Kansas Geological Survey

GROUND-WATER GEOCHEMISTRY IN THE MINERAL INTRUSION AREA OF GROUNDWATER MANAGEMENT DISTRICT NO. 5, SOUTH-CENTRAL KANSAS

Donald O. Whittemore

Kansas Geological Survey Open-File Report 93-2

GEOHYDROLOGY

GROUND-WATER GEOCHEMISTRY IN THE MINERAL INTRUSION AREA OF GROUNDWATER MANAGEMENT DISTRICT NO. 5, SOUTH-CENTRAL KANSAS

Donald O. Whittemore

Kansas Geological Survey Open-File Report 93-2

With Special Acknowledgments to

Patrick M. Cobb
Long Beach, California

Thomas McClain, Lawrence Hathaway, Karmie Galle, Truman Waugh, and Jian Fan
Kansas Geological Survey

Sharon Falk and Dan Zehr
Big Bend Groundwater Management District No. 5

Ralph K. Davis
University of South Dakota

and

Edward T. Marks
Stafford, Kansas

February, 1993

Contents

EXECUTIVE SUMMARY

Saltwater from the underlying Permian bedrock naturally intrudes ground waters in the eastern portion of the unconsolidated aquifer in the Great Bend Prairie. The saline waters also discharge locally to streams in the area. In addition to the natural saltwater, there is concern that oil-field brines and agricultural activities have affected the water quality of the aquifer. A knowledge of the present distribution, concentration, and source of the saline waters and contaminated areas is necessary for preparing water-quality models of the region and for management of the ground-water resources to minimize salinity effects. This report addresses the issues of salinity sources, distribution, and variation, as well as the geochemistry of nutrient species such as nitrate in the mineral intrusion area. The report mainly concerns a geochemical analysis of water-quality data gathered for the observation well network installed as a cooperative effort between the Kansas Geological Survey and Big Bend Groundwater Management District.

The primary source of mineralized water in the Great Bend Prairie aquifer is dissolution of Permian evaporites, primarily halite (rock salt). Water quality in the Permian bedrock underlying the unconsolidated aquifer ranges from saltwater in the northwest and central portions of the observation well network to fresh in the southernmost area. The salinity of water in the bedrock appears to be related to bedrock channels and highs and to recharge and discharge zones in the overlying aquifer. The saline water in the lower part of the unconsolidated aquifer is derived from intrusion of saltwater from the Permian rocks. The distribution pattern of the saline water near the aquifer base indicates that saltwater intrusion occurs where Permian bedrock, especially the Cedar Hills Sandstone, underlies the aquifer. Cretaceous rocks in the western portion of the study area and zones of higher heads in the overlying aquifer restrict saltwater intrusion. The resulting area of saline water near the aquifer base is appreciably smaller than that for the Permian. Water in the upper part of the unconsolidated aquifer is generally fresh except in the northeastern portion of the observation well network. Saline water intrusion to the shallow aquifer is mainly controlled by discharge along streams, especially Rattlesnake Creek and parts

of the South Fork of the Ninnescah River and the Arkansas River, and in the Big and Little Salt marshes.

The salinity of ground waters in the unconsolidated aquifer increases with depth, but at greatly different rates. Comparison of the chloride distribution patterns for the upper aquifer and aquifer base reveals areas with great contrasts in salinity. High contrast locations include north-central Stafford County, a band along the Stafford-Reno county line south from Peace Creek, and northeast and north-central Pratt County. Saltwater intrusion at the aquifer base in these areas has not appreciably dispersed into the middle to upper aquifer as a result of hydrogeologic conditions. These areas are expected to be especially vulnerable to upconing of saline waters pumped by irrigation wells screened in the lower aquifer.

The salinity of aquifer waters has been increased by local contamination from oil-field brines and agricultural activities. Identifiable contribution to ground-water salinity by oil brine was found in 8 wells at 6 of the 52 sites in the observation well network. The oil brine has affected the salinity of the mid to upper aquifer at 3 of these sites and the lower aquifer at the other 3 sites. However, the oil brine contamination has made aquifer water unusable at only one of the observation wells, and the existing natural chloride is too high for irrigation and drinking use in waters from 4 of the other wells. The results suggest that about 12 percent of the region within the network might be expected to have oil-brine contamination at some depth in the aquifer, because oil fields cover a substantial percentage of the network area in addition to the sites with contamination. The percentage could range widely, depending on whether an area is within or distant from an oil field.

Agricultural activities appear to have substantially increased the chloride concentration of ground water in the upper aquifer at 3 sites in the observation well network. The sites do not occur within oil fields. The increases in chloride are associated with nitrate contents that are higher than expected for background in the aquifer. Leaching of salts concentrated in soils by evapotranspiration of irrigation waters and from fertilizers appear to be a major source of the salinity and nitrate increases.

Background values for dissolved nitrate-N in the aquifer are typically less than 2 mg/L but can sometimes approach 4 mg/L. Nitrate concentrations in the ground water generally decrease with depth in the aquifer and from the aquifer to the bedrock. Upper aquifer waters at 5 network sites contained nitrate-N greater than 10 mg/L. Only one of the sites with nitrate-N above 10 mg/L had an identifiable increase in chloride from agricultural activities. Dissolved ammonium ion levels generally increase with depth in the aquifer and into the bedrock, reflecting more reducing conditions (lower dissolved oxygen) with depth. Although ammonium-N concentrations were below 1 mg/L in most of the bedrock wells, concentrations up to 4.8 mg/L indicate that the upper limit of natural dissolved nitrogen could be higher in the bedrock than in the lower aquifer. Oxidation of ammonium ion in the bedrock could be the source of much of the nitrate in bedrock and aquifer-base waters.

There is no clear direction in the chloride concentration variations for the region as a whole during the 1980's. Chloride concentrations were nearly constant at many network well sites, while many others had increases and/or decreases. Nitrate concentrations were either nearly constant or generally increased in the upper aquifer during the data period. The well sites with high nitrate tended to show increases. Chloride concentrations both increased and decreased in upper aquifer waters with nitrate concentrations above the background. The water-quality changes appear to be related more to the local site conditions than to the environment of the network region.

ACKNOWLEDGEMENTS

Patrick Cobb, formerly of the Kansas Geological Survey (KGS), initiated the original saltwater intrusion study in cooperation with the Big Bend Groundwater Management District (GMD5) and was involved in the installation of nearly all of the observation well network. Melvin Kleinschmidt was the KGS staff member who directed the drilling and installation of the wells. Thomas McClain of the KGS was also involved in the earlier phases of the study and assisted in some of the observation well sampling. Ralph Davis was the Manager of GMD5 during much of the sampling period for this study and participated in the cooperative research. Edward Marks was a staff member of the GMD5 at that time and also assisted in the research. Sharon Falk became the Manager of GMD5 after Ralph Davis left and continued the GMD5 participation in the study. Dan Zehr later joined the GMD5 staff and also assisted in the investigation. All of their work is greatly appreciated.

Lawrence Hathaway, Section Chief, Karmie Galle, and Truman Waugh of the Analytical Services Section of the KGS analyzed the observation well network samples. Jian Fan, a graduate research assistant, assisted in producing the plates by digitizing the chloride contours and preparing the plot files using the geographic information system ARC/INFO.

Robert Buddemeier, Section Chief, Marios Sophocleous, David Young, and Margaret Townsend in the Geohydrology Section of the Kansas Geological Survey reviewed all or parts of the report. The reviews of Gerald Hargadine of the Kansas Water Office and William Bryson of the Kansas Corporation Commission are also appreciated. I gratefully acknowledge the assistance of Anna Kraxner, Secretary for the KGS Geohydrology Section, in formatting the tables and assembling the final report pages, and Mark Schoneweis, also in the Geohydrology Section, for drafting selected figures.

INTRODUCTION

This report describes the chemical character and origin of dissolved constituents in ground waters of the eastern part of Big Bend Groundwater Management District No. 5 (GMD5), where mineral intrusion affects water quality (Figure 1). Saltwater from the underlying Permian bedrock naturally intrudes ground waters in the eastern portion of the unconsolidated aquifer in the Great Bend Prairie. The saline waters also discharge locally to streams in the area. There is a concern that changes in the water balance in the system, such as freshwater withdrawals and climatic variations, could increase the intrusion of saltwater into the system.

For example, the pumping rates of water wells in the area could be great enough to cause long-term water-table declines in the aquifer. This could increase the upward flow and dispersion of saltwater into fresh ground waters. In addition to the natural saltwater, oil-field brines have caused pollution in some locations. In other cases, evaporative concentration of irrigation waters may have increased the salinity of soil moisture that is leached to the water table under recharge conditions.

A knowledge of the present distribution, concentration, and source of the saline waters and contaminated areas is necessary for preparing water-quality models of the area and for management of the ground-water resources to minimize salinity effects. In addition to salinity problems, there is concern for the concentration and distribution of other chemical constituents in the ground waters, both those that affect water uses and that are contaminants from agricultural and industrial activities.

The objectives of this study were (1) determine the areal and vertical distribution of saltwater in the unconsolidated aquifer and the uppermost portion of the underlying bedrock in the eastern half of GMD5; (2) determine the geochemical characteristics of the ground waters including areal and vertical changes and natural versus anthropogenic sources of contamination; and (3) explain the origin of the saltwater distribution by correlating the chemical characteristics of the natural waters with the hydrogeology of the system.

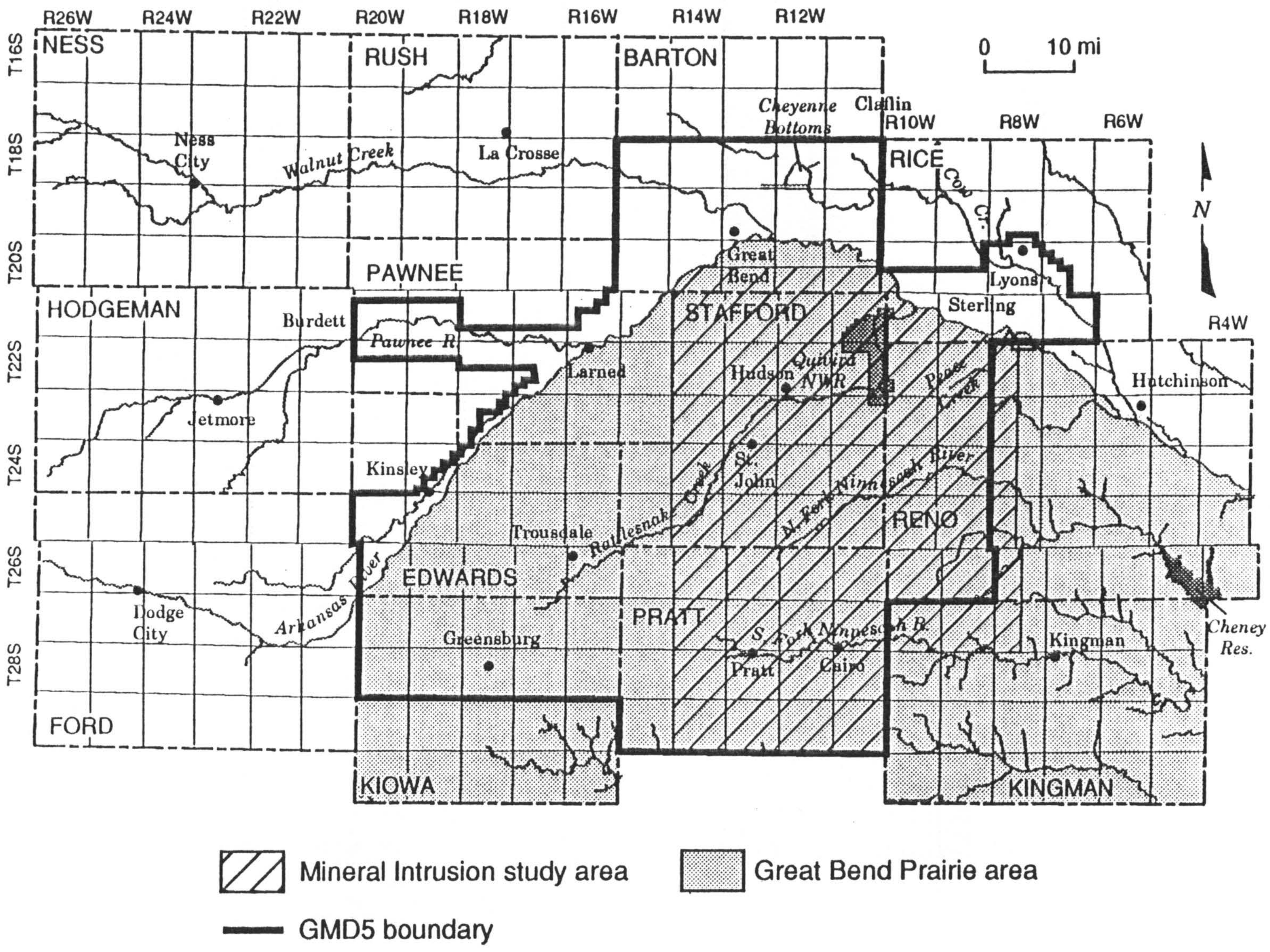

Figure 1. Major features in the region of Big Bend Groundwater Management District (GMD5) and location of the study area.

OBSERVATION WELL NETWORK

Multi-level observation wells were constructed at 52 sites in Stafford County, northern Pratt County, western Reno County, and the southwestern corner of Rice County in GMD5. The wells were constructed by the Kansas Geological Survey (KGS) and GMD5 from 1979 to 1987. The District employed a commercial water-well driller to drill the several wells not installed by the KGS. The well network was designed to have sites as near as practicable to township corners to comprise a grid with approximately six mile separations between sites in the north-south and east-west directions (Figure 2). The sites were numbered in order of installation date. The boundaries delineated by Figure 2 comprise the study area for this report and coincide with the area shown in Plates 1-3 that display the distribution of chloride in the Permian bedrock and upper and lower unconsolidated aquifer.

Three wells were drilled at most of the sites. One of the 3 wells is screened in the Permian bedrock, the second in the lower aquifer commonly at or near the base of the aquifer, and the third in the middle to upper part of the aquifer (Table 1). These are referred to as the bedrock, aquifer-base, and upper-aquifer observation wells in the text of this paper, respectively. There are 47 sites with bedrock wells, 47 sites with aquifer-base wells, and 51 sites with wells in the upper aquifer. At 7 sites, only two wells were installed, while at a few other sites, one of the wells could not serve as a sampling point due to insufficient yield. Four multi-level wells were constructed at 7 sites to allow more detailed determination of the salinity change with depth. The additional well at these sites is screened approximately in the middle of the aquifer and is referred to as the intermediate well while the uppermost well is referred to as the shallow well. One of the 3 most recently constructed sites, number 50, also includes an intermediate level well. None of the most recent sites, numbers 50-52, contains a bedrock well.

The depth to bedrock ranges from 34 to 258 ft at the sites in the network (Table 1). The top of the screened interval of the bedrock wells ranges from the bedrock-aquifer interface to 80 ft below the interface. All the bedrock wells were drilled to and screened in Permian strata. The wells drilled to the greater depths below the bedrock-aquifer interface are in the west-central part

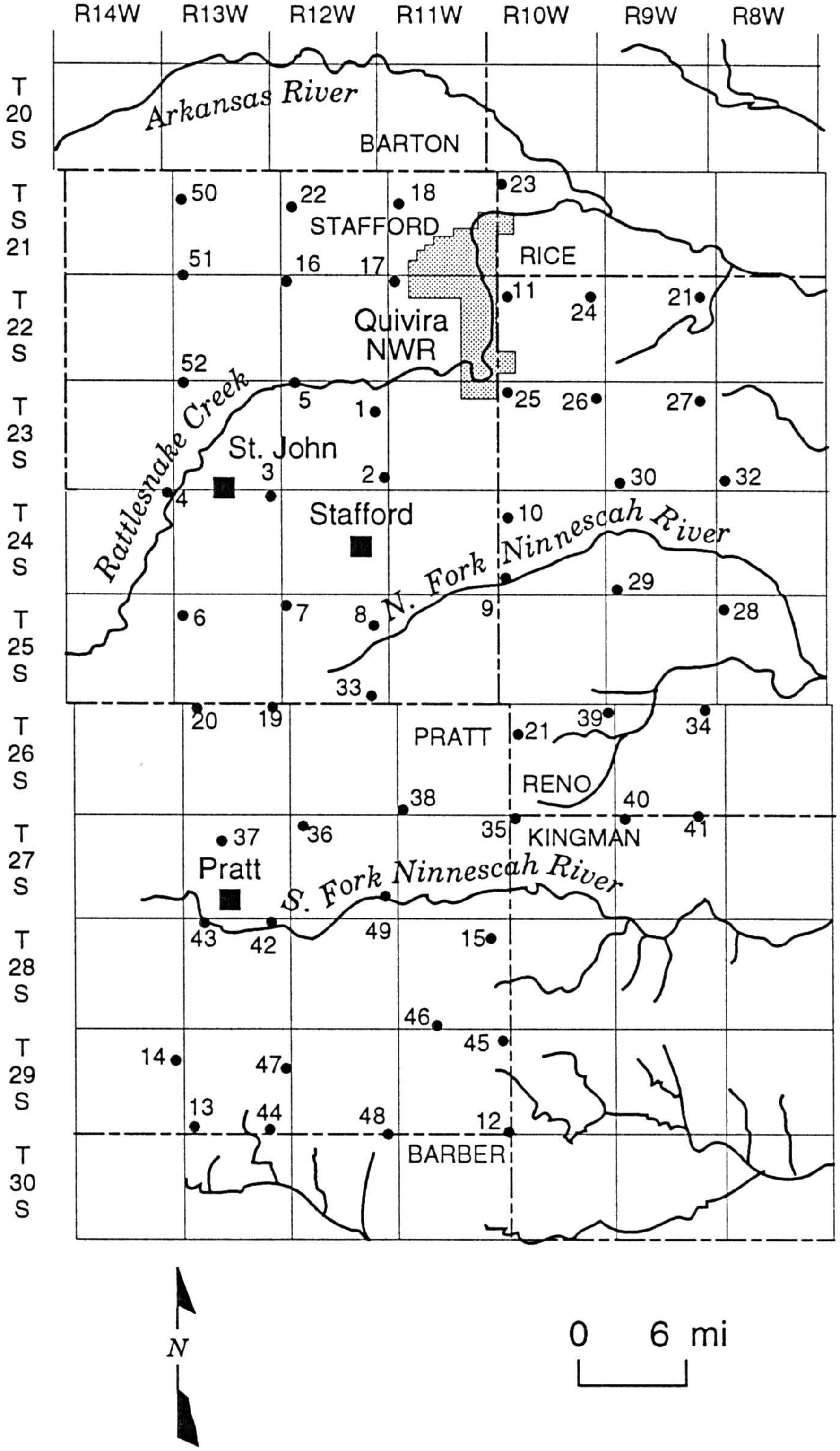

Figure 2. Locations and site numbers for the KGS/GMD5 monitoring-well network.

Table 1. Site elevations, well depths, and approximate water-level elevation for the observation well network The depth to bedrock has been corrected from the original field value using geophysical gamma logs (Rosner, 1988)

Site	Location	Ground-surface elevation	Depth to bedrock	Depths of screened interval Well 1	Well 2	Well 3	Well 4	Elevation of bedrock surface	Elevation of water table from map
1	23S 12W 12BAAA	1827	146	146-149	106-110	36- 40		1681	1821
2	23S 12W 36ABAB	1837	96	99-104	35- 38			1741	1829
3	23S 13W 36DCCC	1898	130	120-140	65- 75			1768	1881
4	23S 14W 36DDCD	1912	129	217-227	106-112	53- 58		1783	1906
5	23S 12W 06BBBA	1855	181	193-198	92-102	40- 50		1674	1850
6	25S 13W 06BCBC	1950	148	216-226	135-145	60- 70		1802	1940
7	24S 13W 36DDDD	1906	150	230-250	150-154	56- 64		1756	1897
8	25S 12W 11AAAD	1848	117	237-257	116-122	87- 92	46-50	1731	1839
9	24S 10W 31CBCB	1755	87	86- 91	62- 65	38- 43		1668	1737
10	24S 10W 06DCCC	1790	156	160-165	143-148	100-105	74-79	1634	1776
11	22S 10W 06CBBB	1763	208	237-241	61- 66			1555	1750
12	29S 11W 36ACCC	1770	142	166-171	130-136	60- 70		1628	1760
13	29S 14W 36AAAD	1905	172	182-188	120-124	53- 58		1733	1868
14	29S 14W 12ABBB	1989	238	280-285	223-228	115-120		1751	1887
15	28S 11W 01AAAD	1725	128	135-140	116-120	57- 62		1597	1690
16	21S 12W 31CCCB	1873	220	243-248	198-203	80- 85		1653	1865
17	21S 12W 36DDCC	1795	114	129-134	102-107	41- 46		1681	1775
18	21S 11W 07BBBA	1810	214	231-236	197-202	45- 50		1596	1795
19	25S 13W 36DCCC	1902	163	180-185	145-150	42- 48		1739	1891
20	25S 13W 31DDAA	1960	198	221-226	189-194	46- 51		1762	1948
21	26S 11W 01DDDA	1801	137	145-150	113-118	43- 48		1664	1776
22	21S 12W 06CCBC	1855	215	231-236	206-211	35- 45		1640	1850
23	21S 10W 06AADD	1743	94	122-127	79- 84	44- 49		1649	1722
24	22S 10W 01ADBC	1736	123	131-136	86- 91			1613	1719
25	23S 10W 06BBAB	1780	110	120-124	95-100	44- 49		1670	1777
26	23S 10W 01AAAA	1738	177	190-195	118-123	60- 65		1561	1731
27	23S 09W 01ADAA	1685	104	115-120	60- 65	30- 35		1581	1678

Table 1. (continued)

Site	Location	Ground-surface elevation	Depth to bedrock	Depths of screened interval				Elevation of bedrock surface	Elevation of water table from map
				Well 1	Well 2	Well 3	Well 4		
28	25S 09W 01ADDA	1668	114	125-130	85- 90	35- 40		1554	1632
29	24S 10W 36AAAA	1731	150	176-181	120-125	62- 65		1581	1689
30	23S 10W 36DAAA	1750	134	155-160	123-128	60- 65		1616	1730
31	22S 09W 01ADAA	1665	93	108-113	85- 90	55- 60		1572	1650
32	23S 09W 25DDDD	1689	172	189-194	161-166	113-118	78-83	1517	1680
33	25S 12W 36CBBA	1872	141	157-162	137-142	78- 83		1731	1840
34	25S 09W 36DDCC	1653	34	48- 53	29- 34			1619	1602
35	26S 10W 31CCCB	1760	153	168-173	150-155	66- 71		1607	1751
36	27S 12W 06BAAB	1892	195	210-215	191-196	146-151	85-90	1697	1869
37	27S 13W 05CABB	1971	238	255-260	235-240	151-156	82-87	1733	1919
38	26S 12W 36ADDA	1844	189	204-209	187-192	80- 85		1655	1814
39	26S 10W 01AAAA	1679	55	73- 78	53- 58	15- 20		1624	1667
40	26S 09W 31CDDD	1735	158	176-181	156-161	97-102		1577	1680
41	26S 09W 35ADAD	1654	83	98-103	78- 83	29- 34		1571	1650
42	28S 13W 01CBAA	1829	160	178-183	157-162	103-108		1669	1814
43	27S 13W 31DDDD	1872	65	88- 93	40- 45			1807	1870
44	29S 13W 35ABBA	1891	186	203-208	173-178	121-126	78-83	1705	1830
45	29S 11W 01DADA	1795	178	192-197	150-155	85- 90		1617	1754
46	29S 11W 06AAAB	1830	177	195-200	164-169	78- 83		1653	1800
47	29S 13W 12ABBA	1900	177	188-193	158-163	82- 87		1723	1828
48	29S 12W 36DCCD	1842	178	187-192	162-167	114-119		1664	1788
49	27S 12W 35AAAA	1737	106	116-121	89- 94	51- 56	27-32	1631	1730
50	21S 13W 06BCCC	1912	223	190-195	120-125	45- 50		1689	1895
51	21S 14W 36DDDA	1915	200	170-175	95-100			1715	1913
52	23S 13W 06BBBC	1920	221	195-200	97-102			1699	1905

of the network and penetrate Cretaceous rocks to reach the Permian. The screened intervals are generally 5 ft in length and range from 3 to 20 ft depending on the character of the bedrock and the construction of the well. Several of the bedrock wells have two-inch diameter casing and screen within the bedrock. The PVC casing and screen for the rest of these wells and all other wells are 5 inch diameter. Screened intervals for most of the Quaternary aquifer wells is 5 ft, with a range of 3-10 ft. Wells were sealed using cement grout.

