	1814.9	1822.8
5/15/95		0	1816.9	1818.2	1827.1	1827.4	1825.1	1815.8	1823.8
5/16/95		0	1817.2	1818.5		1827.9			1824.6
5/17/95		0			1828.1		1825.7	1816.3	
5/19/95		0	1817.3	1819.0	1828.7	1828.7	1825.9	1816.7	
6/19/95		0	1819.2	1820.1	1829.1	1828.6	1826.8	1818.0	1825.5
6/20/95	x	780	1818.7	1817.8	1797.8	1823.3	1825.4	1817.3	1824.1
6/21/95	x	1435	1818.1	1817.8	1797.6	1823.4	1825.4	1817.1	

*-- x indicates irrigation well pumping

**-- annual water use in thousands of gallons (no data available for 1993)

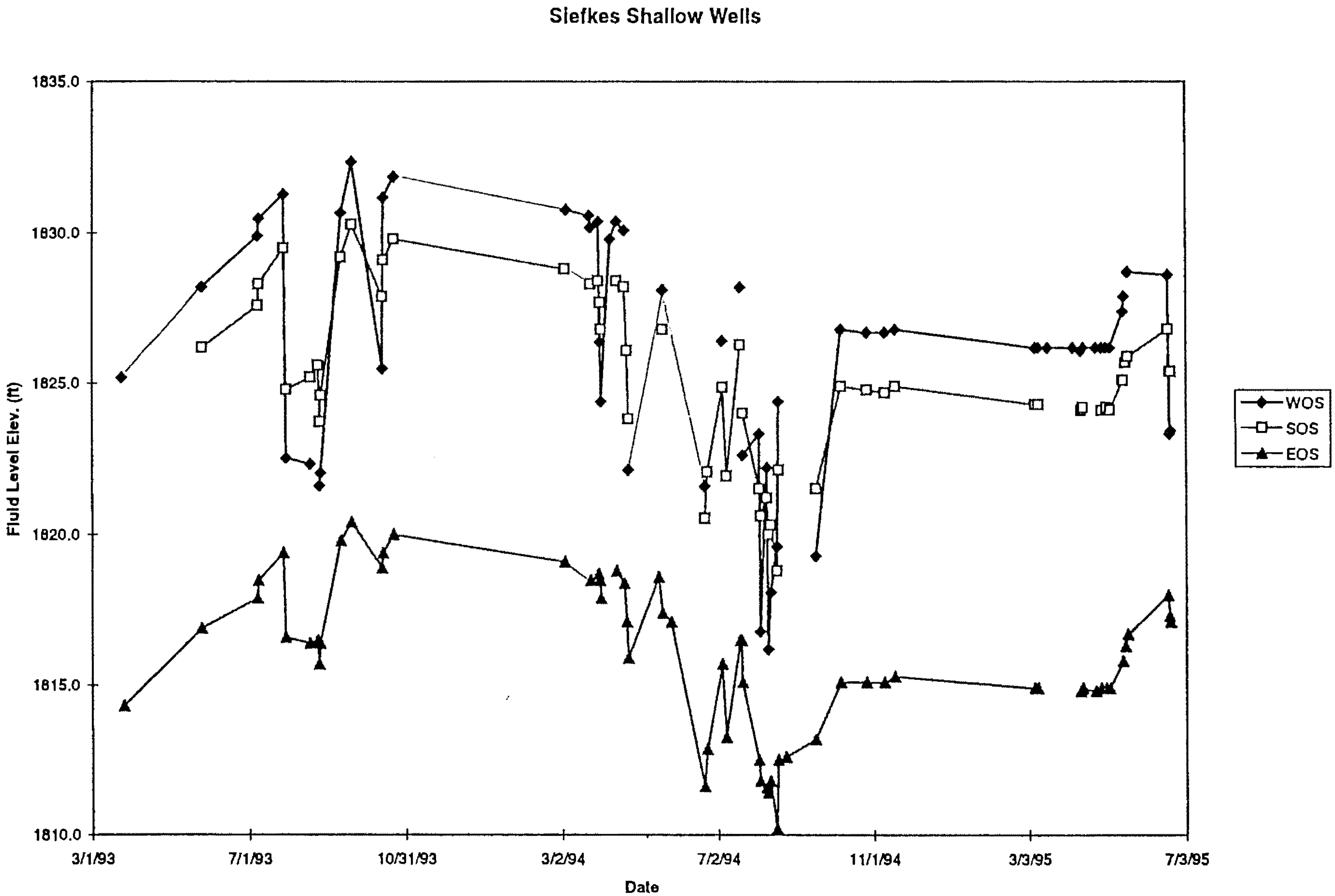

Figure 2. Hydrographs of shallow wells surrounding the Siefkes site. See figure 1 and table 1 for locations and well characteristics.