PROCEDURE

Water samples were collected from the multiple-level wells in the observation well network by the KGS and GMD5. A few casing volumes were pumped from each well to remove any remaining drilling fluid and sediment in the well to provide representative samples. Specific conductance and temperature were monitored during pumping at many sites to help determine when waters representative of the screened interval could be collected. In several cases, flow rates of wells screened in bedrock of relatively low permeability were so slow that only one casing volume could be removed at one time. Some of these wells yielded samples for which high laboratory pH (values above 9 units) indicated that the water pumped was affected by the cement grouting. These wells were resampled until the pH fell to or below 8.5 units. Results with very high pH values were discarded, although values for selected constituents such as chloride and sulfate were retained for samples with pH's less than 10.

Most of the chemical data in this report were determined in the laboratories of the KGS in Lawrence. Samples for determination of chemical properties and inorganic constituents were collected in polyethylene bottles and refrigerated in an ice chest in the field and transferred to a refrigerator after transportation to the laboratory. Samples in which phosphate and nitrogen species were determined were preserved in the field with 2 mL of 6M redistilled HCl. Samples were kept refrigerated until analysis. Charge-balance errors were less than 3 percent for most samples and less than 5 percent for nearly all samples. The larger balance errors were for samples containing relatively small concentrations of total-dissolved solids.

Other chemical data included were determined in the office laboratory of GMD5. The GMD5 analyses include chloride, nitrate, and sulfate concentrations determined using a Hach spectrophotometer and analysis kits. Samples for these analyses were usually refrigerated in the field and office before analysis. Chloride, sulfate, and nitrate were determined by the KGS on 14, 10, and 7 of the same samples, respectively, analyzed by the Groundwater Management District. The average difference between the chloride, sulfate, and nitrate determinations of the Survey and the District are 17, 19, and 20 percent, respectively. Most of the Groundwater Management District values were higher than those of the KGS. The maximum estimated error in the chloride, sulfate, and nitrate determinations of the KGS are 3, 5, and 5 percent, respectively, for concentrations more than an order of magnitude greater than the detection limit. The maximum average error in the GMD5 values are about 20 percent for the 3 constituent determinations.

There is also the possibility that some of the differences between the GMD5 and KGS values are not analytical, but due to sampling. As indicated in the section on variations in salinity below, changes in constituent concentrations could have occurred during pumping due to mixing of waters of differing quality. Assuming that the duplicate samples analyzed by both the KGS and the GMD were collected one after another rather than split from the same sample, some of the differences may be real. The analytical error in the determinations of the District are on the same order as those of many commercial laboratories (Whittemore, 1983). The analyses of the District are good enough to serve their intended purpose, i.e., to determine general water quality and detect substantial changes in constituent concentrations.

The plates illustrating the chloride distribution were produced by first plotting the well network and other available chloride data on a study area map. The isochlors on the plates were hand drawn and considered the chloride point data and the hydrogeology of the study region. The contours were digitized and the digital data processed using the geographic information system software ARC/INFO on a Data General computer. The maps were printed with a Calcomp electrostatic plotter.

HYDROGEOLOGY

The unconsolidated aquifer of the Great Bend Prairie consists of alluvial sands and gravels with interbedded silts and clays deposited by the ancestral Arkansas River. The age of most of the sediment is Quaternary, although some Tertiary deposits probably also occur in the subsurface (Fader and Stullken, 1978). The regional flow in the aquifer is to the east, the same direction as the general topographic slope. Locally, the aquifer waters discharge to streams, including Rattlesnake Creek and the North Fork and South Fork of the Ninnescah River.

The thickness of the unconsolidated sediments underlying the study area range considerably. Thicknesses are generally greatest in valleys cut into the underlying bedrock. In general, the more permeable sand and gravel layers occur in the middle to lower portions of the aquifer, as is typical for most alluvial deposits in Kansas. Discontinuous lenses of low-permeability clays retard both the downward and upward vertical movement of water in the system. Reports describing aspects of the aquifer hydrogeology of the area include Fader and Stullken (1978), Cobb (1980), and Sophocleous and McAllister (1990).

Bedrock underling the unconsolidated aquifer consists of sandstone, siltstone, and shale and is of Cretaceous age in the western part of the study area and Permian in the east (Figure 3). Portions of the Permian red beds contain salt beds or are salt-cemented. Dissolution of the salt has resulted in saltwaters in the bedrock, the source of the natural mineral intrusion to the overlying alluvial aquifer and streams. A descriptive review of the Permian bedrock and its hydrologic relation to the overlying Great Bend Prairie aquifer was written as part of the Mineral Intrusion Study (Young, 1992).

RESULTS OF CHEMICAL ANALYSES

Summaries of the major chemical characteristics for the bedrock, aquifer base, and upper aquifer observation wells are in Tables 2, 3, and 4, respectively; complete sample results for the KGS analyses are in Appendices A-C, D-F, and G-I, respectively. Additional sample results from GMD5 are in Appendix J. A general summary of the ranges for all the constituents

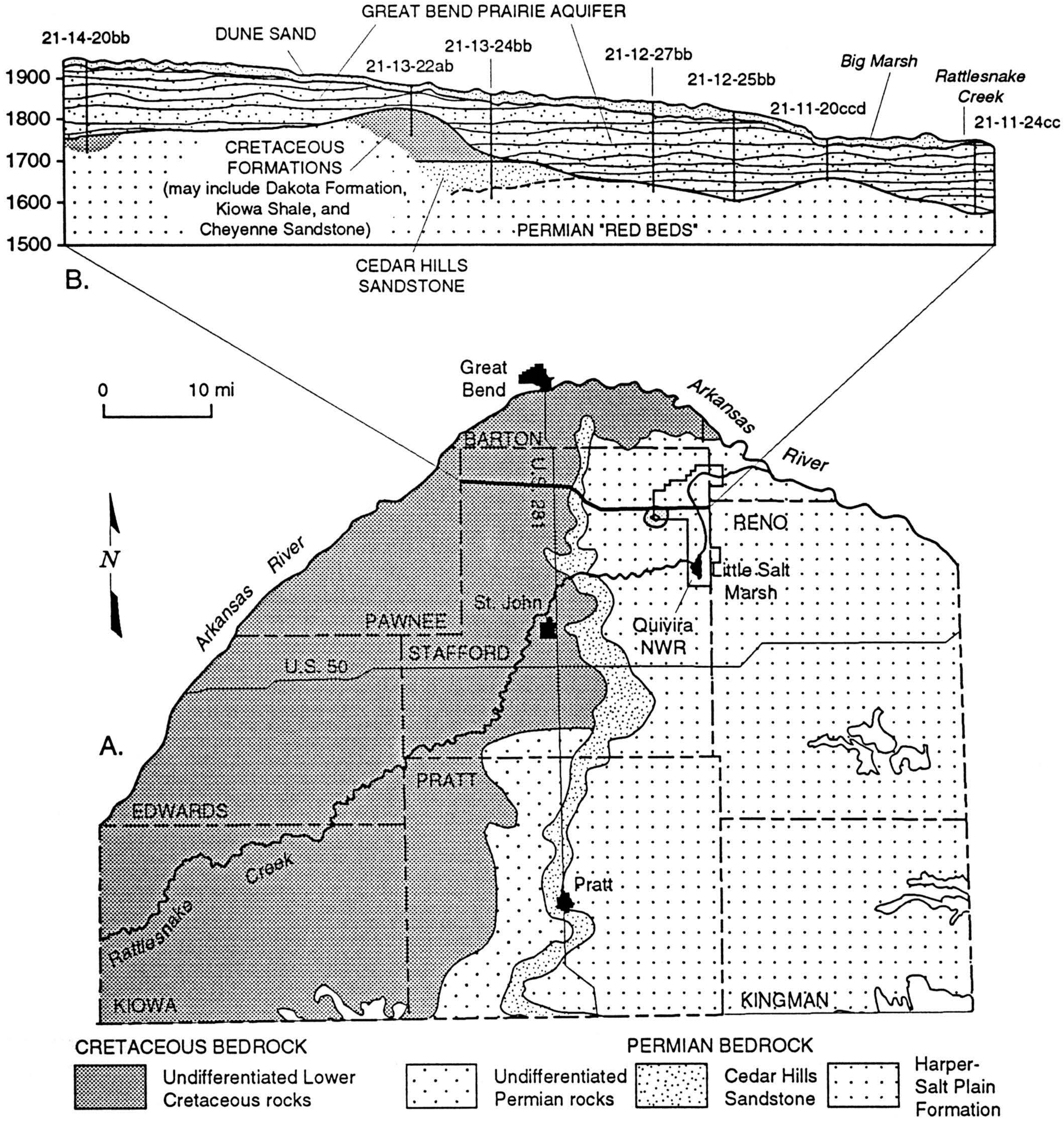

Figure 3. A. Bedrock geology underlying beneath the Great Bend Prairie aquifer and areas in which the Permian formation has the potential to contribute salt water to the overlying aquifer (adapted from Fader and Stullken, 1978). B. Vertical section from west to east across the region, showing the relation of the alluvial Great Bend Prairie aquifer to the underlying Cretaceous and Permian formations (adapted from Latta, 1950).

Table 2. Major chemical characteristics of waters from the bedrock observation wells.

Site-well	Location	Sp.C. uS/cm	Chloride mg/L	Water type
1-1	23S 12W 12BAAA	36900	13200	Na-Cl
2-1	23S 12W 36ABAB	2630	725	Na-Cl
4-1	23S 14W 36DDCD	77600	31000	Na-Cl
5-1	23S 12W 06BBBA	85500	41200	Na-Cl
6-1	25S 13W 06BCBC	102000	42640	Na-Cl
7-1	24S 13W 36DDDD	75900	34200	Na-Cl
8-1	25S 12W 11AAAD	106000	43800	Na-Cl
9-1	24S 10W 31CBCB	10700	3280	Na-Cl
10-1	24S 10W 06DCCC	6230	1710	Na-Cl
11-1	22S 10W 06CBBB	66900	25000	Na-Cl
12-1	29S 11W 36ACCC	680	79	Na,Ca-HCO3,Cl
13-1	29S 14W 36AAAD	443	23	Ca-HCO3
14-1	29S 14W 12ABBB	640	34	Ca-HCO3
15-1	28S 11W 01AAAD	2130	466	Na-Cl
16-1	21S 12W 31CCCB	88500	34800	Na-Cl
17-1	21S 12W 36DDCC	28900	9880	Na-Cl
18-1	21S 11W 07BBBA	35200	12200	Na-Cl
19-1	25S 13W 36DCCC	995	192	Na,Ca-Cl,HCO3
20-1	25S 13W 31DDAA	17400	5200	Na-Cl
21-1	26S 11W 01DDDA	35100	11700	Na-Cl
22-1	21S 12W 06CCBC	82600	32500	Na-Cl
23-1	21S 10W 06AADD	21300	6480	Na-Cl
24-1	22S 10W 01ADBC	6310	1820	Na-Cl
25-1	23S 10W 06BBAB	41000	17400	Na-Cl
26-1	23S 10W 01AAAA	37100	13470	Na-Cl
27-1	23S 09W 01ADAA	6510	1841	Na-Cl
28-1	25S 09W 01ADDA	3560	890	Na-Cl
29-1	24S 10W 36AAAA	60000	22000	Na-Cl
30-1	23S 10W 36DAAA	8000	2410	Na-Cl
31-1	22S 09W 01ADAA	6520	1771	Na-Cl
32-1	23S 09W 25DDDD	7150	1864	Na-Cl
33-1	25S 12W 36CBBA	4250	1160	Na-Cl
34-1	25S 09W 36DDCC	635	74	Ca-HCO3
35-1	26S 10W 31CCCB	21400	6750	Na-Cl
36-1	27S 12W 06BAAB	56800	21800	Na-Cl
37-1	27S 13W 05CABB	7700	2310	Na-Cl
38-1	26S 12W 36ADDA	6910	1908	Na-Cl
39-1	26S 10W 01AAAA	36300	12300	Na-Cl
40-1	26S 09W 31CDDD	2720	663	Na-Cl
41-1	26S 09W 35ADAD	5460	1460	Na-Cl
42-1	28S 13W 01CBAA	15500	4900	Na-Cl
43-1	27S 13W 31DDDD	7500	2198	Na-Cl
44-1	29S 13W 35ABBA	238	23	Na,Ca-Cl,SO4
45-1	29S 11W 01DADA	810	113	Na-HCO3
46-1	29S 11W 06AAAB	1460	313	Na-Cl
47-1	29S 13W 12ABBA	510	31	*
48-1	29S 12W 36DCCD	453	33	Na-HCO3
49-1	27S 12W 35AAAA	84800	32700	Na-Cl

* No complete analysis for sample

Table 3. Major chemical characteristics of waters from the aquifer-base observation wells.

Site-well	Location	Sp.C. uS/cm	Chloride mg/L	Water type
1-2	23S 12W 12BAAA	7000	1980	Na-Cl
3-1	23S 13W 36DCCC	1590	361	Na-Cl
4-2	23S 14W 36DDCD	3320	869	Na-Cl
5-2	23S 12W 06BBBA	55700	20700	Na-Cl
6-2	25S 13W 06BCBC	1730	396	Na-Cl
7-2	24S 13W 36DDDD	991	159	Na-Cl,HCO3
8-2	25S 12W 11AAAD	1420	287	Na-Cl
9-2	24S 10W 31CBCB	5040	1480	Na-Cl
10-2	24S 10W 06DCCC	4900	1340	Na-Cl
12-2	29S 11W 36ACCC	320	8	Ca-HCO3
13-2	29S 14W 36AAAD	395	13	Ca-HCO3
14-2	29S 14W 12ABBB	375	21	Ca,Na-HCO3
15-2	28S 11W 01AAAD	1400	318	Ca,Na-Cl
16-2	21S 12W 31CCCB	79100	30800	Na-Cl
17-2	21S 12W 36DDCC	26000	8750	Na-Cl
18-2	21S 11W 07BBBA	30900	10700	Na-Cl
19-2	25S 13W 36DCCC	1390	300	Na-Cl
20-2	25S 13W 31DDAA	1220	230	Na-Cl
21-2	26S 11W 01DDDA	8020	2320	Na-Cl
22-2	21S 12W 06CCBC	68900	26200	Na-Cl
23-2	21W 10W 06AADD	5150	1020	Na-Cl
25-2	23S 10W 06BBAB	65100	24900	Na-Cl
26-2	23S 10W 01AAAA	34500	12360	Na-Cl
27-2	23S 09W 01ADAA	2800	719	Na-Cl
28-2	25S 09W 01ADDA	758	135	Na-Cl,HCO3
29-2	24S 10W 36AAAA	1620	445	Na-Cl
30-2	23S 10W 36DAAA	1710	362	Na-Cl
31-2	22S 09W 01ADAA	2350	518	Na-Cl
32-2	23S 09W 25DDDD	5300	1476	Na-Cl
33-2	25S 12W 36CBBA	1980	467	Na-Cl
34-2	25S 09W 36DDCC	402	4	Ca-HCO3
35-2	26S 10S 31CCCB	2670	689	Na-Cl
36-2	27S 12W 06BAAB	46600	16850	Na-Cl
38-2	26S 12W 36ADDA	6620	1834	Na-Cl
39-2	26S 10W 01AAAA	930	158	Na,Ca-Cl,HCO3
40-2	26S 09W 31CDDD	1610	319	Na-Cl
41-2	26S 09W 35ADAD	879	148	Na-Cl,HCO3
42-2	28S 13W 01CBAA	14200	4470	Na-Cl
44-2	29S 13W 35ABBA	400	16	Ca-HCO3
45-2	29S 11W 01DADA	477	14	Ca-HCO3
46-2	29S 11W 06AAAB	610	61	Na-HCO3
47-2	29S 13W 12ABBA	470	35	Ca,Na-HCO3
48-2	29S 12W 36DCCD	309	9	Ca,Na-HCO3
49-2	27S 12W 35AAAA	3830	1064	Na-Cl
50-1	21S 13W 06BCCC	1040	158	*
51-1	21S 14W 36DDDA	4980	1350	Na-Cl
52-1	23S 13W 06BBBC	940	155	Na,Ca-Cl,HCO3

* No complete analysis for sample

Table 4. Major chemical characteristics of waters from the upper-aquifer observation wells.

Site-well	Location	Sp.C. uS/cm	Chloride mg/L	Water type
1-3	23S 12W 12BAAA	410	14	Ca-HCO3
2-2	23S 12W 36ABAB	1020	127	Ca,Na-HCO3,Cl
3-2	23S 13W 36DCCC	578	46	Ca,Na-HCO3
4-3	23S 14W 36DDCD	1000	165	Na,Ca-HCO3,Cl
5-3	23S 12W 06BBBA	810	99	Ca-HCO3,Cl
6-3	25S 13W 06BCBC	1440	338	Na,Ca-Cl
7-3	24S 13W 36DDDD	690	56	Ca,Na-HCO3
8-3	25S 12W 11AAAD	1280	242	Na-Cl,HCO3
8-4	25S 12W 11AAAD	1190	201	Na-Cl,HCO3
9-3	24S 10W 31CBCB	3210	787	Na-Cl
10-3	24S 10W 06DCCC	2420	598	Na-Cl
10-4	24S 10W 06DCCC	1000	179	Ca,Na-Cl,HCO3
11-2	22S 10W 06CBBB	4000	1070	Na-Cl
12-3	29S 11W 36ACCC	478	7	Ca-HCO3
13-3	29S 14W 36AAAD	424	11	Ca-HCO3
14-3	29S 14W 12ABBB	200	18	Na,Ca-HCO3,Cl
15-3	28S 11W 01AAAD	552	25	Ca-HCO3
16-3	21S 12W 31CCCB	503	22	Ca-HCO3
17-3	21S 12W 36DDCC	672	28	Ca-HCO3
18-3	21S 11W 07BBBA	371	31	Ca-HCO3,Cl
19-3	25S 13W 36DCCC	495	25	Ca-HCO3
20-3	25S 13W 31DDAA	500	27	Ca-HCO3
21-3	26S 11W 01DDDA	821	92	Ca,Na-HCO3,Cl
22-3	21S 12W 06CCBC	460	9	Ca-HCO3
23-3	21S 10W 06AADD	890	159	Na-Cl,HCO3
24-2	22S 10W 01ADBC	1280	278	Na-Cl
25-3	23S 10W 06BBAB	61300	23100	Na-Cl
26-3	23S 10W 01AAAA	3160	762	Na-Cl
27-3	23S 09W 01ADAA	2700	290	Ca,Na-Cl+NO3
28-3	25S 09W 01ADDA	280	9	Ca,Na-HCO3
29-3	24S 10W 36AAAA	362	17	Ca-HCO3
30-3	23S 10W 36DAAA	400	20	Na,Ca-HCO3
31-3	22S 09W 01ADAA	1600	295	Na-Cl,HCO3
32-3	23S 09W 25DDDD	5700	1600	Na-Cl
32-4	23S 09W 25DDDD	1950	412	Na-Cl
33-3	25S 12W 36CBBA	488	27	Ca-HCO3
35-3	26S 10W 31CCCB	451	10	Ca-HCO3
36-3	27S 12W 06BAAB	921	172	Na,Ca-Cl,HCO3
36-4	27S 12W 06BAAB	495	30	Ca,Na-HCO3
37-3	27S 13W 05CABB	385	19	Ca,Na-HCO3
37-4	27S 13W 05CABB	443	16	Ca-HCO3
38-3	26S 12W 36ADDA	218	19	Na,Ca-HCO3,Cl+NO3
39-3	26S 10W 01AAAA	1100	55	Ca-HCO3,Cl+NO3
40-3	26S 09W 31CDDD	462	5	Ca-HCO3
41-3	26S 09W 35ADAD	346	19	Ca,Na-HCO3
42-3	28S 13W 01CBAA	660	84	Ca,Na-HCO3,Cl
43-2	27S 13W 31DDDD	460	37	Ca,Na-HCO3
44-3	29S 13W 35ABBA	370	14	Ca,Na-HCO3

Table 4. Major chemical characteristics of waters from the upper-aquifer observation wells. (continued)

Site-well	Location	Sp.C. uS/cm	Chloride mg/L	Water type
45-3	29S 11W 01DADA	462	6	Ca-HCO3
46-3	29S 11W 06AAAB	470	9	Ca-HCO3
47-3	29S 13W 12ABBA	425	12	Ca-HCO3
48-3	29S 12W 36DCCD	370	3	Ca-HCO3
49-3	27S 12W 35AAAA	2270	560	Na-Cl
49-4	27S 12W 35AAAA	458	48	Na,Ca-HCO3,Cl
50-2	21S 13W 06BCCC	600	37	*
50-3	21S 13W 06BCCC	600	42	Ca-HCO3,Cl
51-2	21S 14W 36DDDA	500	20	Ca-HCO3
52-2	23S 13W 06BBBC	440	17	Ca-HCO3

* No complete analysis for sample

determined at the 3 different well depths is given in Table 5.

The quality of ground waters from the observation wells ranges from very fresh, i.e., substantially less than 1,000 mg/L total-dissolved-solids (TDS) concentration and approximately less than 1,800 uS/cm (the same as umho/cm) specific conductance, to brine. The greatest concentrations of dissolved constituents that exist in the study are generally in the bedrock, up to 89,300 mg/L TDS, although the aquifer base wells contain up to 58,100 mg/L TDS. The upper aquifer waters usually range from very fresh to moderately saline, up to 3,190 mg/L TDS, except for site 25 which yields saltwater with 41,200 mg/L TDS.

Except for bicarbonate ion, the major cation and anion concentrations vary directly with the specific conductance and TDS concentration. Chloride values range the most widely, 4-43,800, 2.4-32,000, and 2.4-23,100 mg/L in the bedrock, aquifer base, and upper aquifer, respectively. The lower values in the range of dissolved bicarbonate concentrations tend to be associated with very fresh waters and the most concentrated saltwaters, but otherwise, there is little correlation with dissolved solids. Dissolved silica ranges the least, 8.2-99 mg/L, with most concentrations between 20 and 40 mg/L. The upper limit of the silica range increases from the upper aquifer to the bedrock.

Potassium, strontium, boron, and bromide contents generally increase with increasing salinity of the sample. Higher ammonia levels tend to be found in the bedrock and aquifer base waters. Nitrate concentrations are generally higher in the fresh and lower salinity ground waters of the upper aquifer. The range in phosphate was relatively similar for the 3 different well depths, although the upper limits increased from the upper aquifer to the bedrock. Nitrite was detected (>0.01 mg/L) in only 3 of 21, 3 of 31, and 5 of 48 samples analyzed for this dissolved constituent from the bedrock, aquifer base, and upper aquifer.

CHEMICAL WATER TYPES

Of the 47 observation wells in Permian bedrock, all but eight yield waters of Na-Cl type (Table 2). All eight of the ground waters of chemical type other than Na-Cl are fresh. There are

Table 5. Range in specific conductance and dissolved constituent concentrations in waters from the observation well network. Specific conductance is in µS/cm and the other constituent values are in mg/L.

Constituent	Bedrock	Aquifer base	Upper aquifer
Spec. conductance	238 - 100600	309 - 80600	218 - 62000
Total diss. solids	155 - 89300	205 - 57300	150 - 41200
Silica	8 - 99	18 - 65	16 - 56
Calcium	16 - 2000	30 - 948	14 - 726
Magnesium	1 - 890	4 - 514	2 - 313
Sodium	12 - 30800	14 - 21000	10 - 14900
Potassium	1.4 - 104	1.5 - 90	1.1 - 39
Strontium	0.2 - 38	0.16 - 16	0.1 - 12
Bicarbonate	25 - 423	74 - 396	73 - 383
Sulfate	9 - 6290	10 - 3830	5 - 2770
Chloride	4 - 43800	3 - 32000	3 - 23600
Fluoride	0.1 - 0.9	0.2 - 0.9	0.1 - 0.6
Bromide	<0.03 - 7.2	0.03 - 4.0	0.03 - 3.6
Nitrate-N	<0.02 - 12	<0.02 - 5.6	<0.02 - 73
Nitrite-N	<0.01 - 0.3	<0.01 - 0.02	<0.01 - 0.04
Ammonium-N	<0.02 - 4.8	<0.02 - 1.8	<0.02 - 0.06
Phosphate-P	0.03 - 0.4	0.02 - 0.7	<0.03 - 0.8
Boron	0.04 - 8.8	0.04 - 5.5	0.02 - 11

five different types of waters in this group ranging from Na,Ca-Cl,HCO_3 to Ca-HCO_3. Ground waters in the bedrock are, except for two sites, all of Na-Cl type in the northern and central parts of the observation-well network. In the southern part of the network the waters change from Na-Cl progressively to Na,Ca-Cl,HCO_3 to Na,Ca-HCO_3,Cl to Na-HCO_3 to Na,Ca-Cl,SO_4 to Ca-HCO_3. The direction of the change towards Ca-HCO_3 ground waters is not only toward the south, but also towards the southwest where the freshest waters in the bedrock are located.

The change from Na-Cl to Ca-HCO_3 type waters is also shown on a trilinear diagram in Figure 4 as points largely grouped along straight-line trends in each part of the diagram. These trends are primarily interpreted as mixing of fresh, Ca-HCO_3 type waters with various amounts of Na-Cl type waters. One water, site 44, in the anion triangle of Figure 4 falls outside the trend due to a larger percentage of sulfate than for other the ground waters in the bedrock. This water also had the lowest percentage of magnesium in the cation triangle. Although the points representing waters for sites 45 and 48 fall within mixing trends for the individual cation and anion parts of Figure 4, the points fall well outside the mixing trend in the composite chemical part (the diamond). Waters in the bedrock at these two sites are Na-HCO_3 and probably derived their increased sodium and bicarbonate contents by concomitant ion exchange and calcite dissolution. The higher sodium content for water at site 15 than for the mixing trend may also have been derived from ion exchange. Adjustment in carbonate mineral equilibria would not have had as great an affect on the percentage of bicarbonate because the sulfate and chloride concentrations are appreciably higher than at sites 45 and 48.

Ground waters of Na-Cl type occur over a smaller proportion of the observation-well network in the deep part of the aquifer than in the underlying bedrock (Table 3). Of the 47 observation wells at or near the aquifer base, 30 yield waters of Na-Cl type. All 17 of the ground waters of chemical type other than Na-Cl are fresh. The trend of water types with generally decreasing concentration of dissolved solids is Na-Cl to Ca,Na-Cl to Na-Cl,HCO_3 to Na,Ca-Cl,HCO_3 to Na-HCO_3 to Ca,Na-HCO_3 to Ca-HCO_3. The change is similar to, but not identical to that in the bedrock across the network area. The Na-Cl waters are distributed primarily in the northern part

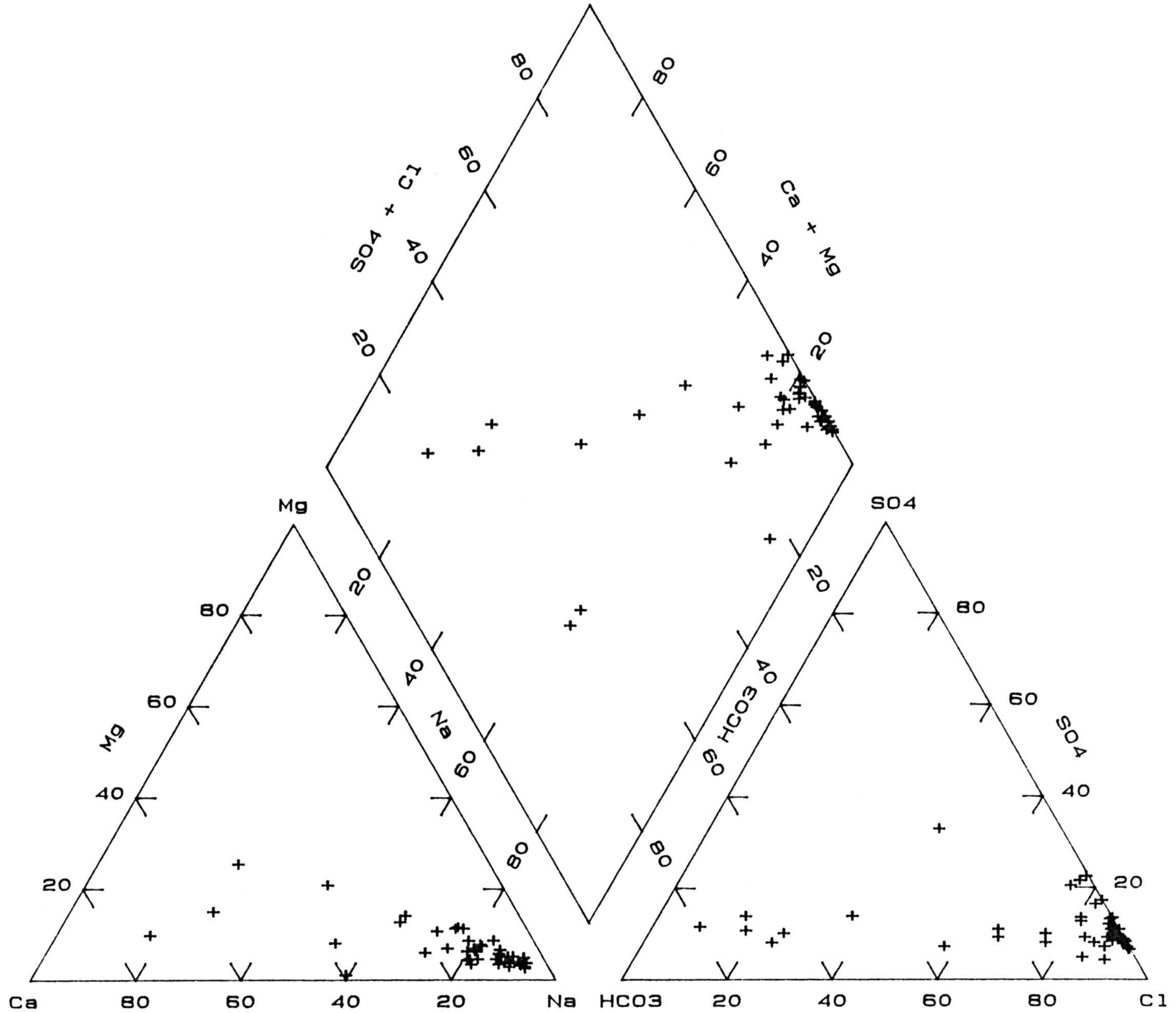

Figure 4. Trilinear diagram of major chemical constituents in Permian bedrock waters sampled from the observation well network.

of the network area and extend into the south through part of the central region of the area. Changes to higher percentages of calcium and bicarbonate contents in the waters are not only towards the south, but also towards the east and west in the southern half of the network.

Mixing trends from sodium to calcium rich and from chloride to bicarbonate-rich ground waters in the deep aquifer are both relatively well defined in the triangular parts of Figure 5, i.e., the scatter of points is occurs within a narrow zone. The chemical composite part of Figure 5 (the diamond), however, displays a much wider band of points than that for the bedrock and which are distributed on both sides of the main mixing trend in Figure 4. These differences are probably related primarily to a combination of the effects of ion exchange and calcite solution/precipitation coupled with mixing of different water types from both the aquifer and the underlying bedrock.

The distribution of chemical types of ground waters in the upper aquifer in the observation-well network (Table 4) is much more complex than that in both the deep aquifer and the bedrock. The water types in order of generally increasing concentrations of dissolved solids range from Na-Cl to Na,Ca-Cl to Ca,Na-Cl+NO_3, to Na-Cl,HCO_3 to Na,Ca-HCO_3,Cl and Na,Ca-HCO_3,Cl+NO_3, to Ca,Na-HCO_3,Cl to Ca-HCO_3,Cl and Ca-HCO_3,Cl+NO_3, to Na,Ca-HCO_3 to Ca,Na-HCO_3 to Ca-HCO_3. Seven sites have Na-Cl type water. Twenty-four of the 52 sites yield shallow ground waters of Ca-HCO_3 type and 6 of Ca,Na-HCO_3 type. The area of Na-Cl waters is relatively small in comparison to that of the deep aquifer and bedrock; Na-Cl water occurs primarily in the north-eastern part and at one site in the central part of the network. A band of mixed cation and anion waters with a core in which sodium and chloride are the predominate cation and anion, respectively, extends from around the Na-Cl water in the north-central part towards the southwestern portion of the network area. The largest areas of Ca-HCO_3 type waters are in the southeast and northwest, while other sites with Ca-HCO_3 waters are scattered in the west-central, east-central, and southwestern parts of the network.

The mixing trends for both cations and anions in upper aquifer waters are similar to those in the base of the aquifer and are displayed as narrow bands of points on the triangular parts of

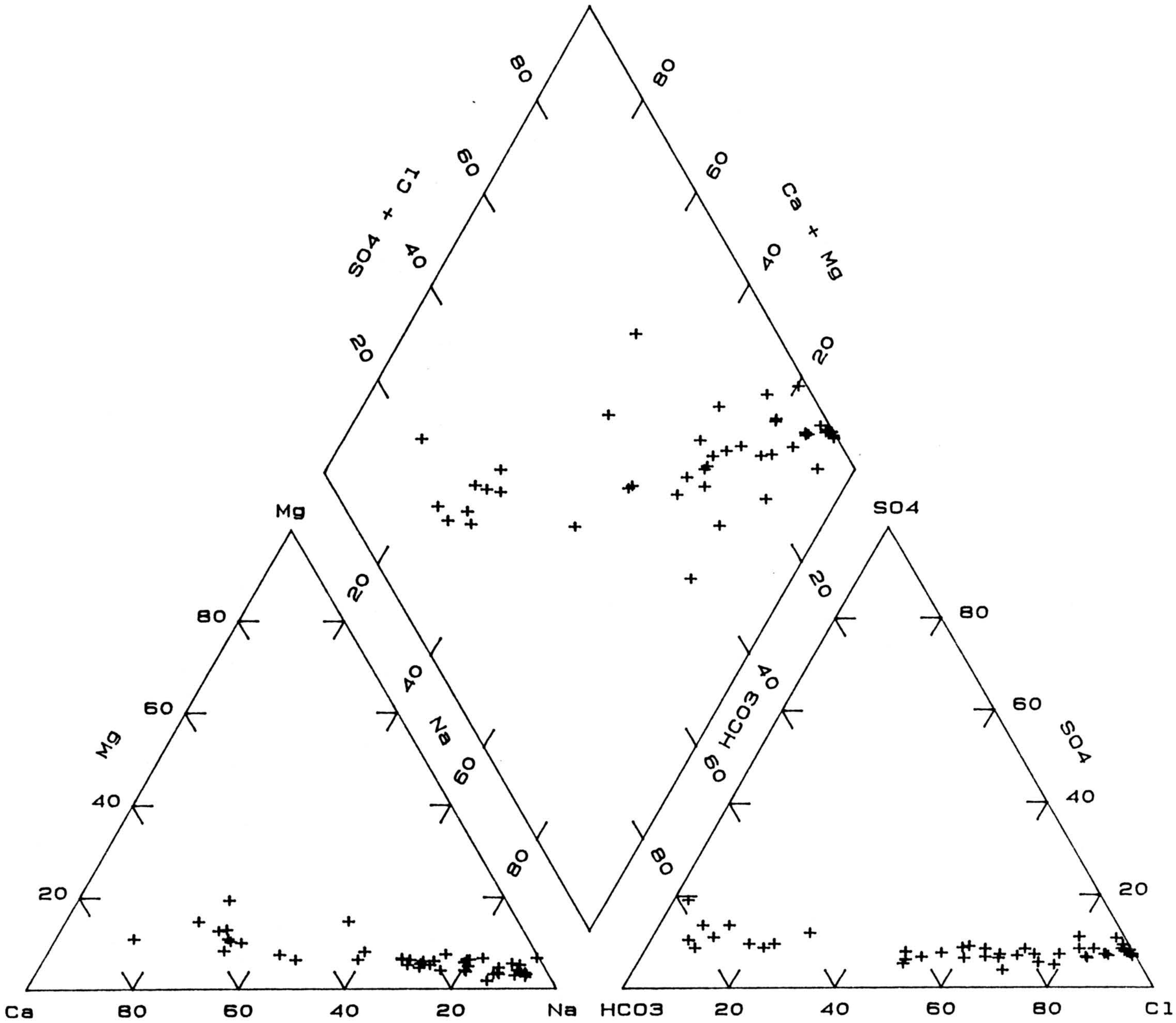

Figure 5. Trilinear diagram of major chemical constituents in waters near the unconsolidated aquifer base sampled from the observation well network.

Figure 6. Points for upper aquifer waters on the composite part of the trilinear diagram (the diamond) are distributed in a wide band. Much of this range in water type is probably due to a combination of mixing of different water types and the effect of ion exchange and calcite equilibria. However, additional effects are contamination by oil-field brines and infiltration of saline soil waters with high concentrations of nitrate from agricultural activities as discussed later. Nitrate concentrations at a few of the sites are high enough, relative to other constituents, that the mixed-anion type of water includes nitrate as indicated by $Cl+NO_3$ in the types progression above. The smaller range in dissolved-solids contents of most of the ground waters in the upper aquifer also contributes to the wider scatter of points on the composite part of Figure 6 as compared to Figures 4 and 5, because small changes in constituent concentrations can affect ion ratios more. The progressively smaller scatter of points along the mixing trends in the triangular parts of Figures 5 and 6 for the aquifer in comparison with Figure 4 for the bedrock indicates that the ranges in magnesium and sulfate concentrations relative to those of the other major constituents is greater in the bedrock waters.

AREAL DISTRIBUTION OF SALINITY

Plates 1-3 display the areal distribution of chloride concentrations in the Permian bedrock, near the aquifer base, and in the upper aquifer, respectively. The contours reflect the chloride values for the 1980's period. The isochlors were based mainly on the data for the observation well network, but also included information for water-supply wells and test holes of other studies. Investigations containing additional data used for the chloride maps were Fent (1950), Latta (1950), Bayne (1956), Lane (1960), Layton and Berry (1973), Stullken and Fader (1976), Hathaway et al. (1978), and Gillespie et al. (1991). The isochlors were located on the basis of both the chloride point data and considerations of the hydrogeology of the study region.

In general, the highest chloride values observed in the bedrock well samples were used for Plate 1 because lower concentrations are thought to represent induced flow of more dilute water from the overlying aquifer as a result of sample pumping. The oil-brine contribution to the

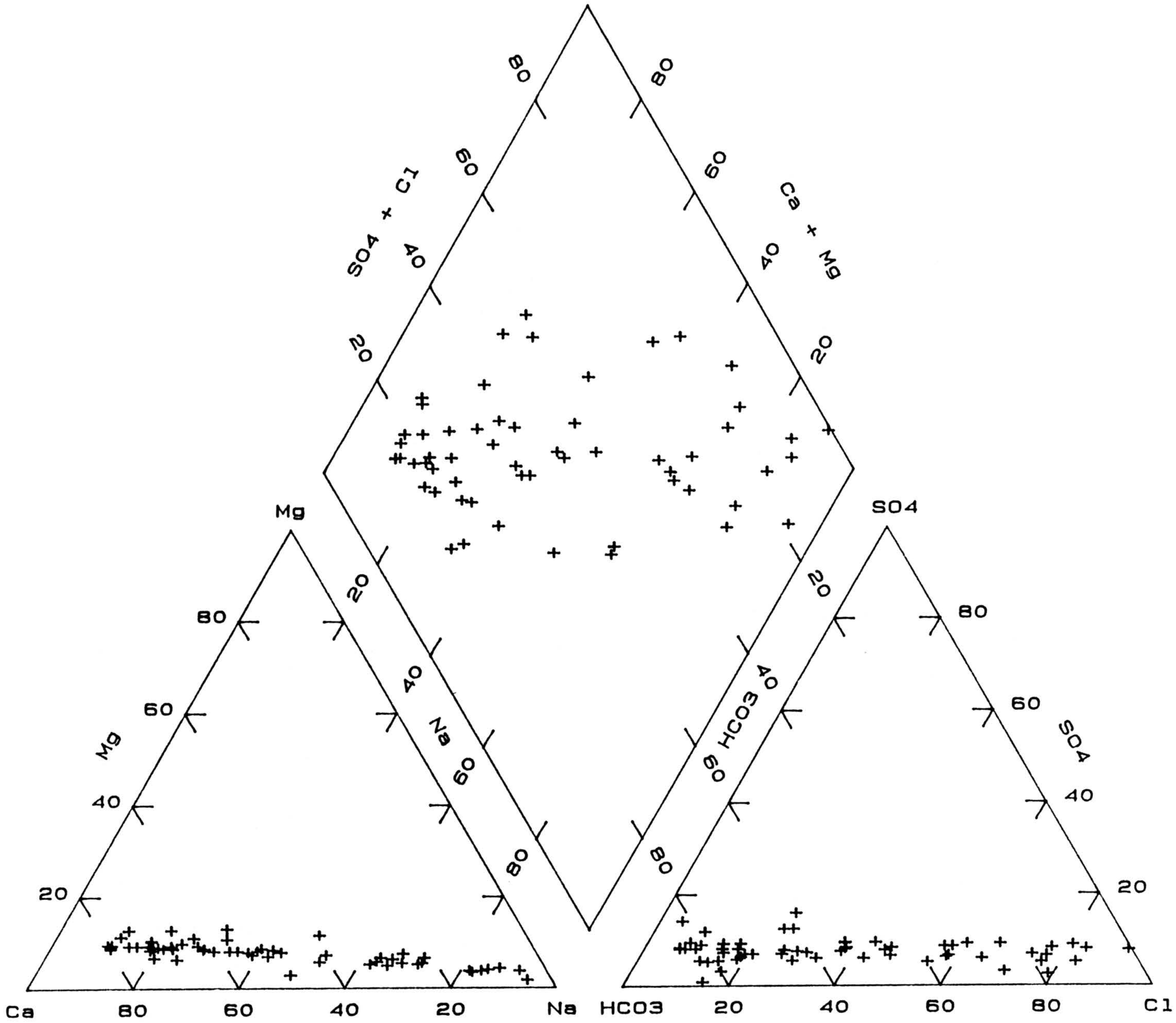

Figure 6. Trilinear diagram of major chemical constituents in waters in the upper unconsolidated aquifer sampled from the observation well network.

chloride values for a few network well waters from the unconsolidated aquifer was subtracted because the contamination is believed to be mainly local. The determination of oil-brine contamination in the presence of natural salinity is discussed later in this report. The colored contour portion of Plates 1-3 represents the extrapolation of the observation well network data to an additional half-township outside the limits of the sites. Some of this area included data from other sources. The Arkansas River was used as the northeastern boundary of the contoured region.

Permian Bedrock

A contour map of chloride values for waters in the Permian bedrock (Plate 1) shows that the highest salinities occur in the northwest and parts of the central portion of the observation well network. Freshwaters are in the bedrock along the southern part of the network area, at one site in the west-central portion of the area (site 19), and at one location in the center of the eastern boundary of the network (site 34). The water at site 19 appears anomalous and may indicate that a representative sample has not yet been obtained. Only one sample was collected from the bedrock well at this site, suggesting the possibility that more saline waters might be obtained after additional pumping. The south side of valley of the South Fork of the Ninnescah River is the approximate boundary for the transition from saline water to freshwater.

A finger of more saline water in the Permian extends eastward across the northern part of the network across Rattlesnake Creek and along Peace Creek, including the area of the Little Salt Marsh. The area of less saline water just to the southwest of Big Salt Marsh is in the area where Cretaceous rocks outcrop. Another zone of less saline water starts in the center of the network near Stafford and extends along the area between Peace Creek and the North Fork of the Ninnescah River. South of this zone, a protrusion of more saline water in the bedrock occurs between the North Fork of the Ninnescah River and Goose Creek. A more isolated, but highly concentrated band of saltwater exists along and to the north of the valley of the South Fork of the Ninnescah River.

Aquifer Base

Plate 2 displays the chloride distribution near the aquifer base. Although many of the deep network wells in the aquifer were installed at or near the bottom of the unconsolidated sediments, many of the wells are screened substantially above the bedrock surface. Thus, some of the spatial variation in the Plate 2 contours could result from the uneven depth distribution of the well screens relative to the bedrock top.

The highest salinities within the lower aquifer occur mainly in the northern part of the observation well network, and in a band extending southward to an area of saltwaters to the northeast of Pratt and north of the South Fork of the Ninnescah River. The area of saline water is appreciably smaller than that for the bedrock (Plate 1). In general, the more saline areas at the aquifer base are shifted somewhat to the east of the saltiest parts of the Permian bedrock, indicating the effect of the easterly regional flow of ground water on the salt intrusion. Comparison of the pattern for the aquifer base saltwaters (Plate 2) in the northwest part of the network with Figure 3 indicates that the zone of salinity increase coincides with the thinning of the Cretaceous cover over the Permian. The saltiest waters occur where the aquifer directly overlies the Cedar Hills Sandstone in the northwestern part of the study area. This saltwater zone ends just to the south of Rattlesnake Creek even though the Cedar Hills Sandstone directly underlies the aquifer to the south and contains saltwater.