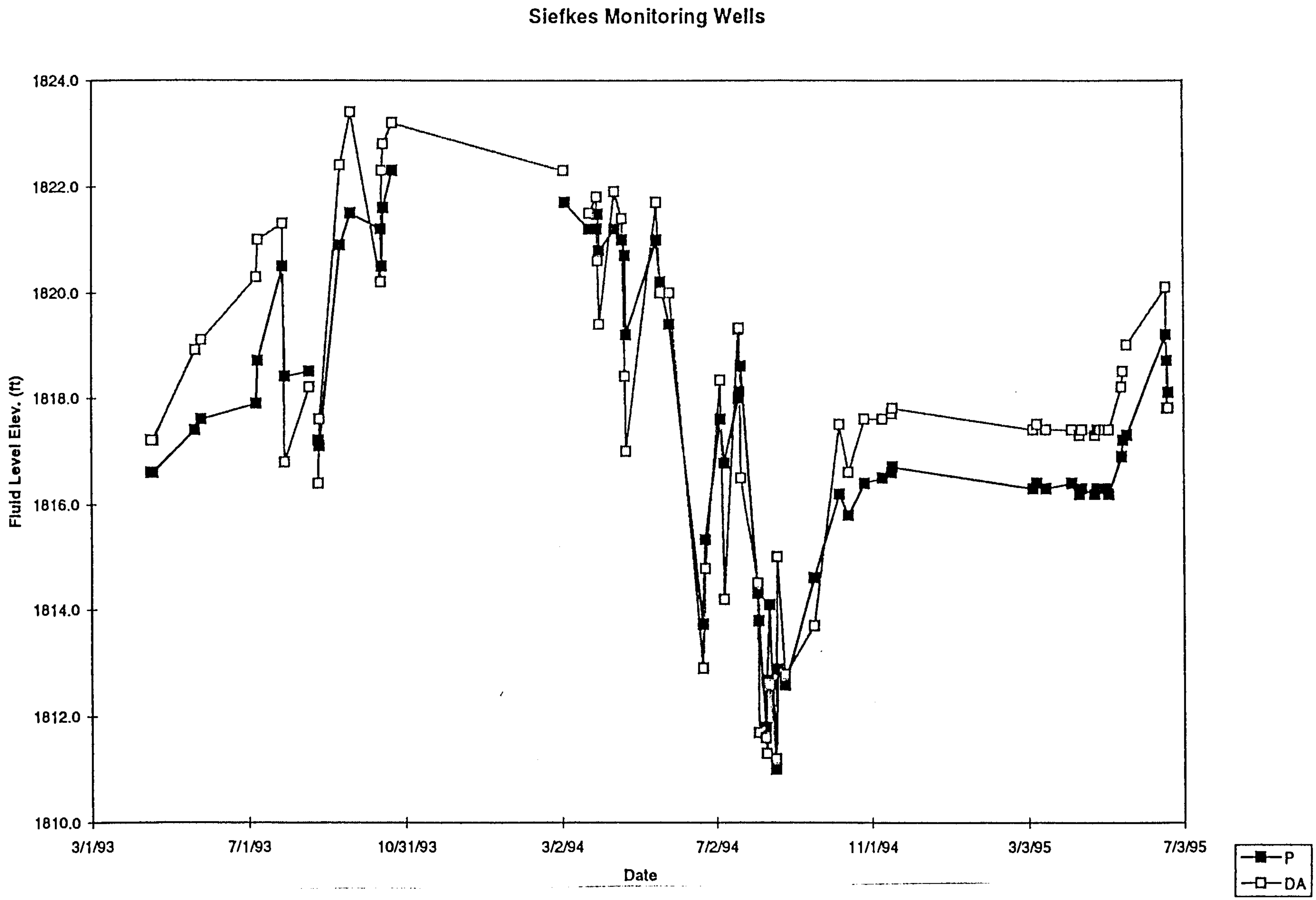

Figure 3. Hydrographs of the Permian (P) and Deep Aquifer (DA - base of Great Bend Prairie Aquifer) monitoring wells at the Siefkes site. See figure 1 and table 1 for locations and well characteristics.

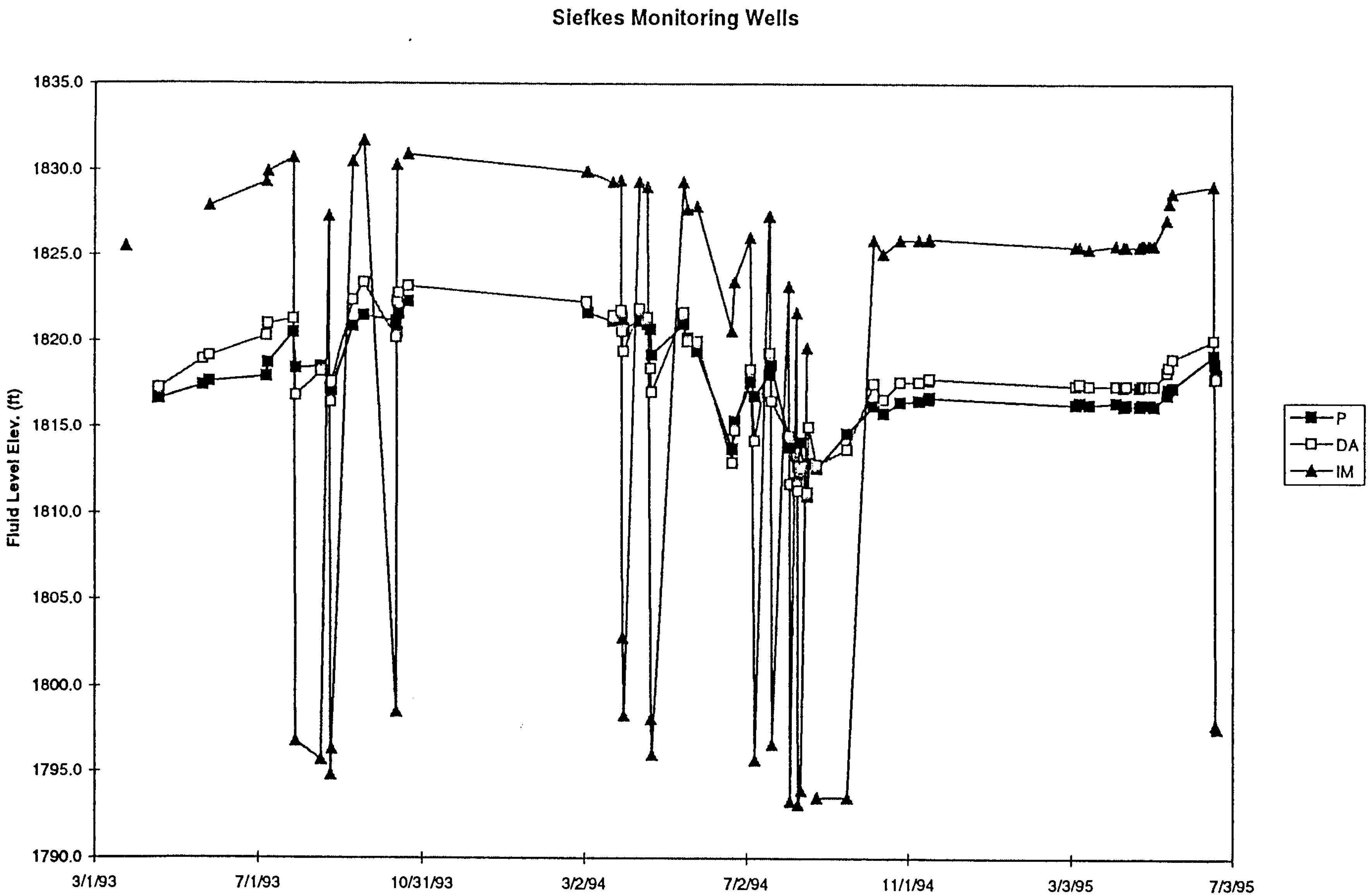

Figure 4. Hydrographs of the Permian (P) and Deep Aquifer (DA - base of Great Bend Prairie Aquifer) monitoring wells at the Siefkes site, rescaled for comparison to the hydrograph of the water table monitoring well (IM) immediately adjacent to the irrigation well. See figure 1 and table 1 for locations and well characteristics.

Spring 1995 brought with it major amounts of precipitation, not unlike the spring of 1993. As a result, spring 1995 conditions were comparable to those in spring 1993, i.e. water levels were higher than normal and ponded water occurred. Planting was delayed because of the wet conditions. The south half of the field was planted to corn and the north half to soybeans.

Water Use and Water Chemistry

The 1994 irrigation season at the Siefkes began March 31 and pumping continued intermittently through early October. A new meter on the irrigation well made it possible to track water use through the season. Cumulative water use (in thousands of gallons) is listed along with water levels in table 2. Table 3 includes actual meter readings and water use in gallons, acre-ft, and cubic meters; and approximate monthly water use is shown in figure 5.

Limited water chemistry data (specific conductance, chloride, and nitrate-N) for the Siefkes irrigation well is listed in table 4. Well information and additional chemistry data for all wells sampled at the Siefkes site are given in tables 5 and 6, respectively. Notice that table 6 reports both nitrate (NO3) and nitrate expressed as nitrogen (NO3-N), while table 4 reports only nitrate-nitrogen (NO3-N). The drinking water limit for NO3-N is 10 mg/L.

During the 1994 irrigation season, the chloride concentration in water samples collected from the Siefkes irrigation well ranged from about 135 mg/L to 335 mg/L (see table 4). Concentrations of 134 to 135 mg/L were observed on the first day of pumping (March 31) and again on July 8 and July 21. Figure 6 shows the rapid increase when the irrigation well is first pumped in early April, and the trend of increasing chloride concentrations through the pumping season. The sample with the highest concentration was collected in August, the month with the most water use (table 3 and fig. 5).

It was discovered that the water chemistry of samples from the irrigation well depends on the amount of time the pump has run prior to sample collection and probably also on how much time has elapsed since the prior pumping period. This is evident from the low chloride concentrations in samples collected July 8 and 21 (table 4 and fig. 6). Both of these samples were collected early in the pumping cycle, and the pump had not run for some time prior to these cycles because of rain storms in early and mid July.

Early in the pumping cycle, more near-surface water (relative to deep formation water) is pumped; hence, the relatively low chloride values and high nitrate-N values. Later in the pumping cycle, after a cone of depression has developed around the well, mostly deep formation water (with a higher chloride concentration) is discharged. Evidence for this is shown in figure 7, which illustrates that nitrate-N and chloride concentrations of Siefkes irrigation well water samples are virtually mirror images of each other. In other words, when the nitrate concentration of pumped water drops, the chloride concentration rises, and vice versa.

While the prevalent source of chloride in the Great Bend Prairie aquifer is the Permian bedrock, the principal source of nitrate is fertilizer applied to the land surface. Therefore nitrate in ground water tends to be concentrated in the upper or shallow ground water. Notice that in the July 8 and 21 samples and in the March 31 sample, all of which were taken early in the pumping cycle, nitrate concentrations were relatively high and chloride concentrations were relatively low.

Table 3. Siefkes irrigation well water use.

	I*	METER READING	USE			CUMULATIVE USE		
		Gallons (x 1000)	Gallons (x 1000)	Acre-ft	Cubic Meters	Gallons (x 1000)	Acre-ft	Cubic Meters
3/31/94	x	25352	0	0	0	0	0	0
4/1/94	x	26032	680	2	2574	680	2	2574
4/8/94		28828	2796	9	10583	3476	11	13157
4/13/94		29402	574	2	2173	4050	12	15329
4/19/94		29402	0	0	0	4050	12	15329
4/21/94	x	29778	376	1	1423	4426	14	16752
4/22/94	x	30535	757	2	2865	5183	16	19618
5/16/94		31124	589	2	2229	5772	18	21847
5/26/94		34645	3521	11	13327	9293	29	35174
6/21/94		41588	6943	21	26279	16236	50	61453
7/5/94		47127	5539	17	20965	21775	67	82418
7/8/94	x	47194	67	0	254	21842	67	82672
7/19/94		52840	5646	17	21370	27488	84	104042
7/20/94		52840	0	0	0	27488	84	104042
7/21/94	x	52897	57	0	216	27545	85	104258
8/3/94		60750	7853	24	29724	35398	109	133981
8/4/94	x	61430	680	2	2574	36078	111	136555
8/9/94		65307	3877	12	14674	39955	123	151230
8/10/94	x	66042	735	2	2782	40690	125	154012
8/12/94	x	66576	534	2	2021	41224	126	156033
8/17/94		70725	4149	13	15704	45373	139	171737
8/24/94	x	74267	3542	11	13406	48915	150	185143
9/16/94	x	81415	7148	22	27055	56063	172	212198
10/6/94		84010	2595	8	9822	58658	180	222021
10/13/94		84680	670	2	2536	59328	182	224556
10/26/94		84680	0	0	0	59328	182	224556
11/9/94		84680	0	0	0	59328	182	224556
11/16/94		84680	0	0	0	59328	182	224556
11/17/94		84680	0	0	0	59328	182	224556
6/19/95		84680	0	0	0	0	0	0
6/20/95	x	85460	780	2	2952	780	2	2952
6/21/95	x	86113	653	2	2472	1433	4	5424