The freshwater zone that protrudes from the west into the center of the study area coincides with the headwaters of Peace Creek and the North Fork of the Ninnescah River. This is an area of higher potentiometric surface in the aquifer which includes a downward movement of water that restricts upward movement of saltwater. The eastward extending finger of saline water present in the bedrock in the northern part of the network is reflected in the aquifer base. The small area of outcropping Cretaceous rock southwest of the Big Salt Marsh is at the northwest part of a local area of freshwater that spreads out in a downgradient flow direction from the outcrop. The transition from saline to freshwater just south of the South Fork of the Ninnescah River occurs over a shorter distance.

Upper Aquifer

Freshwaters occur in the shallow aquifer across most of the observation well network (Plate 3) in sharp contrast to the much greater extent of saline water at the aquifer base. Where there are two wells in the middle to upper part of the aquifer, the map relies mainly on data for the shallower well. Approximate averages were used for sites 8, 49, and 50 because the average depths of the intermediate and shallow wells at these sites are more similar to the shallow well depth at the other six sites with both intermediate and shallow wells (Table 1). The chloride concentration for site 44 is from well 3 because there is no data available for well 4 at this location. The value used for site 34 is the same as that for well 2 at this site because this well is so shallow, even though it is screened just above the bedrock.

The shallow aquifer waters with the highest salinities occur mainly in the northeastern region of the well network. Saline water from the lower aquifer intrudes into the shallower aquifer along most of Rattlesnake Creek downstream of St. John, and along portions of the Arkansas River, Peace Creek, and the North and South Forks of the Ninnescah River. Saltwater also enters the shallow aquifer around Big Salt Marsh and Little Salt Marsh. However, the saline intrusion pattern does not always coincide with the streams and salt marshes. A band of saline water extends north from the clockwise, 90 degree major bend in the Rattlesnake River toward the Arkansas River. A protrusion of slightly saline water spreads from the Little Salt Marsh eastward to the headwaters of Salt Creek. A band of higher chloride water connects the intrusion zones of Peace Creek and the North Fork of the Ninnescah River.

VERTICAL DISTRIBUTION OF SALINITY

Ground-water chloride concentrations increase with depth within the unconsolidated aquifer and from the aquifer to the bedrock at all sites in the observation well network except sites 19 and 25. At these latter two sites, the dissolved chloride increases with depth in the aquifer, but is somewhat lower in the bedrock than at the base of the aquifer. As indicated above in the section on salinity in the bedrock, the single sample from the bedrock well at site 19 may not be representative. The wells at site 25 have been sampled at least a few times each and the results are consistent with the lower chloride in the bedrock water than at the aquifer base.

The percentage change in chloride concentration within the aquifer and from the aquifer to the bedrock ranges widely from site to site, i.e, at some sites the greater percent change in chloride is from the upper to lower aquifer waters, at other sites the change is greater from the aquifer base to the bedrock well depth. The ground-water flow conditions and differing chloride content in bedrock waters at each site vary widely such that no uniform chloride gradient occurs across the area.

Comparison of the chloride distribution at the aquifer base (Plate 2) with that for the upper aquifer (Plate 3) indicates areas where there is a great change in the salinity with depth. For example, areas of freshwater with chloride concentrations less than 100 mg/L in the upper aquifer overlie saltwater with chloride greater than 10,000 mg/L at the aquifer base in the northwestern region of the network in north-central and northeastern Stafford County and in the central part of the network to the northeast of Pratt. The first of these two areas has the greatest contrast in salinities with depth in the aquifer because the aquifer base includes waters with chloride concentrations above 20,000 mg/L. Pumping by irrigation wells in the lower aquifer in regions where the salinity change is great could be expected to result in increases in chloride during the pumping season if there are no substantial clay units to retard upconing of saltwater.

CONTROLS ON SALINITY DISTRIBUTION

The areal distributions of chloride concentration in Plates 1-3 show general patterns of high and low chloride that can be attributed to the salinity of water in the bedrock. Two additional factors probably control most of the complexity in the distribution patterns within the regions of higher salinities. The first of these factors is the unevenness of the bedrock surface. The bedrock surface maps of Fader and Stullken (1978) and Sophocleous et al. (1993) show bedrock ridges and channels of an old erosion surface. The sites of the observation well network are situated in different positions on this surface as can be seen by the wide variation in bedrock depths from site to site. The saltiest waters along the bedrock-deep aquifer interface within a saline region in the network could be expected to be present where the depths to bedrock are the greatest. Saltwaters at the base of the aquifer could preferentially flow within bedrock channels around and along the base of bedrock ridges. The slow flow of freshwater into bedrock ridges and hills below recharge zones would dilute saltwater in the bedrock to lower salinities than at greater depth. The Cretaceous bedrock outcrop to the southwest of the Big Salt Marsh shows this effect on lower salinity waters in the Permian bedrock and an area of freshwaters surrounded by saline waters at the overlying aquifer base.

The other major factor controlling the chloride distribution is the location of recharge and discharge zones. Ground-water discharge along streams and rivers and around Big Salt Marsh and Little Salt Marsh are important for saltwater intrusion patterns. Ground-water flow lines curve upward in the vicinity of the discharge zones, bringing up lower waters to the streams and allowing underlying saltwaters to rise. The four wells at observation site No. 49, which is within 200 ft of the South Fork Ninnescah River, illustrate the upconing. The deeper the well at this site, the higher the water level. The two deeper wells have hydraulic heads above land surface. Heads in the deeper wells at site 4 also are higher than shallower wells; site 4 is within 500 ft of Rattlesnake Creek.

Cross sections in Young (1992) taken from Cobb (1980) show the effect of ground-water discharge on the vertical distribution of chloride concentration in the aquifer (see Figures 6 and 7 in Young). The upconing of saline water in these figures corresponds to the upward bending of ground-water flow lines. Ground-water flow rates increase in the discharge area where flow lines converge underneath the streams. The mixing of freshwater, saline water, and saltwater increases in the subsurface below the discharge zone because hydrodynamic dispersion increases with increasing ground-water velocity.

Recharge in upland areas increases the hydraulic head overlying the Permian bedrock and decreases the rate of upward saltwater intrusion. Where the downward movement is great enough, freshwater can penetrate to the base of the aquifer and even into the bedrock to flush out saline water. Ground-water recharge is clearly responsible for the freshwater overlying saline water in the aquifer, and for the flushing of saltwater from the Permian bedrock south of the South Fork of the Ninnescah River.

The higher chloride concentration at the base of the aquifer than in the bedrock at site 25, and the anomalously high chloride in the upper aquifer at this site, might reflect discharge of saltwater below the Little Salt Marsh that has been further concentrated by evapotranspiration. The area of the salt marsh and to the east is generally a marshy area that could be subject to concentration of shallow ground waters by evapotranspiration during recent geologic time. High salinity is also found in the ground waters immediately underlying the Cheyenne Bottoms (Whittemore and Huggins, 1987). The salinity decreases in the sediments underlying the Bottoms and has a chemistry that indicates evapotranspiration as the most probable mechanism to concentrate fresh to slightly saline waters entering the Bottoms in the past.

IDENTIFICATION OF SALINITY SOURCES

Although natural Permian saltwater is known to be the main source contributing to the salinity of ground waters in the Great Bend Prairie aquifer, local contamination by brines brought to the surface by oil and gas operations has also been documented. Oil production began in the Great Bend Prairie area about 1930. Petroleum fields with past and present production cover a large percentage of the aquifer area (Figure 7). Every township of the study area except one (T. 26 S., R. 10 W.) includes at least one or part of an oil and/or gas field. The colored contour portion of Plates 1-3 comprises a total area of approximately 1,890 square miles. The size of contiguous petroleum fields within this area comprise from a quarter square mile up to about 27 square miles for the Zenith-Peace Creek Field. Several townships in the contoured region contain several petroleum fields that cover over a quarter of the 36 square miles (Figure 7). Township T. 21 S., R. 13 W. in north-central Stafford County includes oil fields that comprise about half of the area.

Practices of oil-brine disposal in the early days of the petroleum industry in Kansas

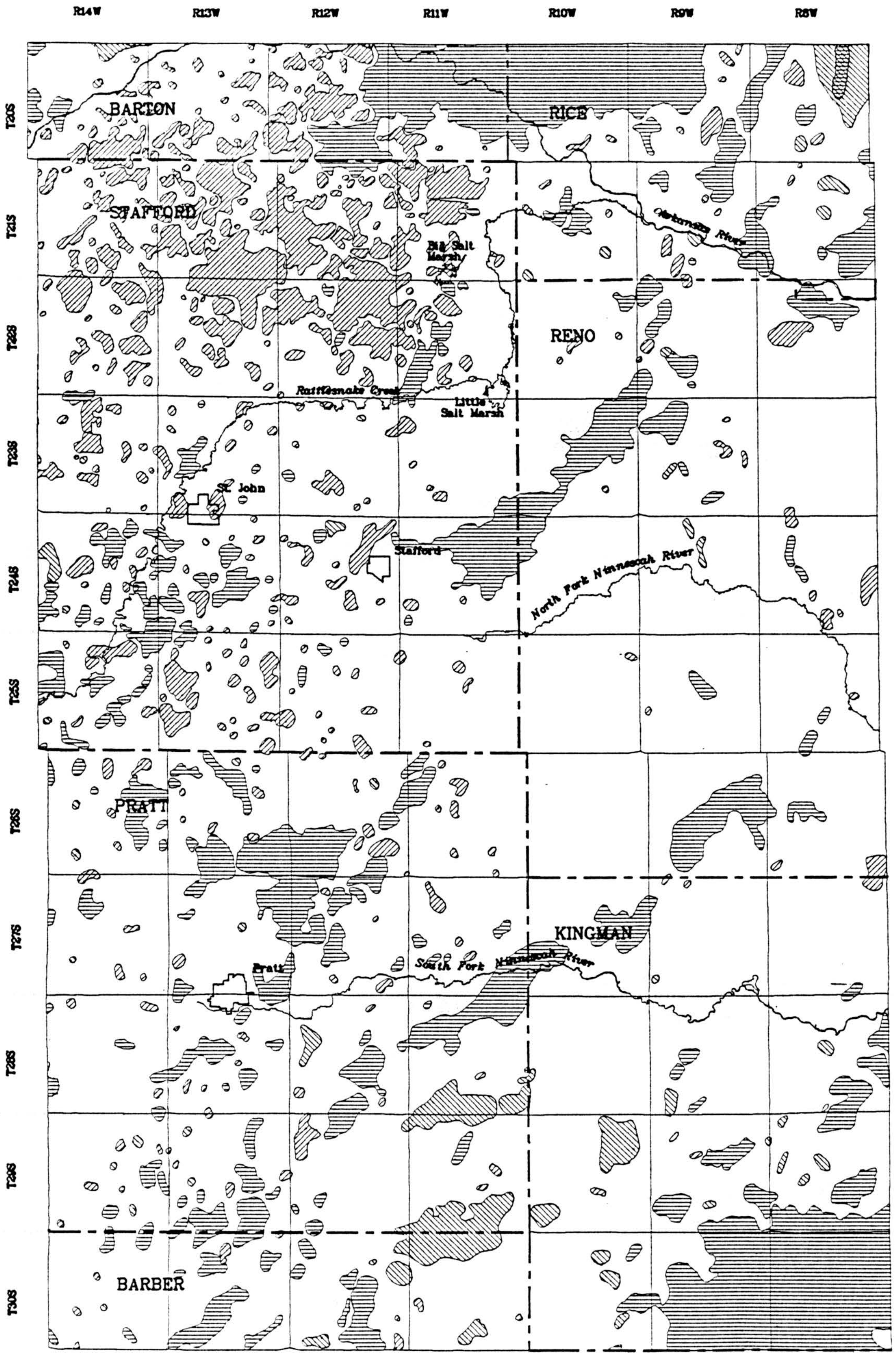

Figure 7. Oil and gas fields in the study area (Kansas Geological Survey, 1989a, 1989b). The map area is the same as for Figure 2 and Plates 1-3. Legend ▨ Oil field; ▧ Gas field; ▤ Oil and gas field.

mainly involved containing the brines in surface pits or letting the brines run into surface drainages. Consequently, ground water and surface water became locally contaminated. For example, a sizable area of the Equus Beds aquifer overlying the Burrton Oil Field was affected by the surface disposal of oil brines (Burrton Task Force, 1981; Whittemore et al., 1985). Subsurface disposal in bedrock containing natural saltwater at shallow to moderate depths or in deep strata began to be important in the 1930's. The beginning of the development of oil fields in the 1930's during which subsurface disposal became important probably helped prevent widespread pollution by oil brine in the Great Bend Prairie. However, until this report, no study has been previously conducted that quantitatively assesses the contribution of oil brine to the salinity of the Great Bend Prairie aquifer.

Another contributor to salinity is the concentration of dissolved solids by evapotranspiration of surface and soil waters. Agricultural practices leading to raised water tables have resulted in saline seeps and soils in low lying areas in some locations in the Great Plains. Concentration of irrigation waters by evapotranspiration can lead to increased soil salinity. The wastes from a high density of stock can also increase the chloride content of soil moisture. The salts from both of these agricultural sources can then be leached to the ground water during recharge events. Any increases in salinity from these sources would be expected to occur in shallower wells in the upper aquifer.

The salinity sources for ground waters in the Great Bend Prairie aquifer were identified using the method of Whittemore (1984, 1988). The identification is based primarily on mixing curves on graphs of bromide/chloride and sulfate/chloride versus chloride concentration, but also include examination of other chemical data such as nitrate. The contributions of oil brine and evapotranspiration concentration to chloride contents in mixtures with natural Permian chloride can be estimated from intersections of mixing curves.

Nearly all of the waters collected from the GMD5 observation-well network fall in a relatively narrow band on the plot of bromide/chloride ratio versus chloride concentration (Figure 8). The plotted symbols represent all the observation network wells from which

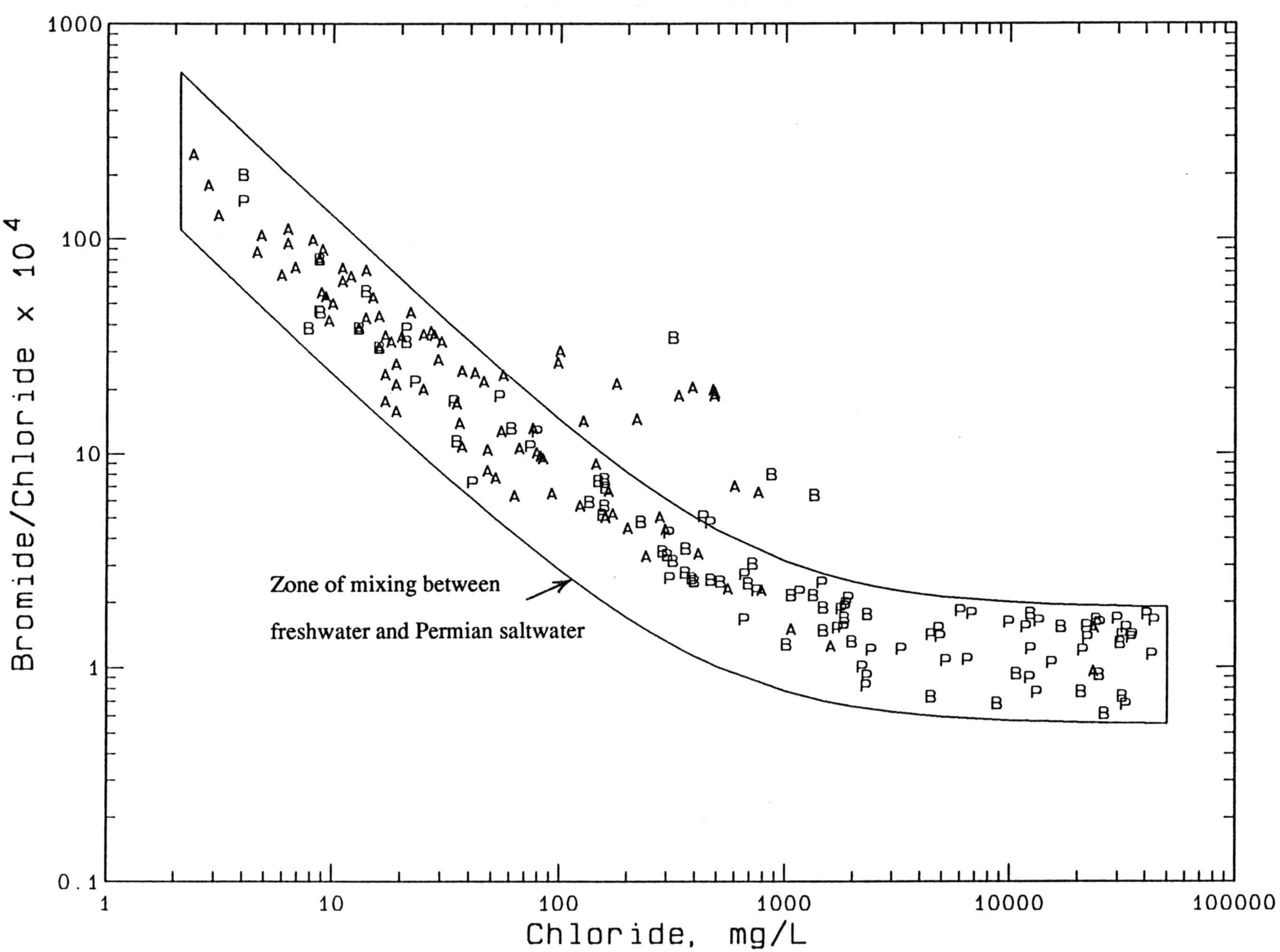

Figure 8. Bromide/chloride weight ratio versus chloride concentration for waters from the observation well network. Legend: P Permian bedrock wells; B Aquifer-base wells; A Upper-aquifer wells.

representative samples were collected and bromide measured, and include more than one sample for several wells. The contiguous band of points is enclosed by mixing curves. Each curve is based on calculations assuming conservative mixing between the low-chloride and high-chloride end points. Bromide and chloride are conservative constituents (essentially unaffected by precipitation, oxidation-reduction, and adsorption processes) in ground waters. The band of points enclosed by the mixing curves represents the mixing of fresh ground waters with Permian saltwater derived from the dissolution of halite (rock salt). Bromide/chloride ratios are very low for halite, which is composed of sodium chloride, because little bromide is incorporated into halite during its precipitation in ancient seas. Furthermore, recrystallization of some Permian salt in the geologic past has probably removed some of the bromide present in the halite.

Points for water samples departing appreciably from the mixing zone in Figure 8 indicate a source or factor additional to simple mixing with natural Permian saltwater that affects the chloride and bromide concentrations. Figure 9 shows the same points for observation well waters as in Figure 8. Instead of the mixing zone, a mixing curve (solid line) has been drawn that passes through the top part of the contiguous band of data points. This curve represents the mixing of waters that have the highest bromide/chloride ratio, given a particular chloride concentration, that would be expected to occur naturally in the unconsolidated aquifer and bedrock. Points above this curve could indicate either additions of both chloride and bromide from an oil brine source, or increases in chloride at a constant bromide/chloride ratio from evapotranspiration concentration.

Oil-Field Brine Contribution to Chloride

All of the observation well waters (9 points for 8 different wells at 7 network sites) in Figure 9 for which oil brine is an expected source of additional chloride have characteristics that help distinguish them from ground waters with increased chloride from agricultural activities. Most importantly, they all contained nitrate-N concentrations lower than 2 mg/L, values less than the approximate upper limit of 4 mg/L for natural dissolved nitrate-N in ground waters

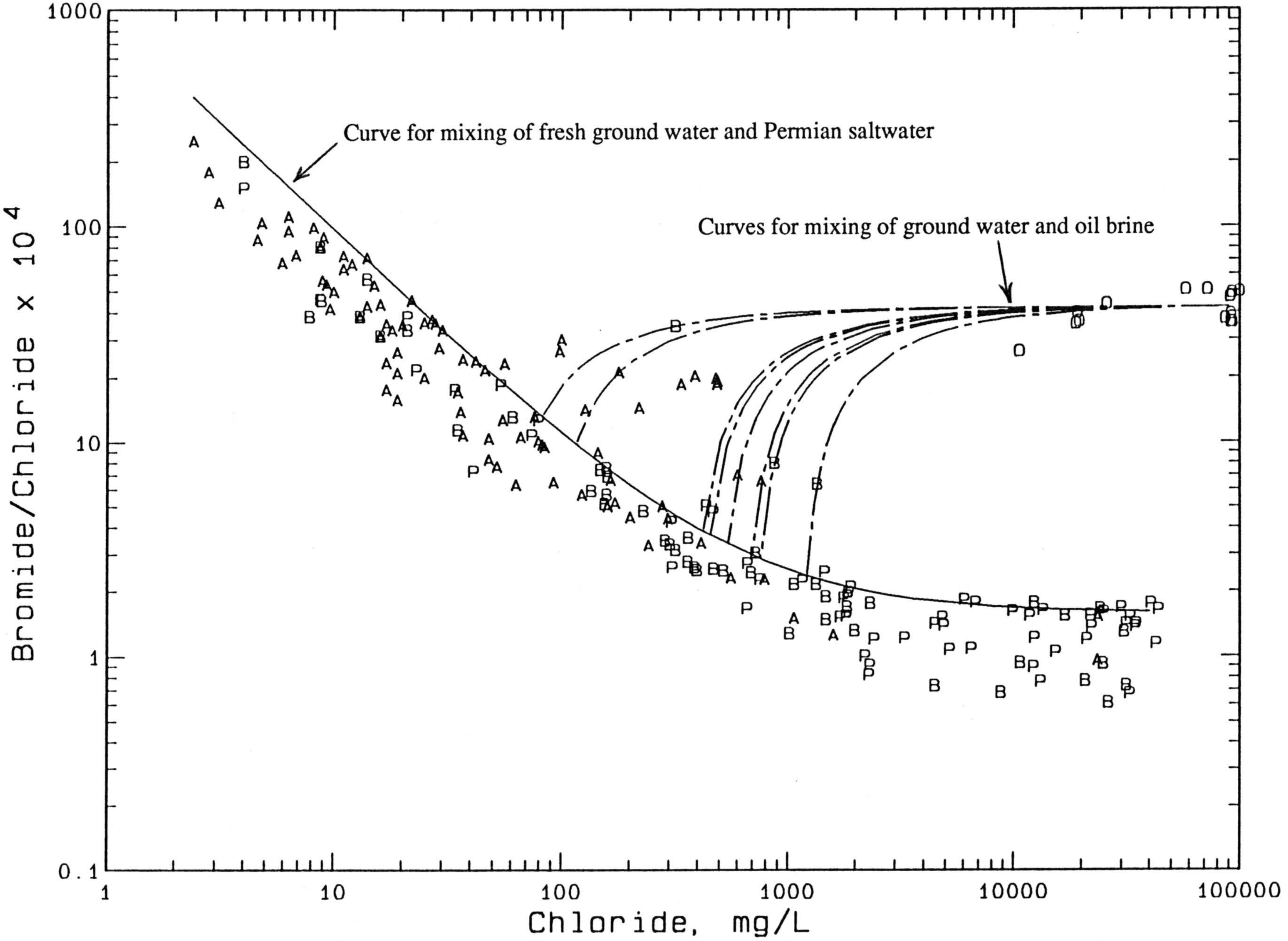

Figure 9. Bromide/chloride weight ratio versus chloride concentration for waters from the observation well network with mixing curves for oil-field brine. Legend: P Permian bedrock wells; B Aquifer-base wells; A Upper-aquifer wells; O Oil-field brine.

underlying the Great Bend Prairie. All of the waters for which agricultural activities are a suspected source of added chloride (7 points for 3 different wells) had nitrate-N contents about 6 mg/L or greater. The calcium/chloride ratios for well waters substantially affected by both the oil-brine and agricultural chloride sources are higher than waters with similar chloride concentrations, but from a natural salinity source. The 3 wells having an identifiable agricultural contribution to chloride are shallow, with a total depth of 50 ft or less. In contrast, the 8 wells identified as having an oil-brine contribution to salinity range in depth from 70 to 140 ft. Past oil-brine contamination at the surface could penetrate to deeper depths than agricultural salinity increases because the density of oil brines is great enough to produce vertical brine flow through fresher water. Also, oil brine contamination could occur in the subsurface portion of the aquifer from corroded disposal wells.