*-- x indicates irrigation well pumping

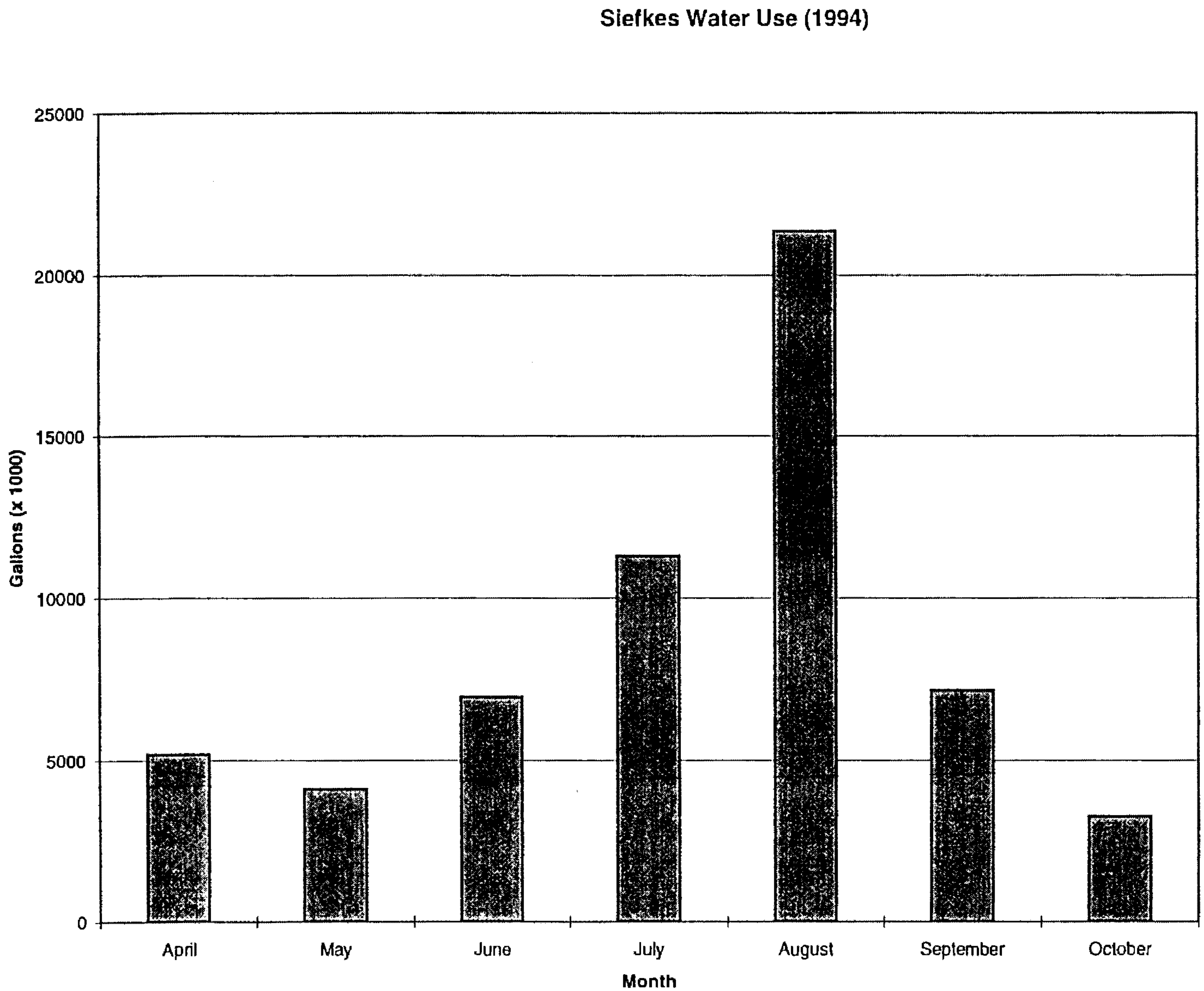

Figure 5. Estimated monthly water use (in thousands of gallons) from the Siefkes irrigation well (1994).

Table 4. Limited water chemistry data from the Siefkes irrigation well.

	Lab SpC uS/cm	Cl mg/L	NO3-N mg/L
	-----	----------	----------
7/28/93	1085	203.1	20.15
7/28/93	1085	206.7	19.52
7/28/93	1105	210.8	19.00
7/29/93	1135	220.9	17.67
8/23/93	1315	279.0	12.61
8/24/93	1350	292.9	12.11
8/24/93	1345	291.6	12.15
8/25/93	1350	292.9	12.02
10/12/93	1315	283.8	11.81
3/31/94	900	135	28.46
4/1/94	1083	203	
4/8/94	1220	253	14.66
4/21/94	1110	212	17.03
4/22/94	1280	266	13.67
6/4/94	1418	306	11.09
7/8/94	900	134.3	27.56
7/21/94	913	134.8	27.33
7/27/94	1480	331.6	9.83
8/1/94	1480	334.3	9.60
8/4/94	1480	330.2	9.69
8/10/94	1480	331.2	9.51
8/12/94	1460	323.6	9.92
8/24/94	1495	335	9.22
9/16/94	1430	316	10.12

SpC = specific conductance
Cl = chloride
NO3-N = nitrate-nitrogen

Table 5. Identification and Information for Sites Sampled for Water Chemistry at or near Siefkes site

Well ID	Legal location	Well description	Well depth ft.
I	21S-12W-27DACC	Siefkes irrigation well	120
IM	21S-12W-27DACC	Siefkes irrigation observ. well	60
P	21S-12W-27DACC	Permian observation well	228
DA	21S-12W-27DADD	Aquifer base observation well	167
S	21S-12W-27DDDC	Siefkes stock well	90
WOS	21S-12W-27DBDC	Oil field supply well W	85
EOS	21S-12W-26CDCC	Oil field supply well E	100
NOS	21S-12W-27ACDD	Oil field supply well N	120
DE	21S-12W-26CC	Siefkes domestic well E	90
DW	21S-12W-26CC	Siefkes domestic well W	96
WI	21S-12W-27C	Irrigation well W	101
WI2	21S-12W-28D	Irrigation well	102
WI3	21S-12W-28A	Irrigation well	
SI	21S-12W-34A	Irrigation well S	
OB1	21S-12W-34A	Oil brine, tank near disposal well	

Table 6. Chemical Properties and Constituent Concentrations in Water Samples Collected from the Siefkes site.

See table 5 for well identification.

Well ID	Date collected	Field Sp.C. uS/cm	Lab Sp.C. uS/cm	Lab pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	NO3-N mg/L	Br mg/L	I mg/L
WOS	3/23/93	730	750								95.6	11.1	130	29.37	0.096	0.001
S	3/23/93	1202	1130								238.2	10.1	26.6	6.01	0.86	0.005
DE	4/15/93	880	820								116	14.5	47.9	10.82	0.32	0.003
DW	4/15/93	820	770								125.7	8	17.4	3.93	0.39	0.002
IM	4/13/93	720	680								90.6	9.3	107	24.17	0.087	0.001
EOS	4/15/93	1370	1320								308.4	14.2	10.2	2.3	0.91	0.002
NOS	4/15/93	810	680								95	14.4	29.8	6.73	0.24	0.003
P	4/14/93		55600								20960	2540	3	0.68		
P	4/15/93		60600	9.55							25240	2870	1.6	0.36	3.84	0.081
DA	4/15/93		37300								13620	1500	0.9	0.2	2.15	0.049
DA	4/15/93		38400	7.8	347	162	8880	<12	3.2	292	13940	1530	0.6	0.14	2.22	0.05
P	6/2/93		70800	7.85	711	370	17800	<25	14.1	277	26670	3180	0.2	0.05	4.14	0.108
I	7/28/93		1085	7.6	136	9.5	53.2	3.4	0.52	157	203.1	15.3	89.2	20.15	0.328	0.002
"	7/28/93		1085								206.7	15.6	86.4	19.52	0.337	0.001
"	7/28/93		1105								210.8	16.2	84.1	19	0.343	0.001
"	7/29/93		1135	7.55	132	9.4	68.3	3.7	0.51	164	220.9	17	78.2	17.67	0.352	0.001
OB1	8/25/93		93300	7.45	2670	1140	18400	152	429	456	36350	230			137	5.56
I	8/23/93		1315	7.6	131	10.1	102	4.3	0.55	194	279	21.8	55.8	12.61	0.424	0.002
"	8/24/93		1350								292.9	22.7	53.6	12.11	0.432	0.002
"	8/24/93		1345								291.6	22.8	53.8	12.15	0.43	0.002
"	8/25/93		1350	7.6	128	10.2	114	4.4	0.55	182	292.9	22.8	53.2	12.02	0.436	0.002
"	10/12/93		1315	7.65	126	9.9	105	4.3	0.55	182	283.8	21.4	52.3	11.81	0.429	0.002
EOS	3/24/94		1283								291	13.8	8.7	1.97	0.91	0.002
NOS	3/24/94		665								91.8	12.6	33.9	7.66	0.249	0.002
WOS	3/24/94		840								115	12	151	34.11	0.121	9E-04
S	3/24/94		1262								290	13.1	23.9	5.4	1.016	0.005
I	3/31/94		900	7.6	129	9.2	21.3	3.3	0.5	133	135	13.2	126	28.46	0.118	0.001
"	4/1/94		1083								203	15.7			0.357	0.001
IM	3/31/94		835								130	10	130	29.37	0.103	8E-04
I	4/8/94		1220		132	9.9	84.9	4.1	0.55		253	18.7	64.9	14.66	0.438	0.001

Table 6 (cont)																
		Field	Lab													
	Date	Sp.C.	Sp.C.	Lab	Ca	Mg	Na	K	Sr	HCO3	Cl	SO4	NO3	NO3-N	Br	I
Well ID	collected	uS/cm	uS/cm	pH	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
-------------	---------	-----	-----	----	----	------	--------	------	-----	----	----------	----------	----------	----------	--------	-------
I	4/21/94		1110								212	16.7	75.4	17.03	0.383	0.002
I	4/22/94		1280								266	20.6	60.5	13.67	0.462	0.002
WI	5/19/94		920	7.6	123	10.1	30.7	4	0.52	170	162.7	18.8	46.8	10.57	0.512	0.004
SI	5/18/94		532	7.8	69.9	4.6	31.7	3.8	0.27	233	33.4	13.8	25	5.65	0.033	9E-04
I	6/4/94		1418	7.6	131	10.3	122	4.4	0.57	183	306	23.8	49.1	11.09	0.47	0.003
WI	6/23/94		800	7.8	104	7.6	34.6	3.7	0.43	186	126.9	15.8	36.2	8.18	0.364	0.003
WI3	6/23/94		1050	7.75	101	7.1	91.3	5.2	0.42	241	186.9	21.4	22.6	5.11	0.234	0.003
WI2	6/23/94		700	7.8	76.6	5.3	55.8	3.7	0.29	214	88.1	19.4	24.4	5.51	0.141	0.003
SI	6/23/94		775	7.85	74	4.9	77.8	4.1	0.29	235	105.5	19.6	20.4	4.61	0.042	0.002
S	6/23/94		1285	7.8	172	17.6	36.7	1.6	0.94	177	292	13.3	23.6	5.33	1.039	0.005
I	7/8/94		900	7.6	133	9.4	23.1	3.4	0.52	143	134.3	13.6	122	27.56	0.112	0.001
I	7/21/94		913								134.8	13.9	121	27.33	0.114	9E-04
I	7/27/94		1480								331.6	25.8	43.5	9.83	0.443	0.002
I	8/1/94		1480								334.3	25.7	42.5	9.6	0.445	0.002
I	8/4/94		1480	7.7	127	10.3	141	4.4	0.57	194	330.2	25.8	42.9	9.69	0.448	0.002
I	8/10/94		1480								331.2	25.8	42.1	9.51	0.44	0.002
I	8/12/94		1460								323.6	25.1	43.9	9.92	0.442	0.002
SI	8/11/94		1015	7.7	74.9	5.5	124	4.3	0.31	230	178	26	19.9	4.5	0.052	0.002
SI*	8/11/94		563	7.6	77.5	4.8	28.9	4.3	0.29	226	45.3	14.8	23.6	5.33	0.036	0.001
WI	8/12/94		770								118.1	16.4	30.2	6.82	0.324	0.004
I	8/24/94		1495								335	26.6	40.8	9.22		
P	8/24/94		68400	9.05						27.2	25850	2918	2.6	0.59		
DA	8/24/94		39400	7.95	345	170	9360	16.7	6.45	298	13880	1557	0.4	0.09	2.18	0.055
I	9/16/94		1430	7.8	129	10.2	135	4.4	0.58	194	316	24.5	44.8	10.12	0.438	0.002
P	9/15/94		70100	8.05	653	359	17500	34.7	13.4	247	26790	3209	1.2	0.27	4.09	0.061
DA	9/15/94		39400								13820	1559	0.5	0.11	2.2	0.05
S	10/13/94		1225								277	13.2	23.9	5.4	0.97	0.005
P	5/17/95		70200								26550	3178	0.9	0.2		
DA	5/16/95		38800								13640	1530	0.4	0.09		
IM	5/17/95		923	7.85	128	9	24.6	3.4	0.51	96.2	145	9.9	146	32.98		

* sample collected from upright--mix from two wells.