The circles on Figure 9 indicate the composition of many oil brines collected from within the observation well network or at most two townships from the edge of the network area, and analyzed at the KGS (Table 6). The oil-brine data are either from unpublished data of Whittemore or from KGS Open-File reports on salinity identification studies for local contamination problems. The data are for 14 brines from at least 6 different oil-producing strata; the lowest bromide/chloride ratio is for Arbuckle Group oil brine from an oil well outside the observation well network area. Oil brines contain much higher bromide/chloride ratios than salt-dissolution waters because the brines in Kansas are trapped seawaters that were previously concentrated in evaporite basins, were altered by mixing with halite-dissolution saltwater, and/or to which bromide has been added from the decomposition of organic matter which formed oil and gas deposits. Seawater has a bromide/chloride weight ratio of 0.0035 at a chloride content of approximately 19,000 mg/L, placing it within the distribution of oil brines on Figure 9.

Each of the dashed lines in Figure 9 represents the calculated mixing of oil brine with natural fresh or saline water to produce the chemistry of the water samples that plot above the solid mixing line. The oil-brine end point for each dashed line is the same and was chosen to have a bromide/chloride weight ratio (0.0042) that is the approximate average for the oil-brine

Table 6. Oil-field brines in or surrounding the observation well network area. Samples were analyzed by the Kansas Geological Survey and are arranged in order of increasing age of the formations from which they were produced.

Formation	County	Location	Cl, mg/l	SO_4, mg/L	Br, mg/L	SO4/Cl	Br/Cl x 10^4
Lansing-Kansas City	Pawnee	23S 15W 30 C	93000	189	322	0.00203	35.7
Lansing-Kansas City	Pawnee	23S 15W 30 C	91000	572	327	0.00628	35.9
Lansing-Kansas City	Pawnee	23S 15W 30 C	86400	390	322	0.00452	37.3
Lansing	Pawnee	23S 15W 30 B	91800	255	358	0.00278	39.0
Arbuckle	Stafford	22S 12W 3 A	19490	1490	71	0.0764	36.4
Lansing	Rice	19S 10W 29 DB	72200	126	366	0.00175	50.7
Lansing	Pratt	27S 11W 25 ADC	92300	143	451	0.00155	48.9
Lansing-Kansas City	Stafford	21S 12W 3 DCD	100500	26	497	0.00026	49.5
Lansing-Kansas City	Stafford	25S 13W 6 ACC	19100	-	76	-	39.8
Kinderhookian	Rice	20S 9W 19 S/2 S/2 D	57600	256	292	0.00444	50.7
Viola	Stafford	23S 11W 36 S/2 B	90600	272	426	0.00300	47.0
Simpson	Stafford	21S 11W 28 ACAB	18830	169	66.6	0.00898	35.4
Simpson Sand	Stafford	22S 11W 33 BAD	25700	1300	112	0.0506	43.6
Arbuckle	Rice	19S 9W 20 C	10580	1580	27.9	0.1493	26.4

data. Each dashed line extends from the oil-brine end point through the point for an observation well water and is extrapolated to intersect with the solid curve. The chloride value at the intersection with the solid curve indicates the natural contribution to the total chloride content of the actual water sample. The chloride added to the ground water from oil brine can be computed as the difference between the natural chloride and the total chloride as given in Table 7.

If the oil-brine end point for the dashed mixing curves were selected to have a lower bromide/chloride ratio, the estimated oil-brine contribution to the total chloride would be greater. Likewise, a higher bromide/chloride ratio for the oil-brine end point would give a somewhat lower estimate. The mixing curve intersections were calculated using the highest and lowest bromide/chloride weight ratios, 0.00507 and 0.00354, for the non-Arbuckle oil brine. This range in oil-brine ratios also represents brines that were collected from within the map area of Plates 1-3. The resultant range in the oil-brine contribution to the total chloride for each water sample is also indicated in Table 7. The percentage range in the oil-brine contribution in the last column in the table includes the effect of analytical error, which amounts from about one to 6 additional percent. The larger the oil brine percentage, the greater the effect of the bromide/chloride ratio and the analytical error on the resultant percent error range.

Even larger contributions from oil brine would result from calculations based on the composition of the Arbuckle saltwater. However, in the case of well 15-2, use of an Arbuckle brine end point would give an oil-brine percentage much greater than 100 percent, an impossibility. The Arbuckle saltwater has a bromide/chloride ratio too low for it to be the possible source for added chloride in this well. Thus, for this well the other oil-brine data are definitely more appropriate for calculating the chloride contamination. The low sulfate/chloride ratios for waters from wells 15-2 and 6-3, which have more than 300 mg/L chloride and an oil brine percentage of 35 or more, in comparison with the sulfate/chloride ratios for other well waters with similar chloride contents also indicate that a non-Arbuckle brine is probably the contamination source. The sulfate/chloride ratio for the Arbuckle water in Table 6 is in the range of what would be expected for the natural ratio in the aquifer ground waters at chloride

Table 7. Estimates of the natural and oil-brine contributions to the chloride concentration of the observation well waters in which oil-brine contamination is suspected. Natural chloride indicates sources from natural freshwater and Permian saltwater. The range in the estimated chloride concentration for the oil-brine contribution is based on the high and low bromide/chloride ratios for the non-Arbuckle brines. The range in the natural chloride (not shown) corresponds to the range in the oil brine. The oil-brine percentage is the oil-brine chloride divided by the total chloride concentration multiplied by 100. The range in the oil-brine percentage reflects the oil-brine range in chloride concentration plus the estimated maximum analytical error. Sample date is year-month-day.

Network site-well	Sample date	Chloride, mg/L Total	Natural	Oil brine	Oil brine, range	Oil brine, %	Oil brine, % range
Wells in Permian bedrock							
15-1	84-01-03	434	420	14	11- 16	3	2- 4
15-1	86-07-11	466	454	13	10- 15	2	2- 4
Wells at or near aquifer base							
4-2	82-11-29	869	756	114	93-132	13	9-17
15-2	82-12-14	318	82	236	194-282	74	57-93
51-1	87-08-19	1,350	1,215	136	110-153	10	7-12
Wells in upper aquifer							
6-3	84-11-01	338	219	119	98-141	35	25-45
10-3	83-12-06	598	542	57	46- 66	9	7-12
10-4	84-11-05	179	116	63	52- 75	35	25-46
26-3	84-11-03	762	692	70	57- 81	9	6-12

concentrations of 318-338 mg/L. The sulfate/chloride ratios for the other oil brines are appreciably lower and better fit the decrease in the ratio for waters from wells 15-2 and 6-3.

Use of a curve for the mixing of freshwater and natural Permian saltwater that was at lower bromide/chloride ratios than in Figure 9 would also produce larger apparent contribution of oil brine for the wells in Table 7. The dashed curves from the oil brine end point passing through the points for the contaminated waters would intersect a shifted solid curve (for example, the long-dashed curve in Figure 10) at lower chloride concentrations that represent the natural source. However, use of such a shifted curve could result in assigning some chloride increase from possible agricultural sources to an oil-brine source. Overall, the values in Table 7 are conservative estimates of the oil-brine contribution.

Five of the 6 sites indicated in Table 7 as having oil-brine contamination are either located within or on the edge of oil fields as delineated by maps of the Kansas Geological Survey (1988a, 1988b) and shown in Figure 7. The two sites that are on the boundary edge are in a downgradient direction of ground-water flow from the oil fields. Although site 4 is not within an oil field, a small oil field lies approximately one-fourth mile in an upgradient direction of ground-water flow.

The amounts of chloride contributed by oil brine to the total chloride of the sampled ground waters (Table 7) range from just detectable (13 mg/L) to 236 mg/L. Oil brine comprises the major amount of chloride in the ground water at only one well. Although the pollution additions to the chloride concentration exceed 50 mg/L for the 7 aquifer wells listed in Table 7, the natural chloride at 4 of these locations is too high for the water to be usable for irrigation or drinking supplies. The ground water at only one location, near the aquifer base at site 15, was changed from a usable to an unusable supply for these purposes.

Nearly all of the contamination for the different wells was detected within the unconsolidated aquifer and occurs both within the upper and the lower parts of the aquifer. However, the bedrock well water at site 15 appears to contain a very small amount of diluted oil brine. The aquifer-base water at site 15 contains the greatest amount of oil-brine contamination

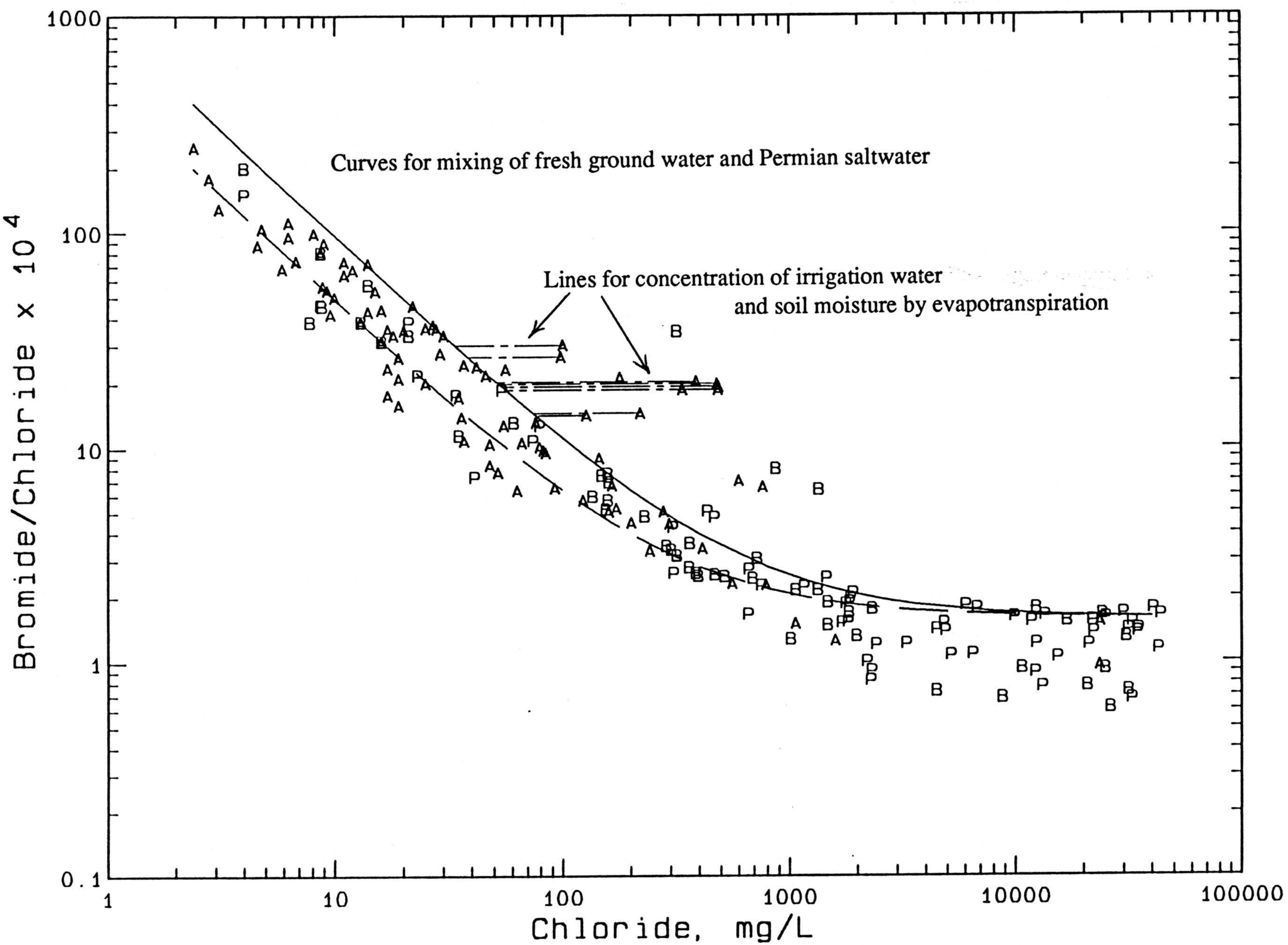

Figure 10. Bromide/chloride weight ratio versus chloride concentration for waters from the observation well network with mixing lines for evapotranspiration concentration. Legend: P Permian bedrock wells; B Aquifer-base wells; A Upper-aquifer wells.

of any network well. The trace of oil-brine contamination in the bedrock at this site could possibly be some water that entered during the drilling and was not completely removed during pumping of the well before sampling.

Oil-field brine has been chemically identified as contributing to salinity in the aquifer in at least 3 other locations within the observation well network (Table 8). The predominant salinity source in the Andrews and Mawhirter domestic well waters in southwest Stafford County was identified for an oil company in 1981 (Whittemore, unpublished). The estimates for the chloride sources in the two well waters are based on an oil-brine (Table 6) collected from a separator tank in the same section as the Mawhirter domestic well. The estimated concentration for the natural chloride source for both wells is about 200 mg/L. The natural chloride concentration expected for upper aquifer water in this area is estimated to be near 100 mg/l based on data used for Plate 3, while water at the aquifer base should contain approximately 400 mg/L dissolved chloride (Plate 2). The 200 mg/L value computed for natural chloride from the mixing curves fits within this range.

Salinity sources were identified for the Kansas Corporation Commission (KCC) in ground waters at a site of known oil-brine contamination in eastern Pratt County (Whittemore, 1990a). The analyses included 4 monitoring well waters of the Corporation Commission, 3 observation well waters from a U.S. Geological Survey site in the same investigation area, a sample of oil brine from a tank battery at the site, a sample from the saltwater recovery system, and water from the nearby South Fork of the Ninnescah River. The estimated chloride concentrations for the different salinity sources are listed in Table 8 for the two waters in which oil-brine contamination was found. The chloride concentrations for the other 6 monitoring and observation wells ranged from 69 to 162 mg/L and contained less than 2 percent chloride from oil brine. The other well waters plot within or at the upper boundary of the mixing zone of freshwater with Permian saltwater in Figure 9. The Ninnescah River water had a chloride content of 279 mg/L and a bromide/chloride ratio that would plot in the middle of the natural ratio range at this chloride on Figure 9.

Table 8. Estimates of the natural and oil-brine contributions to the chloride concentration of domestic, monitoring, brine recovery, and irrigation well waters in which oil-brine contamination is suspected or known. Natural chloride indicates sources from natural freshwater and Permian saltwater. The estimated chloride concentration for the oil-brine contribution is based a bromide/chloride weight ratio of 0.0042. The oil-brine percentage is the oil-brine chloride divided by the total chloride concentration multiplied by 100. The estimated error in the values would be similar to the ranges in Table 8 for similar chloride and percentage ranges. Sample date is year-month-day.

Location	Sample date	Br, mg/L	Chloride, mg/L			Oil brine, %
			Total	Natural	Oil brine	
Andrews and Mawhirter domestic wells, Stafford County						
24S-13W-31DDC	81-07-09	2.03	677	202	480	71
25S-13W-06AAB	81-07-09	2.33	744	193	556	75
Maxedon Lease, monitoring well 3 and recovery system, Pratt County						
27S-11W-25ADCB	89-11-??	0.82	203	62	141	70
27S-11W-25ADCD	89-11-??	10.8	2,270	86	2,184	96
Newell irrigation well, Reno County						
24S-10W-19DACC	82-07-20	0.71	260	118	142	55
"	82-07-27	0.90	305	118	187	61
"	82-08-01	0.95	323	124	199	62
"	82-08-07	0.99	334	126	208	62
"	82-08-13	1.03	345	128	218	63
"	82-08-21	1.06	354	130	225	63
"	82-08-25	1.06	356	132	225	63
"	82-08-29	1.08	357	128	230	64
"	82-09-05	1.08	397	169	228	57
"	82-09-18	1.10	392	159	233	60

A study was conducted to determine the salinity sources in an irrigation well water from western Reno County in cooperation with GMD5 (Whittemore and Hathaway, 1983). The KGS had previously examined irrigation water quality across the Great Bend Prairie aquifer in 1977 (Hathaway et al, 1978). The previous investigation included a chloride concentration of 311 mg/L for a sample collected from the Newell irrigation well on July 27, 1977. In 1982, GMD5 collected 10 samples from the well during the irrigation season and sent them to the KGS for determination of ground-water quality changes with pumping and salinity sources. The chloride concentrations in the waters slowly climbed during pumping (Table 8). The salinity sources were reexamined for this current report to estimate more accurately the proportion of each. The same bromide/chloride ratio was used for the oil-brine end member of calculated mixing curves as for the mixing curves in Figure 10. The estimated chloride for the natural Permian source slowly rose during the summer. The predicted chloride for water at the aquifer base is between 500 and 1,000 mg/L (Plate 2). The pumping stress appears to have caused higher chloride water to rise from deeper in the aquifer to the irrigation well screen. The chloride from oil-brine also increased during the pumping suggesting that a greater concentration of oil brine is present at some horizontal or vertical distance from the well screen. The rate of increase in the oil-brine contamination was slightly greater than that for the natural source for most of the irrigation season. However, towards the end of the pumping the percentage of the oil-brine source dropped somewhat. This could reflect the localized nature of the pollution in contrast with the more widespread occurrence of the natural salinity.

Another investigation for the KCC was conducted at the Siefkes subsidence site (NE sec. 3, T. 22 S., R. 12 W.) in northeast Stafford County (Whittemore, 1990b). The KCC installed two monitoring wells in the aquifer in the subsidence area of a plugged well used in the past for oil-brine disposal. Both monitoring wells contain screened intervals of 50 ft that extend from depths of 80 and 85 ft in the aquifer middle to 130 and 135 ft at the aquifer base. Water collected from the top of the screened interval was fresh, with chloride contents of 18-72 mg/L. Samples collected from the bottom of the wells were saline with chloride concentrations of 2,390-5,220 mg/L. Points for the freshwaters and the saline waters would lie within the mixing zone of freshwater and Permian saltwater if plotted on Figure 9. Thus, no presence of oil brine could be identified in the waters.

Agricultural Contribution to Chloride

Irrigation waters in GMD5 usually are pumped from the lower part of the unconsolidated aquifer. Although the waters must be fresh for use on crops, the water generally is more saline than the natural upper-aquifer waters as a result of Permian saltwater intrusion. Evaporation concentration of the irrigation waters sprayed from the air, as in center pivot systems, can be substantial during hot, dry days. Evapotranspiration of soil moisture from irrigation water or animal waste can also produce higher salinities. Sophocleous, et al. (1990a, 1990b) and Whittemore (1991) documented and chemically identified, respectively, local salinity increases in shallow ground waters in GMD5 resulting from agricultural activities. For example, the ground-water chloride concentration decreases from several hundred mg/L at a depth of 20 ft below the surface to about 100 mg/L at a depth of 34 ft at recharge study site 6, and from near or over 100 mg/L to 30-40 mg/L for a depth increase from 30 to 70 ft at recharge site 7 (Sophocleous, 1990a).

The amount of chloride contributed by evapotranspiration as a result of agricultural practices can be calculated in an analogous manner as for the oil brine. In this case, however, the dashed mixing lines are horizontal (Figure 10) and extend from the points for the affected ground water to intersect with the solid curve for the mixing of freshwater and natural Permian saltwater. An end point representing saline soil water contributing to the increased ground-water chloride would exist at even higher chloride concentrations, but at the same bromide/chloride ratio. The similar and conservative chemical character of bromide and chloride in surface and subsurface waters that are not very dilute results in little change in the ion ratio during evapotranspiration concentration. The increase in chloride with essentially the same bromide/chloride ratio for water from well 2-2 is consistent with this expectation.

The upper aquifer at 3 well sites contains identifiable chloride contributions from agricultural activities based on ground-waters sampled from the network (Table 9). None of the 3 sites is located in an oil field; distances to the nearest oil field range from about 0.5 to 1.5 mile. The nitrate-N contents for upper-aquifer wells 2-2, 5-3, and 27-3 were 6-8.8, 5.9, and 51-73 mg/L, respectively, for the sample dates in Table 9 based either on nitrate determination in the same sample or estimation from nitrate data for sample(s) nearest the sample date. Observation wells at 13 other sites contain nitrate concentrations about 6 mg/l or greater. However, except for well 7-3, any related chloride increases that might exist at these sites are not great enough to place points for the waters outside of the main band of points and above the solid curve on Figure 10. Well 7-3 could possibly have about 10 or more mg/l chloride added from agricultural sources. However, the sample for this well does not plot far enough from the main band of points to be included in the same group of waters in Table 9. The relative analytical error at the lower chloride and bromide concentrations is also greater, and thus, could comprise a more significant proportion of the shift on Figure 10. The nitrate-N for the well 7-3 sample was 5.6 mg/L, suggesting that some agricultural effect is present.

The high chloride attributed to agricultural sources for water from well 27-3 is not unreasonable, even though well 27-2 in the lower aquifer at this site is only 65 ft deep and yielded water containing 719 mg/L chloride. Well 27-3 is shallow - 35 ft total depth. In addition to the very high nitrate concentration, the sulfate content for the four samples listed in Table 9 ranged from 117 to 201 mg/L in contrast with the lower sulfate of 70 mg/L for well 27-2. The sulfate/chloride ratio for the more saline water in the bedrock well 27-1 is close to that of the water from well 27-2. Concentration of waters by evapotranspiration increases the sulfate content of soil moisture as well as chloride. Not as much sulfate may be leached from soil salts to the ground water as chloride, because the sulfate minerals, mainly gypsum ($CaSO_4 \cdot H_2O$), are not as soluble as chloride salts. Thus, the increase in chloride can be greater in shallow ground water than the sulfate. However, much of the sulfate can be leached, which is reflected in the sulfate concentration higher than expected for natural sources in the shallow ground water at this

Table 9. Estimates of the natural and agricultural contributions to the chloride concentration of the observation well waters suspected of being substantially affected by agricultural activities. Natural chloride indicates sources from natural freshwater and Permian saltwater. The estimated agriculture chloride concentrations are computed using the intersections of the horizontal lines with the mixing curves through the main band of points in Figure 9; the minimum agricultural chloride is the intersection with the solid curve and the maximum agricultural chloride is the intersection with the dashed curve. The natural chloride concentration associated with the maximum agriculture chloride would be correspondingly smaller than the maximum natural chloride value. The minimum agriculture percentage is the minimum agriculture chloride value divided by the total chloride concentration multiplied by 100. The range in the agriculture percentage reflects the range in the two agriculture chloride values plus the estimated maximum analytical error. Sample date is year-month-day.