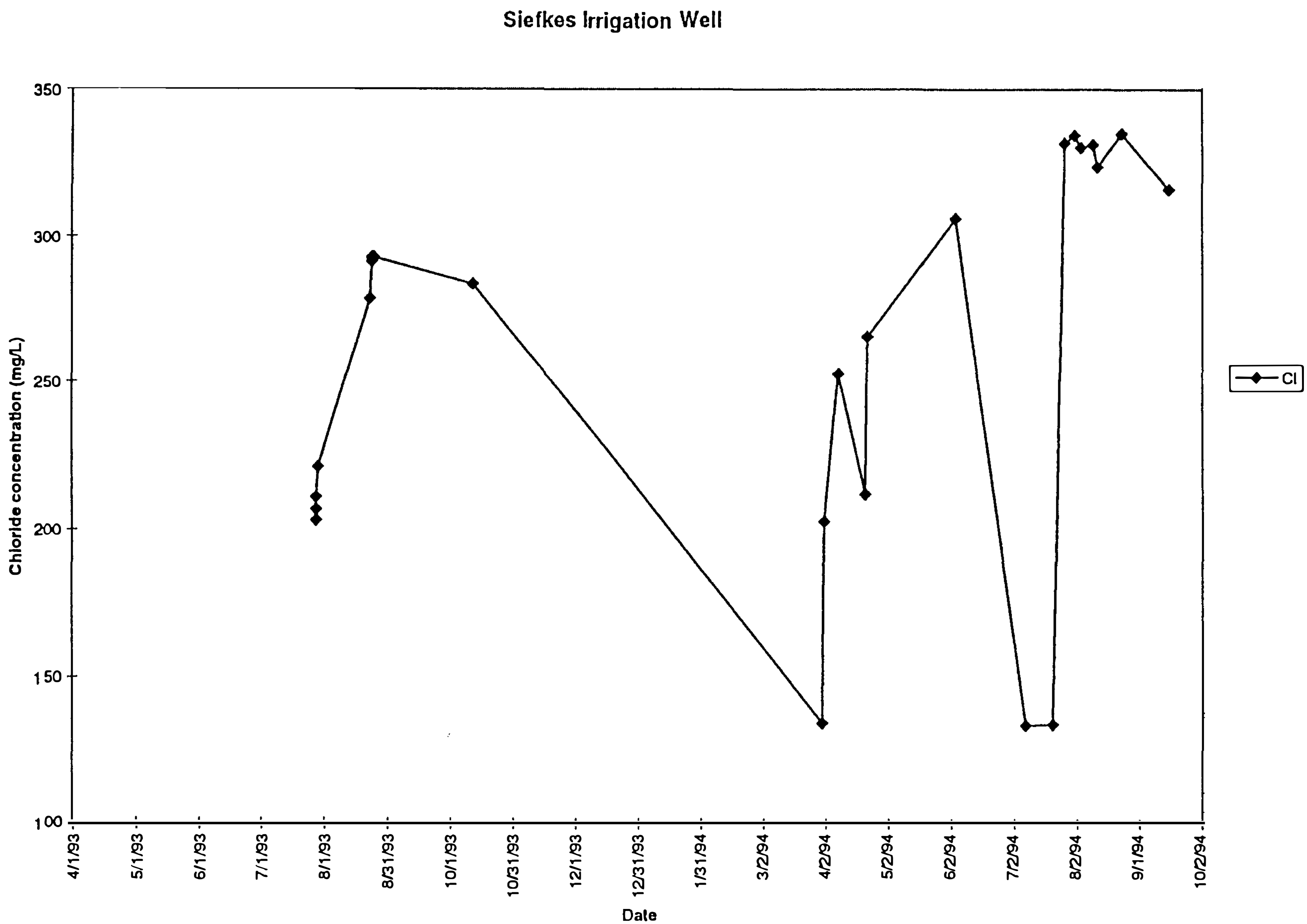

Figure 6. Chloride concentration (mg/L) of water samples collected from the Siefkes irrigation well.

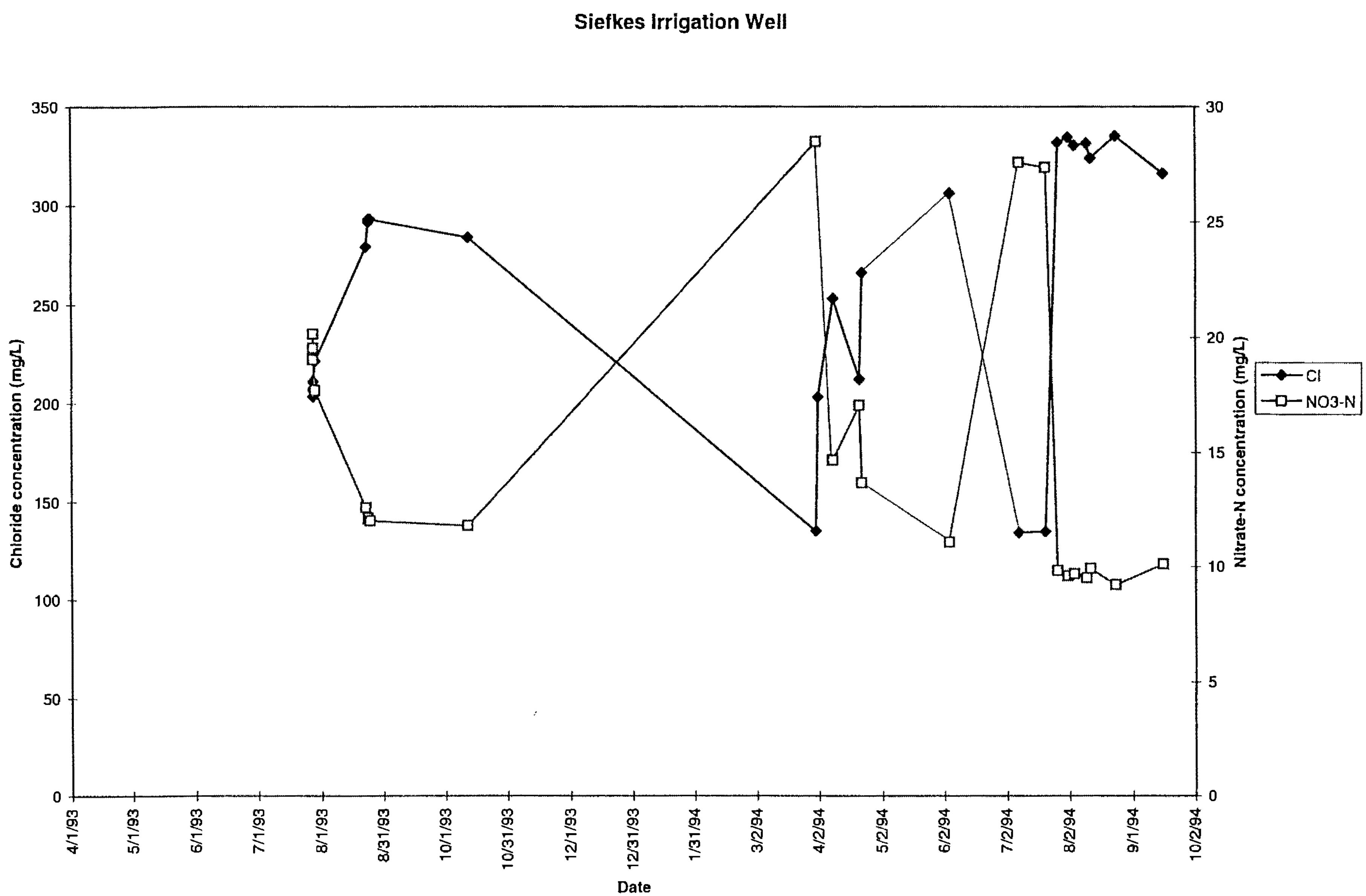

Figure 7. Chloride and nitrate-N concentrations (mg/L) of water samples collected from the Siefkes irrigation well.

Conversely, the August 24 sample had the highest chloride concentration and the lowest nitrate-N concentration. This sample was collected after about 16 hours of pumping and was preceeded by fairly heavy pumpage. August was the month with the most water use (fig. 5). As of August 24, 49 million gallons had been pumped (of the total 59 million gallons in 1994).

There are three factors present at the Siefkes site that probably offer some protection against irrigation well water becoming even more saline during the pumping season. The first is that the irrigation well has two screened intervals, one at 90-120 ft and a shallower one at 60-80 ft below land surface. The shallower inlet may help to dilute the salinity deeper in the formation. The second factor is the presence of an approximately 10 ft thick clay unit at 130 ft below land surface (discussed below). The third is that Mr. Siefkes does not pump continuously. As part of a program offered by the electric company, in exchange for lower electricity rates, he turns off (or does not run) irrigation wells between 2 and 9 pm. Also, prior to the 1995 pumping season, the irrigation system was converted to low pressure drop nozzles to increase efficiency.

Transition Zone Characteristics

As chloride concentrations in the Siefkes irrigation well water rose during the 1994 pumping season, so did the elevation of the 500 mg/L chloride concentration (as determined by curve fitting as explained by Garneau, 1995) in the aquifer. Information on transition zone characteristics, including the 500 mg/L chloride level, is contained in table 2 of Garneau et al. (1995). Figure 8 shows that heads in the DA and IM wells drop below the Permian head soon after the pump is turned on, and the 500 mg/L elevation begins rising soon thereafter (in both 1993 and 1994). While water levels in wells showed a net drop of 4 to 5 ft over the 1994 pumping season, the 500 mg/L elevation rose about 3 ft. This can apparently be attributed directly to pumping. Notice on figure 8 that over the pre-1994 winter, the elevations of the Permian and deep aquifer heads, and the 500 mg/L elevation dropped. But after pumping commences (1993 and 1994) and reduces the freshwater heads, the 500 mg/L elevation rises.

Chloride profiles produced from down-hole conductivity logs (Garneau, 1995) from the Siefkes Permian well show significant salinity increases during the pumping season. The detailed profiles in figure 9 show the significant salinity buildup in a permeable zone above a thick (approximately 7 ft) clay layer or lens 130 ft deep at the Siefkes site. The chloride concentration in the aquifer above the clay lens reached about 1600 mg/L in September/October. There is also a salinity buildup centered at a depth of approximately 115 ft, which is in a permaeble zone above a thinner clay lens at approximately 121 ft. The salinity buildup in these permeable zones continues through October, even after pumping has ceased. Obviously the clay layers or lenses, particularly the thicker one, offer some protection to the freshwater aquifer from the bulk saltwater below. Computer simulations by Ma and Sophocleous (1995) support this.

The 500 mg/L level dropped overwinter 1994 and in early spring 1995 to an elevation comparable to spring 1993 and 1994 levels. This reflects simulations by Ma and Sophocleous (1995), which show that recovery of upconing is significant during the nonpumping period and enhanced by recharge. The recovery of the 500 mg/L elevation and the disappearance of the salinity buildup above the clay lenses are probably due to advection and dispersion during regional flow once the well stops pumping. See also OFR 95-45a for discussion of controls on transition zone characteristics.