		Chloride, mg/L					
Network site-well	Sample date	Total	Natural, maximum	Agri-culture, minimum	Agri-culture, maximum	Agri-culture, minumum, %	Agri-culture, % range
2-2	84-11-07	127	76	51	89	40	37-74
2-2	91-12-04	220	74	147	183	67	64-85
5-3	83-11-17	100	34	66	83	67	64-85
5-3	84-11-06	98	38	60	79	61	59-83
27-3	84-01-26	483	56	429	456	89	87-95
27-3	84-05-14	488	54	436	461	89	88-95
27-3	84-11-02	479	52	429	453	89	88-95
27-3	86-08-04	389	51	340	364	87	86-94

site. At least one other location in GMD5 has a documented salinity exceeding that of well 27-3. Chloride concentrations as high as several hundred to over 1,000 mg/L have been found in ground water at a depth of 20 ft at a recharge study site near observation well network site 2 (Sophocleous et al., 1990a). The recharge study site was next to a flood-irrigated field. Nitrate-N contents of this water were 4.3-6.6 mg/L during the same period.

The question arises, could the higher ground-water salinities at the 3 sites in Table 10 represent accumulations of soil salts over long periods of time prior to agricultural activities, and which are now being leached to the ground water by increased amounts of recharge water from irrigation? The depth distribution of clay layers and sandy sections in the soils at the recharge sites appear to have some control on the distribution of soil salinity and nitrate movement (Sophocleous et al., 1990a; Townsend and Marks, 1990; Townsend and Young, 1992). Prior to cultivation, the prairie vegetation was grass with deep roots. The evapotranspiration by these plants could have concentrated some salts in the soils, such as observed in the caliche-like soil layers. An approximate equilibrium of salts leached to the ground water during recharge events balanced by constituent inputs from precipitation and leaching of soil matter could have been reached. Ground-water flow through the aquifer should have been great enough to maintain low chloride concentrations in the shallow ground waters not susceptible to substantial mineral intrusion from below.

Cultivation of the prairie actually allowed increased infiltration of recharge as a result of the removal of the prairie grasses with their long root systems which had been able to utilize deep soil moisture. Some of the accumulated salts in the soils could have been leached into the shallow ground water at a faster rate than natural as a result of cultivation. The presence of irrigation certainly would have accelerated the leaching of any natural soil salts, as well as substantially adding to the salt content by evaporation of the waters spayed above and flooded on the surface, and evapotranspiration of soil moisture near the surface. Thus, whether the original source of increased salinity found in the upper aquifer at the sites in Table 9 is mainly ancient or recent soil salts, agricultural activities are the expected cause for the entrance of the salts to the

Table 10. Relative variations in chloride concentration in samples from observation wells screened in the middle to upper part of the aquifer. The magnitude of the variations are relative to percent changes in the average chloride concentration for samples from the well. The term "constant" indicates no substantial change.

Site-well number	Sampling period	Number of samples	Relative change in chloride concentration during sampling period
1-3	1978-1990	5	Constant
2-2	1978-1991	7	Increase, with rise in increase rate
3-2	1978-1984	4	Small increase and decrease
4-3	1978-1986	5	Small increase and decrease
5-3	1978-1986	5	Constant
6-3	1978-1986	4	Increase and decrease
7-3	1978-1986	6	Constant
8-3	1979-1983	2	Constant
8-4	1979-1986	5	Small increase and decrease
9-3	1979-1986	5	Small decrease
10-3	1979-1983	3	Decrease from first sample, then constant
10-4	1979-1986	5	Constant
11-2	1979-1986	4	Small decrease
12-3	1980-1986	5	Constant
13-3	1980-1986	5	Constant
14-3	1983-1986	3	Increase and decrease
15-3	1982-1986	4	Small increase
16-3	1981-1990	7	Fluctuations
17-3	1981-1986	6	Fluctuations
18-3	1981-1984	5	Appreciable decrease
19-3	1983-1991	5	Constant, then small increase
20-3	1984-1986	4	Constant, then increase and decrease
21-3	1982-1986	6	Increase
22-3	1981-1990	6	Small increase
23-3	1983-1986	4	Small decrease
24-2	1983	2	Constant
25-3	1983-1986	5	Constant
26-3	1983-1986	4	Constant
27-3	1984-1991	6	Constant, then decrease
28-3	1981-1986	5	Decrease from first sample, then constant
29-3	1981-1986	6	Constant, then increase and decrease
30-3	1983-1986	4	Constant, then increase and decrease
31-3	1983-1986	4	Small decrease
32-3	1983	1	-
32-4	1983-1986	4	Decrease
33-3	1983-1986	4	Constant
35-3	1983-1986	5	Constant
36-3	1983	1	-
36-4	1982-1986	4	Constant
37-3	1983	1	-
37-4	1983-1986	5	Constant
38-3	1982-1986	4	Constant
39-3	1983-1986	5	Decrease, increase, and decrease
40-3	1983-1986	5	Small increase

Table 10. (continued)

Site-well number	Sampling period	Number of samples	Relative change in chloride concentration during sampling period
41-3	1982-1986	5	Constant
42-3	1983-1986	4	Constant
43-2	1982-1986	5	Constant
44-3	1982-1986	4	Constant
45-3	1982-1986	4	Constant
46-3	1982-1986	4	Constant
47-3	1982-1986	4	Constant
48-3	1984-1986	4	Constant
49-3	1982	1	-
49-4	1982-1986	4	Constant
50-2	1987	1	-
50-3	1987	1	-
51-2	1987	1	-
52-2	1987	1	-

water table at a rate much greater than before soil cultivation.

The 3 sites of Table 9 represent only about 6 percent of the total sites in the network. If cultivation before the turn of the century were a major cause of leaching of ancient soil salts at faster rates, would increases in shallow ground-water salinity still be seen? Would the ground-water flow in the aquifer have been great enough to flush and dilute this increased salt input? Is the shallow ground-water flow at sites 2, 5, and 27 slower than the other sites such that possibly higher historical salinities have not been removed? Variations in the salinities of the shallow ground waters play an important role in answering such questions. The ground-waters from well 27-3 have generally markedly decreased in salinity since first sampling. The chloride content of 2 samples collected in 1990 and 1991 samples had dropped to below 300 mg/L (Appendix J), in comparison with 479-488 mg/L in 1984 (Table 9). Sulfate was determined in the 1984-1986 samples. The increase in sulfate concentration observed during this time compared to the decrease in chloride does not fit fluctuations in salinity from changes in the amount of salinity from deeper waters. The relatively rapid changes suggest that more recent agricultural activities are important in salinity effects.

During 1978 to 1991, the chloride content of waters from well 2-2 increased from 72 to 220 mg/L (Appendix H and Table 9). Nitrate concentrations of the waters also steadily increased and sulfate values rose at a rate faster than could be explained by effects of deeper, natural saline water, fitting recent agricultural activities as the source. The initial 72 mg/L chloride observed in 1978 fits quite closely with the 76 mg/L value calculated from mixing-curve intersection (Figure 10 and Table 9). Additional information supporting agricultural sources of salinity in the shallow ground waters at site 2 can be found in Whittemore (1991).

TEMPORAL VARIATION IN SALINITY

Samples were collected at different times for nearly all of the shallow wells and some of the intermediate level wells in the aquifer to determine whether the concentrations of major and selected minor constituents varied. Many multiple samplings were also made for the deep aquifer and bedrock wells, primarily to determine whether representative samples had been collected. The data from the analyses of the Groundwater Management District (Appendix J) were used to help determine water-quality variations, with the consideration of the greater errors in these values than for those of the Survey.

Ground waters in the bedrock are probably too deep to exhibit appreciable temporal variations in quality related to short-term changes in recharge. Increases in the salinity of waters collected at different times from several of the bedrock wells probably reflect more representative sampling of the ground water in the vicinity of the screened interval. The pumping rate possible from many of the bedrock wells was small because the sediments were generally silty with a substantially lower permeability than the overlying aquifer. This resulted in a longer time needed to completely remove all water introduced during drilling and well installation.

Samples from the bedrock wells at sites 7 and 11 exhibited anomalous variations. At site 7, the second of the 3 samples had a much lower total-dissolved-solids concentration than the first and last samples. The chloride value for the last sample agreed within 3 percent of the value for the first sample. A concentration of 34,200 mg/L was therefore used in the chloride contour diagram. The chloride concentration at site 11 greatly rose from 6,930 to 25,000 mg/L, dropped to 4,460 mg/L over a span of five years, and then increased to 4,830 mg/L during the two years prior to the last sample collection. The variations in chloride may indicate different amounts of induced downward movement of fresher water from the overlying aquifer by pumping for sample collection. The tops of the screened intervals of the wells at sites 7 and 11 are 80 ft and 29 ft below the depth to bedrock, respectively, thus, if mixing with fresher water is the explanation for the salinity variations in these two wells, the fresher water would have to pass through a substantial amount of Permian strata. The possibility exists that the grouting between the top of the screen and the aquifer does not completely seal the interval, allowing fresher water from the aquifer base to mix with the ground water from the bedrock during pumping. The value of 4,460 mg/L chloride after several sampling times was used to estimate the chloride content at the aquifer base at this site, because no well was installed to sample the lower aquifer.

At site 41, the chloride content of ground water from the bedrock well steadily decreased during the sampling period until the last sample. The chloride concentration determined by the KGS and the GMD5 in the samples from the last collection date appreciably differed. Assuming that the error in the GMD5 value is no greater than 20 percent and that the samples were waters collected one after another rather than split from the same sample, the results suggest that the salinity of the water changes during pumping. The changes might be caused by mixing of fresher aquifer waters drawn down towards the screened interval by pumping. The bedrock depth is relatively shallow at site 41 and the top of the screened interval of the well is only 15 ft below the interface between the bedrock and the aquifer. The specific conductance of water from the bedrock at sites 7, 11, and 41 should be monitored continuously during pumping, if any additional samples are collected, to determine whether the variations are or related to pumping stress.

Most waters collected at different times from the aquifer-base wells that were sampled more than once contained chloride concentrations that were nearly constant considering analytical error. An appreciable increase in chloride content occurred with time in samples collected in 1983-1985 from the deep aquifer well at site 23. However, the sample collected and analyzed by the GMD5 in 1986 had essentially the same chloride as the previous sample for 1985, suggesting that the last samples are representative of deep aquifer water at this location. Small increases were observed for the aquifer-base waters at sites 9 and 29. These increases could possibly be related to the upconing of deeper, more saline water present at each site during pumping for sampling.

The chloride concentration in the second sample from the aquifer-base at site 6 was substantially smaller than in the initial sample. The bottom of the screen in the deep well at the site is only 3 ft above the bedrock surface. A possible explanation for the salinity decrease is a greater mixing of fresher aquifer waters with saline water just above the bedrock during the second pumping. This would be facilitated if the saline water layer above the bedrock was thin and the bedrock permeability is low at site 6.

Four to 5 samples were collected during 1978-1986 from most, and 5-7 samples collected during 1978-1992 for several of the upper-aquifer wells in the observation network (Table 10). Only one to 3 samples were taken from the intermediate depth wells in the aquifer. The relative changes in chloride concentration for the middle to upper part of the aquifer summarized in Table 10 indicate that no consistent pattern of variations were observed across the well network in the upper part of the aquifer during this time. Chloride contents at some sites remained relatively constant, others decreased, some increased, while still others fluctuated. The most common variation for the 1978-1986 interval was a decrease at the end of the period. The 5 sites at which samples were collected after 1986 exhibited increases, a decrease, or were constant. Variations in sulfate concentration during the same period were less pronounced than those for chloride.

Sites with observed variations in chloride concentration are located in the middle to northern part of the observation well network, while most of the sites in the southern part of the network, where bedrock and aquifer waters tend to have lower dissolved solids, exhibited no substantial changes in chloride. Thus, variations may be more pronounced where changes in ground-water quality with depth are greater. The increase in salinity at site 2 has been attributed primarily to leaching of soil moisture concentrated by evapotranspiration (Whittemore, 1991). Site 27, another location where agricultural activities appear to have contributed to ground-water chloride, showed an appreciable decrease in chloride from 479-488 mg/L in 1984 to 268-290 during 1990-1991. The large decrease does not correlate with changes at other sites, further suggesting that much of the salinity is anthropogenic, was higher in the past, and is now being diluted. The overall patterns in the variations in the observation well network suggest that differences in recharge and local anthropogenic effects with time and from site to site during the sampling period are currently more important in affecting salinity variations of the shallow aquifer waters than a network-wide change from pumping stresses.

DISTRIBUTION OF AND VARIATION OF NUTRIENT CONSTITUENTS

Nitrate was determined for at least one sample from all of the network wells, ammonium ion and phosphate for most of the wells, and nitrite for many of the wells. Ranges observed in the nutrient species concentrations are listed in Table 5. Nitrate concentrations in the ground water generally decrease with depth in the aquifer and from the aquifer to the bedrock. The greater decrease is from the upper aquifer to the aquifer base. The lowest nitrate concentrations usually occur in the ground waters with the highest chloride content (Figures 11-13). A general inverse relationship between chloride and nitrate occurs in waters from the aquifer base and underlying bedrock suggesting that fresher waters from recharge tend to be related with higher nitrate.

The distribution of nitrate concentrations indicates that the maximum background nitrate-N is less than 4 mg/L (Figures 11-13). Only one bedrock well yielded water with greater than 3.6 mg/L and only two wells gave water with more than 3 mg/L nitrate-N for the last samples collected from the aquifer base. Many of the upper aquifer waters contained greater than 3 mg/L nitrate-N. Samples from the shallowest wells at sites 17, 27, 39, 40, and 50 contained nitrate greater than the maximum drinking-water limit of 10 mg/L, although the value at site 50 (10.6 mg/L) was close to the standard. Only site 27 of these 5 had an identifiable increase in chloride from agricultural activities. Nitrate concentrations were either nearly constant or generally increased in the upper aquifer during the data period. The sites with high nitrate tended to show increases. For example, the nitrate-N increase was 51 to 73 mg/L at site 27 during 1982-1984, even though the chloride concentration decreased from 483 to 389 mg/L in the same period.

The nitrate-N content of about 11 mg/L in the bedrock water at site 34 is anomalously high in comparison with the values for the bedrock wells at all the other sites and the low nitrate for the aquifer well at site 34. The bedrock well at this site yields freshwaters with a low chloride content. The site area is surrounded by saline bedrock waters as shown on Plate 1. Recharge by oxygenated waters that have flushed saline waters from the bedrock and are oxidizing ammonium ion adsorbed on the sediments might be the cause of the anomalous nitrate.

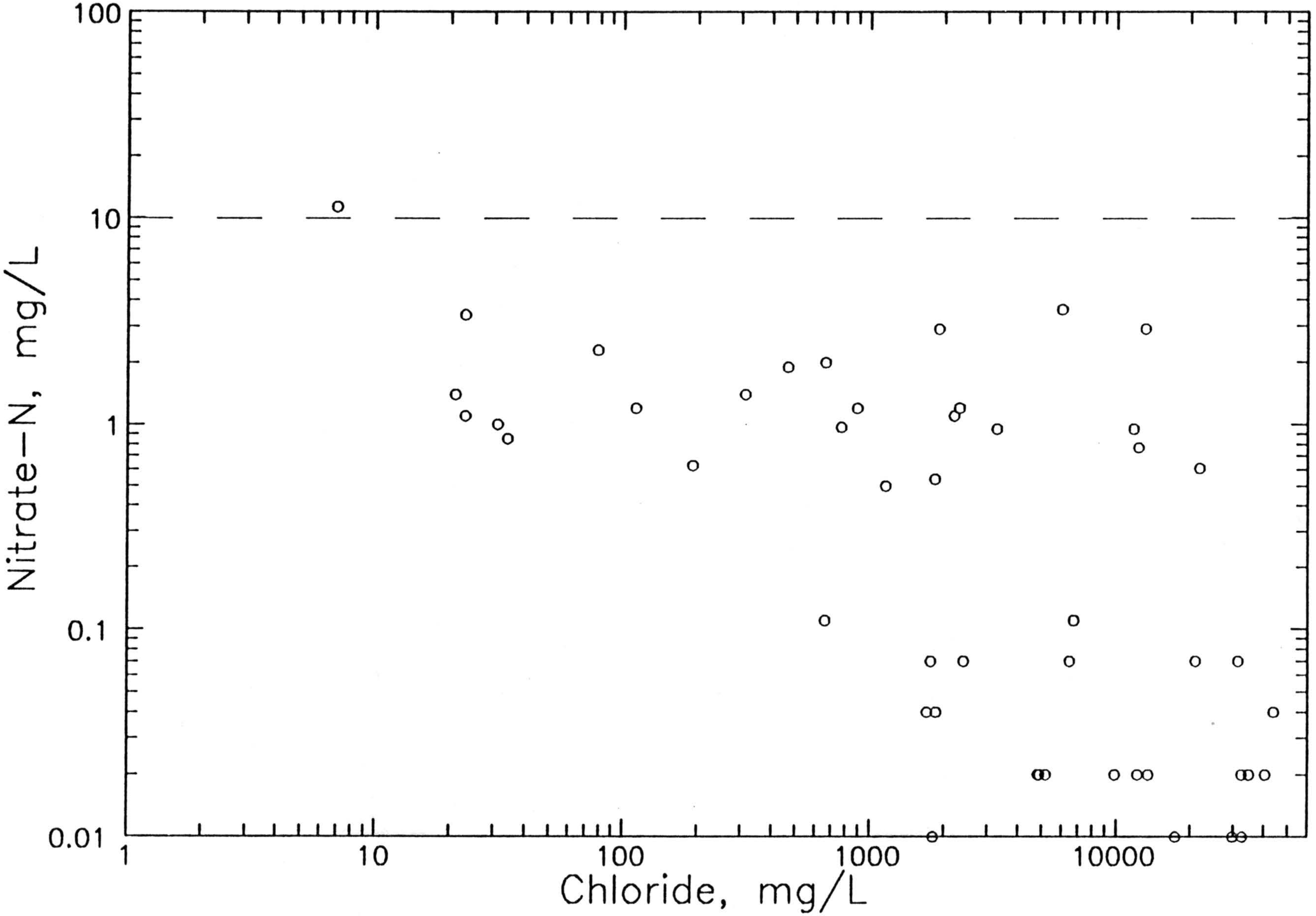

Figure 11. Relationship between nitrate and chloride concentrations for Permian bedrock waters from the observation well network. The horizontal dashed line represents the maximum contaminant limit (10 mg/L) for nitrate-N in public drinking-water supplies.

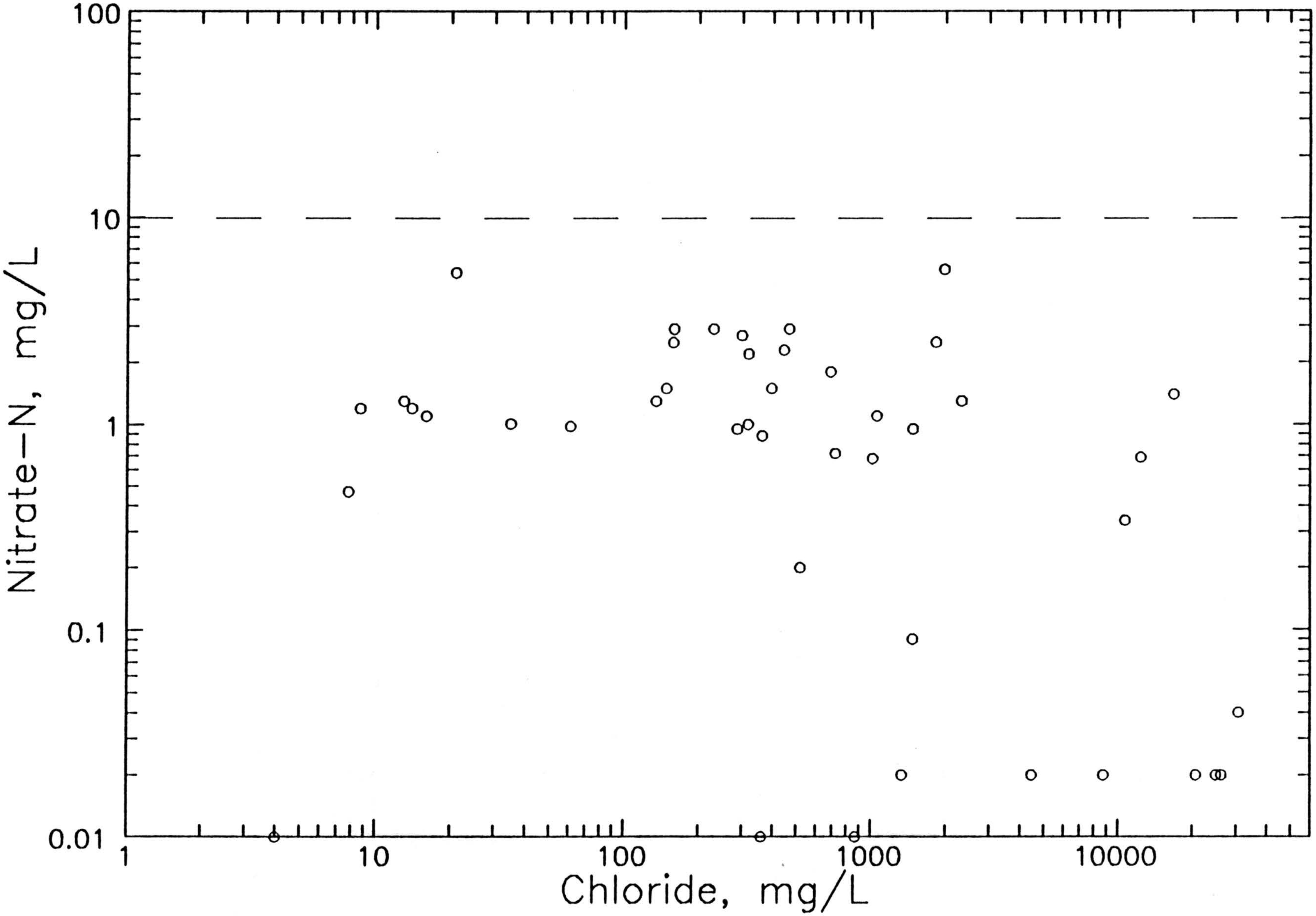

Figure 12. Relationship between nitrate and chloride concentrations for aquifer-base waters from the observation well network. The horizontal dashed line represents the maximum contaminant limit (10 mg/L) for nitrate-N in public drinking-water supplies.