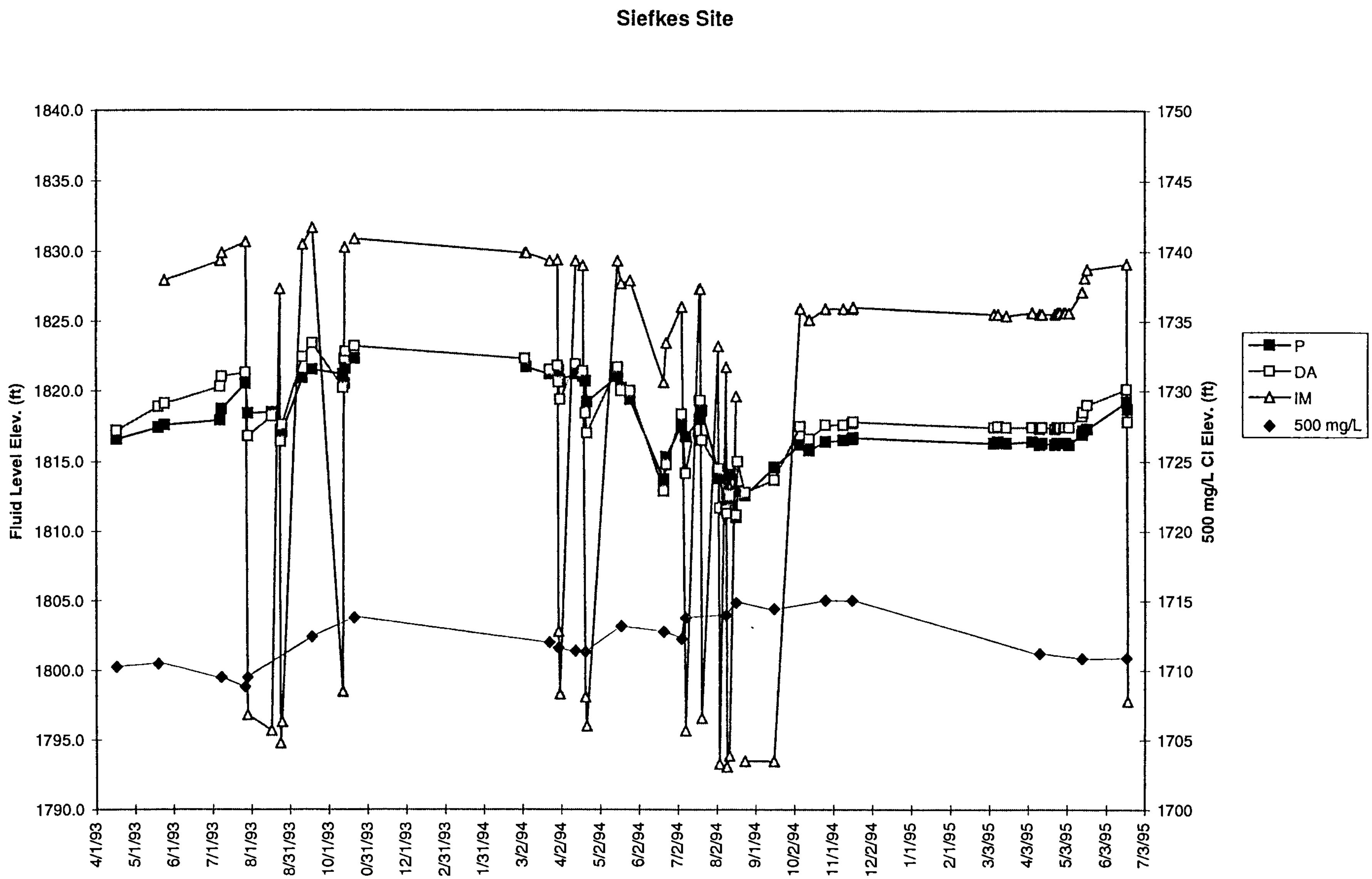

Figure 8. Hydrographs of the Permian (P), Deep Aquifer (DA), and water table (IM) monitoring wells at the Siefkes site, shown along with the elevation of the 500 mg/L chloride level estimated by Garneau et al. (1995).

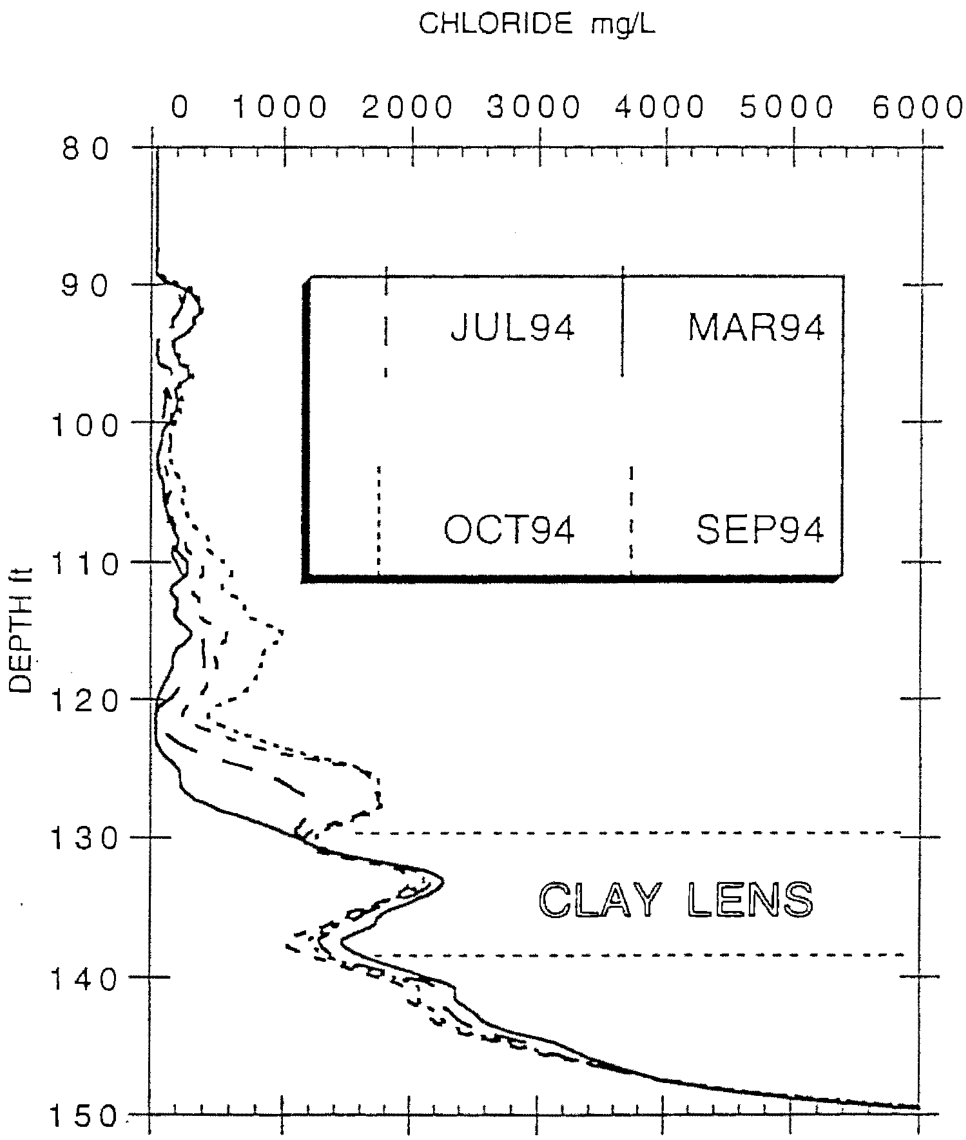

Figure 9. Detail of transition zone changes during 1994 at the Permian monitoring well following the onset of pumping at the Siefkes Intensive Study Site.

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