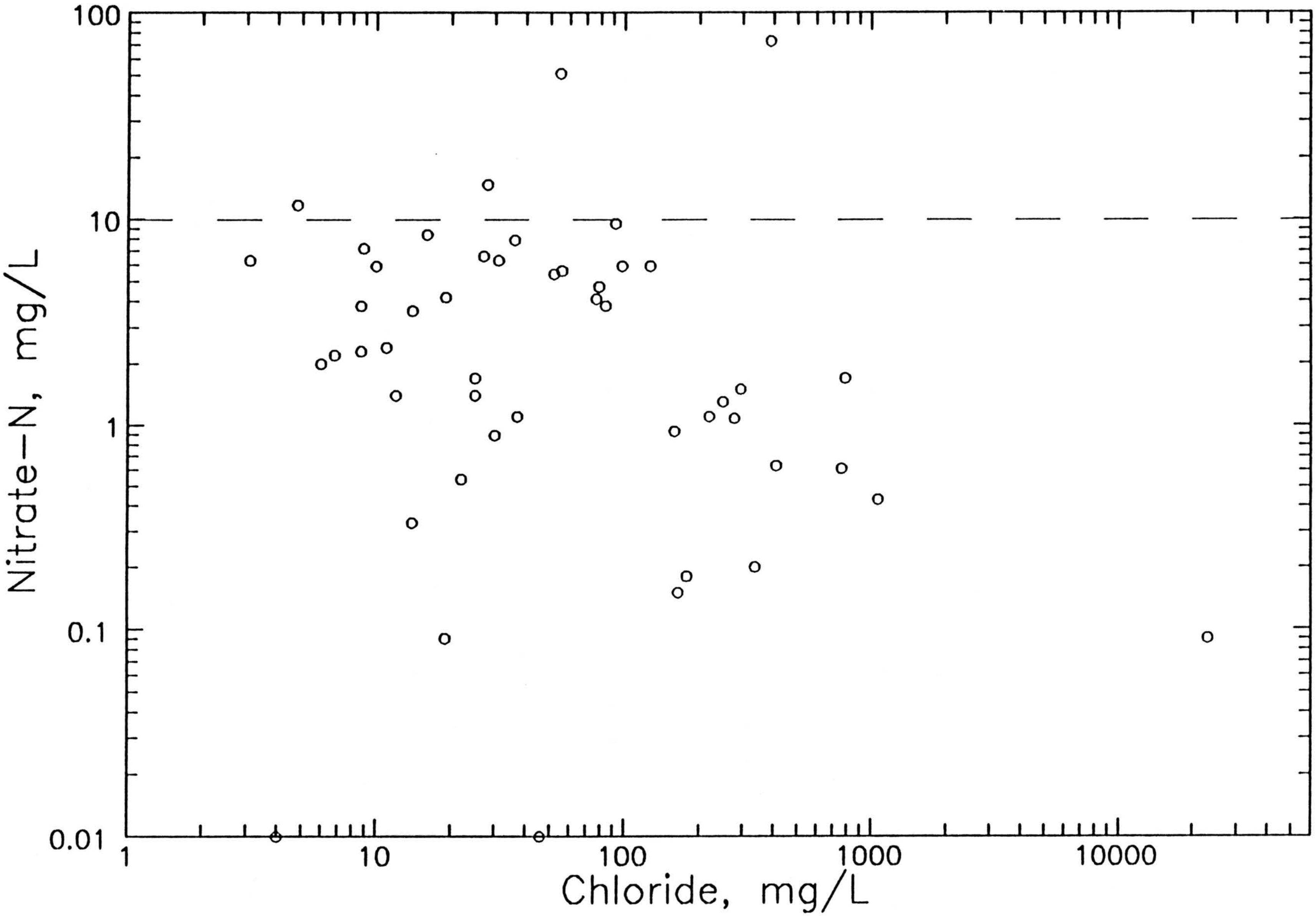

Figure 13. Relationship between nitrate and chloride concentrations for upper aquifer waters from the observation well network. The horizontal dashed line represents the maximum contaminant limit (10 mg/L) for nitrate-N in public drinking-water supplies.

Dissolved ammonium ion levels generally increase with depth in the aquifer and into the bedrock, reflecting more reducing conditions (lower dissolved oxygen) with depth (Table 5). Higher ammonium ion levels were associated with low nitrate concentrations. Ammonium ion concentrations were below 1 mg/L as nitrogen in most of the bedrock wells but were in the 3-4.8 mg/L range at 5 network sites. The total-dissolved concentration of all nitrogen species at the aquifer base is substantially less than the ammonium ion concentration in the bedrock water at 4 of these sites. The other network site does not include an aquifer base well but the total-dissolved nitrogen in the upper aquifer well is also appreciably less than the ammonium ion content in the bedrock well water. This indicates that most of the ammonium ion is derived from the Permian sediments and not the aquifer. Oxidation of ammonium ion in the bedrock sediments is probably the source of much of the nitrate in bedrock waters.

Nitrite contents are low in both aquifer and bedrock waters. No discernible pattern was observed in dissolved nitrite with depth although the data are more limited than for the other nutrient species. Most of the nitrite-N concentrations were less than 0.01 mg/L. The highest nitrite-N was 0.3 mg/L in the bedrock water at network site 48 which also contained detectable nitrate and ammonium ion. The aquifer base well at site 48 also contained nitrite, although at a near-detection level. No recognizable pattern exists for dissolved orthophosphate with depth; concentrations as phosphate-P were generally less than 0.2 mg/L. The higher concentrations of orthophosphate in a few of the earlier samples from the observation wells might reflect traces of drilling water. Ferric oxyhydroxide coatings on the sediment particles, especially in the Permian red beds, can readily adsorb phosphate and probably control its concentration.

CONCLUSIONS

The primary source of mineralized water in the Great Bend Prairie aquifer is dissolution of Permian evaporites. The chemical water type is Na-Cl, reflecting the main salinity source of dissolved halite. Water quality in the Permian bedrock underlying the unconsolidated aquifer ranges from saltwater in the northwest and central portions of the observation well network to fresh in the southernmost area. Fingers of more saline water in the bedrock appear to be related to bedrock channels and discharge zones, while protrusions of less saline water occur in bedrock highs and beneath recharge zones in the overlying aquifer.

The saline water in the lower part of the unconsolidated aquifer is derived from intrusion of saltwater from the Permian rocks. The distribution pattern of the saline water at the aquifer base indicates that saltwater intrusion occurs where Permian bedrock, especially the Cedar Hills Sandstone, underlies the aquifer. Cretaceous rocks in the western portion of the study area restrict saltwater intrusion. However, not all aquifer areas are as saline as would be expected from comparison of saline water distribution in the Permian bedrock immediately underlying the aquifer. Aquifer recharge areas are important in restricting mineral intrusion in these locations. The resulting area of saline water at the aquifer base is appreciably smaller than that for the Permian.

Water in the upper part of the unconsolidated aquifer is generally fresh except in the northeastern portion of the observation well network. Saline water intrusion to the shallow depths of the aquifer is mainly controlled by discharge along streams, especially Rattlesnake Creek and parts of the South Fork of the Ninnescah River and the Arkansas River, and in the Big and Little Salt marshes. The saline water is more concentrated and widespread in areas of shallow water tables in northeast Stafford, northwest Reno, and southwest Rice counties.

The salinity of ground waters in the unconsolidated aquifer increases with depth, but at greatly different rates. Comparison of the chloride distribution patterns for the upper aquifer and aquifer base reveal areas with great contrasts in salinity. Saltwater intrusion to the base of the aquifer in these areas has not dispersed into the upper aquifer, possibly due to protection by low permeability clays or lateral ground-water flow that minimizes the time for upward dispersion of salinity. High contrast locations include north-central Stafford County, a band along the Stafford-Reno county line south from Peace Creek, and northeast and north-central Pratt County. The area of townships T. 21 and 22 S., R 12 W. and the eastern halves of townships T. 21 and 22 S., R. 13 W. in north-central Stafford County exhibit the greatest salinity increase with depth.

These areas are expected to be especially vulnerable to upconing of saline waters pumped by irrigation wells screened in the lower aquifer. The actual amount of upconing will be controlled by the presence or absence of clay layers in the lower aquifer.

The salinity of aquifer waters has been increased by local contamination from oil-field brines and agricultural activities. The regular distribution of well sites in the observation network near township-range corners approximates a random sampling of the aquifer, allowing a general assessment of contamination across the study area. Identifiable contribution to ground-water salinity by oil brine was found in waters from 8 wells at 6 of the 52 sites in the observation well network. The oil brine affected the salinity of the mid to upper aquifer at 3 of these sites and the lower aquifer at the other 3 sites. Oil-brine pollution has made water unusable for irrigation and drinking supply in the lower part of the aquifer at only one site, whereas the natural chloride concentration in parts of the aquifer at 4 of the other sites with oil brine is already too high for these uses. The results suggest that about 12 percent of the region within the network might be expected to have oil-brine contamination at some depth in the aquifer, because oil fields cover a substantial percentage of the network area in addition to the sites with contamination. However, the distribution of the expected pollution could range appreciably, with a near zero percentage in locations distant from oil fields to greater than 12 percent within some oil fields. The presence of oil brine in the aquifer at 3 additional locations described in this report support the expectation of oil-brine contamination at other places besides the network wells.

Agricultural activities appear to have substantially increased the chloride concentration of ground water in the upper aquifer at 3 sites in the observation well network. The expected natural chloride concentration is well below 100 mg/L at all these sites and the sites do not occur within oil fields. The agriculturally related increase in chloride concentration has made shallow ground water unusable for irrigation and drinking use at one site. The increases in chloride are associated with nitrate contents that are higher than expected for background in the aquifer. Leaching of salts concentrated in soils by evapotranspiration of irrigation waters and from fertilizers appear to be a major source of the salinity and nitrate increases. If the 3 sites are representative of the GMD5 region, then approximately 6 percent of the network area could have ground waters in the upper aquifer with salinity significantly affected by agricultural activities. The fact that other investigations within the network area have shown even greater salinity increases in wells screened closer to the water table than the network wells suggests that the 6 percent value may underestimate salinity increases at the aquifer top.

Background values for dissolved nitrate-N in the aquifer are typically less than 2 mg/L but can sometimes approach 4 mg/L. Nitrate concentrations in the ground water generally decrease with depth in the aquifer and from the aquifer to the bedrock. Upper aquifer waters at 5 network sites contained nitrate-N greater than 10 mg/L. This suggests that nearly 10 percent of the network area had nitrate concentrations exceeding the drinking-water limit in the upper aquifer at sometime during the 1980's. Only one of the sites with nitrate-N above 10 mg/L had an identifiable increase in chloride from agricultural activities. Nitrite-N contents are low in both aquifer and bedrock waters; most are <0.01 mg/L. Dissolved ammonium ion levels generally increase with depth in the aquifer and into the bedrock, reflecting more reducing conditions (lower dissolved oxygen) with depth. Although ammonium ion concentrations were below 1 mg/L as nitrogen in most of the bedrock wells, the presence of 3-4.8 mg/L ammonium-N at 5 sites indicates that the upper limit of natural dissolved nitrogen could be higher in the bedrock than in the lower aquifer. Oxidation of ammonium ion in the bedrock could be the source of much of the nitrate in bedrock waters, and in aquifer-base waters where upward flow occurs from the Permian.

There is no clear direction in the chloride concentration variations for the region as a whole during the period of available data (mainly the 1980's). Chloride concentrations were nearly constant at many network well sites, while many others had increases and/or decreases. Nitrate concentrations were either nearly constant or generally increased in the upper aquifer during the data period. The well sites with high nitrate tended to show increases. Chloride concentrations both increased and decreased in upper aquifer waters with nitrate concentrations above the background. The water-quality changes appear to be related more to the local site conditions than to the environment of the network region. Natural sources of salinity vary from changes in recharge and discharge in the system and from pumping stresses. Oil-brine and agricultural sources of chloride and nitrate also will vary from these factors, as well as the rate of contamination input or effects. Additional sampling of the network sites at which increased salinity was found from anthropogenic activities should be useful for further understanding changes in the salinity distribution. A couple of the bedrock wells in the network for which anomalously low salinities were obtained and which were only sampled once should be resampled to determine whether the existing data are representative.

REFERENCES

Bayne, C.K., 1956. Geology and ground-water resources of Reno County, Kansas. Bulletin 120, Kansas Geological Survey, 130 p.

Burrton Task Force, 1984. Proposed Burrton intensive groundwater use control area. Available from Kansas Department Health and Environment, Topeka, Kansas, 103 p.

Cobb, P.M., 1980. The distribution and mechanisms of salt water intrusion in the fresh water aquifer and in Rattlesnake Creek, Stafford County, Kansas. MS thesis, Department of Civil Engineering, University of Kansas, Lawrence, 176 p.

Fader, S.W., and Stullken, L.E., 1978. Geohydrology of the Great Bend Prairie, south-central Kansas. Irrigation Series 4, Kansas Geological Survey, 19 p.

Fent, O.S., 1950, Geology and ground-water resources of Rice County, Kansas. Bulletin 85, Kansas Geological Survey, 142 p.

Gillespie, J.B., Hargadine, G.D., Myers, N.C., and Hargadine, D.A., 1991. Geohydrologic data for the South Fork Ninnescah River valley and adjacent plains in Pratt and Kingman counties, south-central Kansas. Open-File Report 91-186, U.S. Geological Survey, Lawrence, Kansas, 55 p.

Hathaway, L.R., Galle, O.K., Waugh, T.C., and Dickey, H.P., 1978. Chemical quality of irrigation waters in Ford County and the Great Bend Prairie of Kansas. Chemical Quality Series 7, Kansas Geological Survey, 41 p.

Kansas Geological Survey, 1989a. Oil and gas fields, Great Bend Quadrangle in Kansas, Map M 18-7.

Kansas Geological Survey, 1989b. Oil and gas fields, Pratt Quadrangle in Kansas, Map M 18-10.

Lane, C.W., 1960. Geology and ground-water resources of Kingman County, Kansas. Bulletin 144, Kansas Geological Survey, 174 p.

Latta, B., 1950. Geology and ground-water resources of Barton and Stafford counties, Kansas. Bulletin 88, Kansas Geological Survey, 228 p.

Layton, D.W., and Berry, D.W., 1973. Geology and ground-water resources of Pratt County, south-central Kansas. Bulletin 205, Kansas Geological Survey, 33 p.

Rosner, M.L., 1988. The stratigraphy of the Quaternary alluvium in the Great Bend Prairie, Kansas. MS thesis, Department of Geology, University of Kansas, Lawrence, 183 p.

Sophocleous, M.A., and McAllister, J.A., 1990. Hydrologic-balance modeling of the Rattlesnake Creek watershed, Kansas. Ground Water Series 11, Kansas Geological Survey, 72 p.

Sophocleous, M.A., Townsend, M.A., Orountiotis, C., Evanson, R.A., Whittemore, D.O., Watts, C.E., and Marks, E.T., 1990. Movement and aquifer-contamination potential of atrazine and inorganic chemicals in central Kansas croplands. Ground Water Series 12, Kansas Geological Survey, 64 p.

Sophocleous, M.A., Townsend, M.A., and Whittemore, D.O., 1990, Aquifer contamination potential of atrazine in central Kansas croplands: Journal of Hydrology *115*: 115-137.

Sophocleous, M.A., Arnold, B., McClain, T., and Stern, A., 1993. Configuration of the pre-Cenozoic bedrock surface of the Great Bend Prairie Region of Kansas. Kansas Geological Survey, in press.

Stullken, L.E., and Fader, S.W., 1976. Hydrogeologic data from the Great Bend Prairie, south-central Kansas. Basic Data Series, Ground-Water Release No. 5, Kansas Geological Survey, 50 p.

Townsend, M.A., and Marks, E.T., 1990. Occurrence of nitrate in soil and ground water in sandy soils in south-central Kansas. Proceedings of National Water Well Association, 1990 Cluster Conferences, Agricultural Impacts on Ground Water Quality Session, Feb., 1990, Kansas City, MO, p. 145-157.

Townsend, M.A., and Young, M.A., 1992. Factors affecting nitrate concentrations in ground water in east-central Stafford County, Kansas. Open-File Report 92-34, Kansas Geological Survey, 35 p.

Whittemore, D.O., Sophocleous, M., Bryson, W.R., Schoof, J., and Bell, T.C., 1985. An interagency study of oilfield brine pollution in Kansas. Groundwater Contamination and Reclamation Symposium, Amer. Water Resources Assoc., p. 109-116.

Whittemore, D.O., 1984. Geochemical identification of salinity sources; *in* R.H. French (ed.), Salinity in Watercourses and Reservoirs (Proceedings of the International Conference on State-of-the-Art Control of Salinity). Ann Arbor Science, Butterworth Publishers, Stoneham, MA, p. 505-514.

Whittemore, D.O., 1988, Bromide as a tracer in ground-water studies: Geochemistry and analytical determination: Proceedings Ground Water Geochemistry Conference, National Water Well Assoc., Dublin, OH, p. 339-360.

Whittemore, D.O., 1990a. Geochemical characterization of waters at the Maxedon Lease, Pratt County. Report for Kansas Corporation Commission, 6 p.

Whittemore, D.O., 1990b. Geochemical identification of saltwater contamination at the Siefkes subsidence site. Report for Kansas Corporation Commission, 6 p.

Whittemore, D.O., 1991. Geochemical identification of salinity sources in ground waters at and near site 2 of the observation-well network of Groundwater Management District No. 5. Open-File Report 91-61, Kansas Geological Survey, 15 p.

Whittemore, D.O. and Hathaway, L.R., 1983. Identification of saltwater sources affecting groundwater from R. Newell irrigation well, Reno County. Open-File Report 83-14, Kansas Geological Survey, 5 pp.

Whittemore, D.O. and Huggins, D.G., 1987. Chapter 3: Water Quality; *in* Cheyenne Bottoms: An Environmental Assessment. Prepared by Kansas Biological Survey and Kansas Geological Survey, for Kansas Fish and Game Commission, p. 31-54.

Young, D.P., 1992. Mineral intrusion: Geohydrology of Permian bedrock underlying the Great Bend Prairie aquifer in south-central Kansas. Open-File Report 92-44, Kansas Geological Survey, 47 p.

Appendix A. Chemical Properties of Observation Well Waters from the Permian Bedrock.

Site-well	Location	Sample date	Sp.C., lab, uS/cm[a]	pH, lab	Total dissolved solids, calculated, mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
1-1	23S 12W 12BAAA	78-10-25	33600	7.2	24650	1652	96.0	92.1	0.733
1-1	" " "	83-01-20	36900	7.6	24160	1775	90.0	91.2	0.654
2-1	23S 12W 36ABAB	78-10-26	2450	7.3	1581	339	11.1	74.8	0.645
2-1	" " "	83-03-01	2630	7.4	1445	355	9.6	71.3	0.549
4-1	23S 14W 36DDCD	78-10-24	66700	7.1	55670	8396	86.1	82.3	0.834
4-1	" " "	82-11-29	77600	7.0	53290	8580	81.7	81.3	0.686
5-1	23S 12W 06BBBA	78-10-26	85200	8.4	74610	4083	188.6	93.5	0.875
5-1	" " "	83-11-17	79900	7.7	56770	3645	149.9	92.3	0.710
6-1	25S 13W 06BCBC	83-05-02	85500	7.9	64307	6680	123.5	88.2	0.752
6-1	" " "	83-12-13	98900	8.4	74250	7620	129.6	88.1	0.750
6-1	" " "	86-07-07	102000	7.5					
7-1	24S 13W 36DDDD	78-10-25	75900	8.0	64830	5043	142.1	90.8	0.854
7-1	" " "	83-05-03	18900	7.8	11790	1100	56.0	89.3	0.623
8-1	25S 12W 11AAAD	79-10-31	108000	9.4	82750	6684	158.6	90.5	0.766
8-1	" " "	83-12-09	106000	8.1	89340	6136	171.0	91.5	0.842
9-1	24S 10W 31CBCB	79-10-31	10000	7.4	5995	928	28.1	82.0	0.599
9-1	" " "	83-01-11	10700	7.4	6261	930	28.9	82.3	0.585
10-1	24S 10W 06DCCC	79-11-01	6050	7.6	3350	568	19.8	80.4	0.553
10-1	" " "	83-02-23	6230	7.6	3451	575	20.1	80.4	0.554
11-1	22S 10W 06CBBB	79-11-02	21300	8.6	12920	1322	53.8	87.8	0.606
11-1	" " "	83-11-16	66900	8.4	47260	4223	110.4	89.4	0.706
11-1	" " "	84-11-14	14000	8.0	8242	905	41.0	86.9	0.588
11-1	" " "	86-07-09	14800						
12-1	29S 11W 36ACCC	82-12-07	335	7.8	188	95	1.1	34.4	0.562
12-1	" " "	86-07-15	680	8.0	381	182	2.2	45.0	0.560
13-1	29S 14W 36AAAD	82-11-30	443	8.2	266	165	0.8	23.2	0.601
14-1	29S 14W 12ABBB	80-11-13	330	8.3	218	145	0.5	18.9	0.662
14-1	" " "	82-12-15	320	7.9	208	140	0.4	15.5	0.652
14-1	" " "	84-02-03	640						
15-1	28S 11W 01AAAD	84-01-03	1880	8.8	1094	53	24.3	93.5	0.582

Appendix A. (continued)

Site-well	Location	Sample date	Sp.C., lab, uS/cm[a]	pH, lab	Total dissolved solids, calculated, mg/L	Hard-ness, mg/L CaCO3	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
15-1	28S 11W 01AAAD	84-05-15	2100	8.4	1158	76	21.1	91.9	
15-1	" " "	86-07-11	2030	9.8					
16-1	21S 12W 31CCCB	83-05-04	1750	8.0	982	132	12.5	82.7	0.561
16-1	" " "	84-01-27	88300	8.0	62320	3883	155.0	92.4	0.705
16-1	" " "	84-05-14	88500	7.8	64020	4272	154.4	92.0	0.723
17-1	21S 12W 36DDCC	83-05-10	28900	7.7	18670	1406	79.3	91.3	0.646
18-1	21S 11W 07BBBA	83-05-09	35200	7.5	23550	2284	77.3	88.9	0.669
19-1	25S 13W 36DCCC	83-03-02	995	7.8	560	227	3.4	52.1	0.563
20-1	25S 13W 31DDAA	84-01-25	17400	7.5	11360	2272	29.5	75.5	0.652
21-1	26S 11W 01DDDA	83-12-13	35100	7.4	23260	2824	65.7	86.0	0.662
22-1	21S 12W 06CCBC	83-05-05	82600	7.3	61450	4776	142.9	91.1	0.743
23-1	21S 10W 06AADD	83-02-24	21300	7.7	13360	1856	43.7	83.3	0.627
24-1	22S 10W 01ADBC	83-05-11	6310	7.8	3450	640	19.8	79.3	0.546
25-1	23S 10W 06BBAB	83-02-18	6900	7.8	3684	351	30.1	88.5	0.534
25-1	" " "	85-04-05	41000						
25-1	" " "	86-07-09	40800	7.7	31100	3707	74.9	85.9	0.762
26-1	23S 10W 01AAAA	83-11-21	37100	7.2	24860	3060	68.1	86.0	0.669
27-1	23S 09W 01ADAA	84-01-11	6510	7.6	3631	827	17.2	74.8	0.557
28-1	25S 09W 01ADDA	83-12-08	3550	9.0					
28-1	" " "	84-05-18	3580	8.4	2042	426	12.4	74.2	0.570
28-1	" " "	86-08-08	3500						
29-1	24S 10W 36AAAA	84-11-03	60000	8.1	43070	3386	113.2	90.5	0.717
29-1	" " "	85-04-04	58700						
30-1	23S 10W 36DAAA	83-11-21	7700	8.7	4236	693	22.3	80.4	0.550
30-1	" " "	84-11-03	8000	7.6	4436	733	22.4	80.0	0.554
31-1	22S 09W 01ADAA	83-11-14	6520	7.6	3660	670	19.3	78.8	0.561
32-1	23S 09W 25DDDD	83-05-19	7150	7.7	4280	1050	16.5	71.5	0.598
33-1	25S 12W 36CBBA	83-03-01	4250	7.7	2260	372	16.5	80.7	0.531
34-1	25S 09W 36DDCC	83-05-24	379	8.2	253	153	0.8	25.9	0.668
34-1	" " "	84-11-12	635						

Appendix A. (continued)

Site-well	Location	Sample date	Sp.C., lab, uS/cm[a]	pH, lab	Total dissolved solids, calculated, mg/L	Hard-ness, mg/L CaCO3	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./Sp.C.[b]
34-1	25S 09W 36DDCC	85-04-04	380						
35-1	26S 10W 31CCCB	82-12-23	21400	7.4	13240	1341	54.4	87.8	0.618
36-1	27S 12W 06BAAB	83-05-26	56800	7.6	40030	2599	127.1	92.5	0.704
37-1	27S 13W 05CABB	83-03-03	7780	9.6	4265	627	23.9	82.2	0.548
37-1	" " "	84-01-03	7484	8.8	4199	659	23.5	81.6	0.561
37-1	" " "	84-11-14	7700	8.0	4311	666	23.2	81.5	0.559
38-1	26S 12W 36ADDA	83-03-07	6910	7.7	3680	407	27.5	86.9	0.532
39-1	26S 10W 01AAAA	83-01-10	36300	7.7	23400	2601	67.2	86.7	0.644
40-1	26S 09W 31CDDD	83-03-09	2720	7.9	1498	246	13.3	80.6	0.550
41-1	26S 09W 35ADAD	83-06-20	5460	8.8	3101	495	20.1	81.7	0.568
41-1	" " "	84-05-15		8.1		288	18.0	83.9	
41-1	" " "	86-08-27	3050						
42-1	28S 13W 01CBAA	83-05-26	15500	7.8	9567	1574	34.8	81.4	0.617
43-1	27S 13W 31DDDD	84-11-14	7500	7.7	4146	642	22.9	81.5	0.552
44-1	29S 13W 35ABBA	84-11-12	382	10.4					
44-1	" " "	86-07-03	238	7.8	155	41	1.7	55.8	0.652
45-1	29S 11W 01DADA	82-12-09	653	8.2	379	121	3.8	62.4	0.580
45-1	" " "	86-07-15	810						
46-1	29S 11W 06AAAB	82-12-10	1460	8.7	798	173	7.4	70.1	0.546
46-1	" " "	84-05-07	1460	8.4		153	7.7	72.3	
46-1	" " "	86-07-07	1460						
47-1	29S 13W 12ABBA	84-11-12	510	9.4					
48-1	29S 12W 36DCCD	83-12-03	489	9.6	295	45	4.2	59.6	0.604
48-1	" " "	84-01-05	384	8.6	246	59	3.4	63.8	0.642
48-1	" " "	84-05-15	412	8.4		76	2.8	58.4	
48-1	" " "	85-04-04	453	8.4					
48-1	" " "	86-07-03	398	7.9					
49-1	27S 12W 35AAAA	82-11-23	84800	7.8	60890	5591	125.7	89.1	0.718

---

[a] Specific conductance in u-siemens/cm (same values as umhom/cm) at 25 °C.

[b] Specific conductance/calculated total dissolved solids

Appendix B. Concentration of Major Dissolved Constituents in Observation Well Waters from the Permian Bedrock. All concentrations are in mg/L.

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
1-1	23S 12W 12BAAA	78-10-25	22	390	165	8970	202	1690	13270
1-1	" " "	83-01-20	56	421	176	8720	203	1500	13140
2-1	23S 12W 36ABAB	78-10-26	22	103	20	471	255	110	725
2-1	" " "	83-03-01	24	111	19	416	228	96	659
4-1	23S 14W 36DDCD	78-10-24	14	1930	869	18140	81	3600	31000
4-1	" " "	82-11-29	66	1966	892	17400	78	2900	29900
5-1	23S 12W 06BBBA	78-10-26	18	961	409	27700	152	4180	41200
5-1	" " "	83-11-17	81	906	336	20800	162	3080	31400
6-1	25S 13W 06BCBC	83-05-02	47	1823	517	23200	47	4130	34500
6-1	" " "	83-12-13		2002	637	26000	28	5100	40500
6-1	" " "	86-07-07					25	4800	42640
7-1	24S 13W 36DDDD	78-10-25	12	1110	552	23200	76	5660	34200
7-1	" " "	83-05-03	27	281	97	4270	158	976	6030
8-1	25S 12W 11AAAD	79-10-31		1650	623	29800	0	6290	44300
8-1	" " "	83-12-09	38	1500	581	30800	69	12500	43800
9-1	24S 10W 31CBCB	79-10-31		278	57	1970	213	484	3080
9-1	" " "	83-01-11	28	272	61	2030	208	470	3280
10-1	24S 10W 06DCCC	79-11-01		152	46	1090	246	241	1691
10-1	" " "	83-02-23	44	148	50	1110	257	254	1707
11-1	22S 10W 06CBBB	79-11-02		406	75	4500	43	957	6930
11-1	" " "	83-11-16	30	1230	280	16500	17	4170	25000
11-1	" " "	84-11-14	23	239	75	2840	173	501	4460
11-1	" " "	86-07-09						541	4829
12-1	29S 11W 36ACCC	82-12-07	8.2	30	4.9	25.2	102	20	41
12-1	" " "	86-07-15	18	45	17	70	196	43	79
13-1	29S 14W 36AAAD	82-11-30	25.5	52.6	8.3	24.3	186	29	23.0
14-1	29S 14W 12ABBB	80-11-13	28.1	51	4.3	16	179	8.6	8.1
14-1	" " "	82-12-15	27.6	49.4	4.1	12.2	164	19	8.7
14-1	" " "	84-02-03						120	34
15-1	28S 11W 01AAAD	84-01-03	15	9.7	7.1	409	239	86	434
15-1	" " "	84-05-15		15	9.5	426	288	88	465
15-1	" " "	86-07-11						83	466

Appendix B. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
16-1	21S 12W 31CCCB	83-05-04	21	43	6.2	333	175	53	420
16-1	" " "	84-01-27		868	417	22200	129	3910	34800
16-1	" " "	84-05-14	15	862	515	23200	188	4467	34800
17-1	21S 12W 36DDCC	83-05-10	26	339	136	6840	255	1316	9880
18-1	21S 11W 07BBBA	83-05-09	37	473	268	8490	403	1848	12230
19-1	25S 13W 36DCCC	83-03-02	22	75	9.7	118	203	33	192
20-1	25S 13W 31DDAA	84-01-25	11	648	159	3240	66	2050	5200
21-1	26S 11W 01DDDA	83-12-13	19	673	278	8030	142	2440	11740
22-1	21S 12W 06CCBC	83-05-05	55	830	657	22700	423	4484	32500
23-1	21S 10W 06AADD	83-02-24	26	353	237	4330	254	1779	6480
24-1	22S 10W 01ADBC	83-05-11	18	174	50	1155	210	118	1819
25-1	23S 10W 06BBAB	83-02-18	11	88	32	1300	189	163	1985
25-1	" " "	85-04-05						1607	15313
25-1	" " "	86-07-09	24	786	424	10490	124	1868	17430
26-1	23S 10W 01AAAA	83-11-21	22	812	251	8660	203	1530	13470
27-1	23S 09W 01ADAA	84-01-11	17	183	90	1140	228	236	1841
28-1	25S 09W 01ADDA	83-12-08						315	866
28-1	" " "	84-05-18	14	90	49	593	45	349	898
28-1	" " "	86-08-08						337	885
29-1	24S 10W 36AAAA	84-11-03	20	786	346	15150	50	4658	22030
29-1	" " "	85-04-04						4527	20989
30-1	23S 10W 36DAAA	83-11-21	9.2	240	23	1350	14	282	2300
30-1	" " "	84-11-03	12	228	40	1400	31	307	2409
31-1	22S 09W 01ADAA	83-11-14	14	158	67	1150	244	378	1771
32-1	23S 09W 25DDDD	83-05-19	28	261	97	1230	188	693	1864
33-1	25S 12W 36CBBA	83-03-01	19	98	31	735	236	90	1160
34-1	25S 09W 36DDCC	83-05-24	26	40	13	25	147	18	4.0
34-1	" " "	84-11-12						24	74
34-1	" " "	85-04-04						18	6.7
35-1	26S 10W 31CCCB	82-12-23	38	305	141	4580	202	1300	6750
36-1	27S 12W 06BAAB	83-05-26	29	675	222	14900	156	2293	21800
37-1	27S 13W 05CABB	83-03-03	13	230	13	1377	94	271	2290
37-1	" " "	84-01-03	16	223	25	1390	76	302	2180

Appendix B. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
37-1	27S 13W 05CABB	84-11-14	17	214	32	1376	110	294	2306
38-1	26S 12W 36ADDA	83-03-07	24	117	28	1280	174	216	1908
39-1	26S 10W 01AAAA	83-01-10	32	625	253	7880	160	2200	12300
40-1	26S 09W 31CDDD	83-03-09	22	74	15	481	223	120	663
41-1	26S 09W 35ADAD	83-06-20	19	116	50	1030	184	331	1457
41-1	" " "	84-05-15		66	30	704	198	221	990
41-1	" " "	86-08-27						164	767
42-1	28S 13W 01CBAA	83-05-26	21	413	132	3180	150	838	4900
43-1	27S 13W 31DDDD	84-11-14	17	208	30	1335	101	290	2198
44-1	29S 13W 35ABBA	84-11-12						40	26
44-1	" " "	86-07-03	26	16	0.3	26	29	32	23
45-1	29S 11W 01DADA	82-12-09	17.3	29.4	11.6	97	272	26	54
45-1	" " "	86-07-15						26	113
46-1	29S 11W 06AAAB	82-12-10	15.6	33.2	21.9	224	202	70	305
46-1	" " "	84-05-07		32	18	220	186	70	308
46-1	" " "	86-07-07						67	313
47-1	29S 13W 12ABBA	84-11-12						26	31
48-1	29S 12W 36DCCD	83-12-03	21.5	7.5	6.4	65	190	29	27
48-1	" " "	84-01-05	20	16	4.8	62	170	18	21
48-1	" " "	84-05-15		20	6.5	57	179	21	22
48-1	" " "	85-04-04					178	20	33
48-1	" " "	86-07-03					170	18	21
49-1	27S 12W 35AAAA	82-11-23	99	1430	491	21600	76	4410	32700

Appendix C. Concentration of Minor Dissolved Constituents in Observation Well Waters from the Permian Bedrock. All concentrations are in mg/L.

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
1-1	23S 12W 12BAAA	78-10-25	14	7.1	0.6	3.4	0.05				
1-1	" " "	83-01-20	28	6.9	0.5	2.94	0.10	0.1	<0.01	3.2	1.0
2-1	23S 12W 36ABAB	78-10-26	3.6	1.0	0.4	0.05	0.05				
2-1	" " "	83-03-01	6.5	0.8	0.3	0.11	0.29	0.2	<0.01	0.18	0.11
4-1	23S 14W 36DDCD	78-10-24	42	38	0.2	0.11	1.50				
4-1	" " "	82-11-29	95	37	0.2	0.01	0.12	1.15	<0.01	8.8	5.0
5-1	23S 12W 06BBBA	78-10-26	49	20	0.6	0.36	0.05				
5-1	" " "	83-11-17	70	16	0.8	0.07	0.04	0.7		7.1	4.4
6-1	25S 13W 06BCBC	83-05-02	37	28	0.1	0.59	0.03	2.4		4.9	4.7
6-1	" " "	83-12-13				0.02					7.1
6-1	" " "	86-07-07				0.02					4.9
7-1	24S 13W 36DDDD	78-10-25	38	23	0.3	0.34	0.6				
7-1	" " "	83-05-03	8.1	4.7	0.4	3.6	0.03	0.5		0.90	1.1
8-1	25S 12W 11AAAD	79-10-31	56	30	0.2	0.14	0.07			2.82	
8-1	" " "	83-12-09	64	28	0.3	0.04	0.09	4.8		4.9	7.2
9-1	24S 10W 31CBCB	79-10-31	6.9	2.8	0.2	2.62	0.08			0.23	
9-1	" " "	83-01-11	11	2.8	0.2	0.95	0.06	0.1	<0.01	0.28	0.40
10-1	24S 10W 06DCCC	79-11-01	7.0	2.1	0.5	0.05	0.07			0.20	
10-1	" " "	83-02-23	10	2.0	0.4	0.04	0.08	0.1	<0.01	0.70	0.26
11-1	22S 10W 06CBBB	79-11-02	21	6.2	0.3	0.27	0.02			0.28	
11-1	" " "	83-11-16	19	22	0.1	0.1	0.02	3.0		3.7	4.0
11-1	" " "	84-11-14	15	3.4		0.14					0.63
11-1	" " "	86-07-09				<0.02					0.73
12-1	29S 11W 36ACCC	82-12-07	7.2	0.24	0.4	0.27	0.14	0.03	<0.01	0.07	0.03
12-1	" " "	86-07-15	2.9			2.3					0.10
13-1	29S 14W 36AAAD	82-11-30	6.9	0.33	0.3	1.1	0.36	<0.10	<0.01	0.07	0.05
14-1	29S 14W 12ABBB	80-11-13	3	0.28	0.3	2.48				0.03	
14-1	" " "	82-12-15	2.8	0.24	0.2	0.85	0.06	0.11	<0.01	0.04	0.04
14-1	" " "	84-02-03									0.06
15-1	28S 11W 01AAAD	84-01-03	6.5	0.4	1.1	1.92	0.04	0.1		0.34	0.22
15-1	" " "	84-05-15	3.9			2.10					
15-1	" " "	86-07-11				1.92					0.22

Appendix C. (Continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
16-1	21S 12W 31CCCB	83-05-04	14	1.4	0.8	0.84	0.16	0.6		0.26	
16-1	" " "	84-01-27	63			0.02					
16-1	" " "	84-05-14	48	20	0.4	<0.1	0.19	3.4		3.15	4.9
17-1	21S 12W 36DDCC	83-05-10	2.2	5.4	0.5	0.02	0.06	0.8		1.66	1.6
18-1	21S 11W 07BBBA	83-05-09		8.3	0.6	0.02	0.03	0.8		1.49	1.1
19-1	25S 13W 36DCCC	83-03-02	6.4	1.2	0.3	0.63	0.05	0.3	<0.01	0.12	<0.03
20-1	25S 13W 31DDAA	84-01-25	11	9.5		0.02	0.02	0.2		0.81	0.56
21-1	26S 11W 01DDDA	83-12-13		11	0.4	0.95	0.41	0.3		2.2	1.8
22-1	21S 12W 06CCBC	83-05-05		17	0.5	0.02	0.26	4.4		7.04	2.2
23-1	21S 10W 06AADD	83-02-24	25	5.8	0.6	0.07	0.15	0.8	<0.01	2.9	0.7
24-1	22S 10W 01ADBC	83-05-11	11	2.0	0.6	<0.02	0.03	0.3		0.83	0.28
25-1	23S 10W 06BBAB	83-02-18	11	1.1	0.6	0.02	0.12	0.5	<0.01	0.54	
25-1	" " "	85-04-05									1.6
25-1	" " "	86-07-09	19			<0.02					2.7
26-1	23S 10W 01AAAA	83-11-21		12	0.3	<0.1	0.1	0.49		1.17	2.2
27-1	23S 09W 01ADAA	84-01-11	6.6	3.1	0.6	0.54	0.11	0.2		0.36	0.35
28-1	25S 09W 01ADDA	83-12-08									
28-1	" " "	84-05-18	16	5.8	0.4	1.1	0.02	0.2			
28-1	" " "	86-08-08				1.20					0.21
29-1	24S 10W 36AAAA	84-11-03	40	16		0.07					3.0
29-1	" " "	85-04-04									2.5
30-1	23S 10W 36DAAA	83-11-21	17	7.1	0.2	0.18	0.01	0.2		0.21	
30-1	" " "	84-11-03	19	5.8		0.07					0.29
31-1	22S 09W 01ADAA	83-11-14		2.0	0.6	0.07	0.04	0.1		0.38	0.33
32-1	23S 09W 25DDDD	83-05-19	11	3.8	0.4	0.04	0.03	0.2		0.97	0.37
33-1	25S 12W 36CBBA	83-03-01	7.3	1.0	0.5	0.50	0.08	0.2	<0.01	0.28	0.26
34-1	25S 09W 36DDCC	83-05-24	1.4	0.2	0.4	12.0	0.06	<0.1		0.04	0.06
34-1	" " "	84-11-12				11.3					0.08
34-1	" " "	85-04-04									
35-1	26S 10W 31CCCB	82-12-23	26.2	4.7	0.5	0.11	0.07	0.14	0.01	1.9	1.2
36-1	27S 12W 06BAAB	83-05-26	18	11	0.5	0.61	0.06	0.4		2.74	3.4
37-1	27S 13W 05CABB	83-03-03	16	2.8	0.3	1.49	0.14	0.7	0.12	0.33	0.19
37-1	" " "	84-01-03	16	3.3	0.3	1.47	0.07	0.3		0.28	

Appendix C. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
37-1	27S 13W 05CABB	84-11-14	10	2.8		1.2					0.21
38-1	26S 12W 36ADDA	83-03-07	7.1	1.3	0.4	2.94	0.09	0.1	<0.01	0.48	0.40
39-1	26S 10W 01AAAA	83-01-10	15	7.9	0.4	0.77	0.04	0.2	<0.01	2.7	1.5
40-1	26S 09W 31CDDD	83-03-09	3.5	0.5	0.5	2.01	0.20	0.2	<0.01	0.22	0.18
41-1	26S 09W 35ADAD	83-06-20	3.5	2.0	0.6	0.47	0.13	0.2		0.53	0.36
41-1	" " "	84-05-15	3.4			1.1					
41-1	" " "	86-08-27				0.97					0.21
42-1	28S 13W 01CBAA	83-05-26	3.0	5.7	0.5	0.02	0.03	0.2		0.89	0.68
43-1	27S 13W 31DDDD	84-11-14	11	2.8		1.1					0.22
44-1	29S 13W 35ABBA	84-11-12									
44-1	" " "	86-07-03	2.8			3.4					<0.03
45-1	29S 11W 01DADA	82-12-09	4.2	0.34	0.6	1.2	0.24	<0.02	<0.01	0.16	0.10
45-1	" " "	86-07-15				1.17					0.06
46-1	29S 11W 06AAAB	82-12-10	27	0.60	0.8	0.15	0.10	0.12	<0.01	0.6	0.13
46-1	" " "	84-05-07	23			0.20					0.08
46-1	" " "	86-07-07				1.42					0.08
47-1	29S 13W 12ABBA	84-11-12									
48-1	29S 12W 36DCCD	83-12-03	39.7	0.14	0.7	1.16	0.06	0.03	0.34	0.16	
48-1	" " "	84-01-05	13	0.2	0.9	1.64	0.06	0.2		0.16	0.08
48-1	" " "	84-05-15	9.1			1.8					
48-1	" " "	85-04-04									
48-1	" " "	86-07-03				1.42					0.04
49-1	27S 12W 35AAAA	82-11-23	104	23.1	0.3	<0.01	0.09	2.96	<0.01	5.7	5.0

Appendix D. Chemical Properties of Observation Well Waters from Near the Aquifer Base.

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
1-2	23S 12W 12BAAA	78-10-25	6700	7.4	3974	388	30.7	88.4	0.593
1-2	" " "	84-11-08	7000	7.8	3856	446	27.5	86.5	0.550
3-1	23S 13W 36DCCC	78-10-23	1660	7.0	910	239	7.09	69.3	0.548
3-1	" " "	83-01-14	1590	7.8	889	254	6.60	67.1	0.559
4-2	23S 14W 36DDCD	78-10-24	3370	7.8	1960	278	16.0	82.4	0.581
4-2	" " "	82-11-29	3320	7.7	1839	273	15.4	81.3	0.554
5-2	23S 12W 06BBBA	78-10-26	51700	7.3	39890	2282	133.0	93.2	0.771
5-2	" " "	83-01-20	55700	7.4	37750	2410	122.3	92.4	0.677
6-2	25S 13W 06BCBC	78-10-24	5010	7.4	3082	507	18.2	79.9	0.615
6-2	" " "	83-01-18	1730	7.9	940	211	8.13	73.3	0.543
7-2	24S 13W 36DDDD	78-10-25	1020	7.8	615	91	8.94	82.0	0.603
7-2	" " "	83-01-18	991	7.9	568	93	8.08	80.2	0.574
8-2	25S 12W 11AAAD	79-10-30	1450	7.8		188	7.47	72.7	
8-2	" " "	83-01-11	1420	7.9	793	180	7.39	73.0	0.559
9-2	24S 10W 31CBCB	79-10-31	4460	7.7	2498	551	14.0	74.8	0.560
9-2	" " "	83-01-11	5040	7.6	2917	642	14.7	74.2	0.578
10-2	24S 10W 06DCCC	79-11-01	4920	7.6	2748	530	16.2	77.6	0.558
10-2	" " "	83-02-25	4900	7.6	2766	486	17.3	79.4	0.564
12-2	29S 11W 36ACCC	82-12-07	320	7.8	205	130	0.68	22.5	0.643
13-2	29S 14W 36AAAD	80-11-12	398	8.1	255	140	1.28	35.1	0.642
13-2	" " "	83-06-22	395	8.1	252	153	1.05	29.2	0.638
14-2	29S 14W 12ABBB	80-11-12	400	8.3	248	135	1.15	33.2	0.620
14-2	" " "	83-06-21	395	8.2	248	146	1.11	31.1	0.628
14-2	" " "	84-01-04	375	7.8		142	1.12	31.7	
15-2	28S 11W 01AAAD	82-12-14	1400	7.6	761	387	3.02	43.3	0.543
16-2	21S 12W 31CCCB	81-09-28	80100	7.0	58150	4037	143.8	91.8	0.725
16-2	" " "	83-01-24	80600	7.3	57340	4215	138.7	91.2	0.711
16-2	" " "	84-01-24	79100						
16-2	" " "	84-05-14	79100	7.4	56620	3782	146.5	92.2	0.715
17-2	21S 12W 36DDCC	81-09-28	26800	7.3	16690	1317	71.4	90.6	0.622

Appendix D. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L CaCO3	Sodium adsorp-tion ratio	Soluble Soluble sodium, %	T.D.S./ Sp.C.[b]
17-2	21S 12W 36DDCC	83-01-21	26000	7.5	16140	1313	68.9	90.2	0.620
18-2	21S 11W 07BBBA	81-09-30	30000	7.2	20730	1969	69.3	88.5	0.690
18-2	" " "	83-01-24	30900	7.4	19620	1843	68.3	88.6	0.635
19-2	25S 13W 36DCCC	83-03-02	1390	7.7	770	189	6.90	71.0	0.554
20-2	25S 13W 31DDAA	83-12-13	1220	7.9	675	113	8.70	80.1	0.554
21-2	26S 11W 01DDDA	83-06-15	8020	7.9	4513	511	31.0	87.1	0.562
22-2	21S 12W 06CCBC	81-09-29	66500	6.9	48600	3795	118.7	90.4	0.730
22-2	" " "	83-01-24	68900	7.1	48680	3990	117.8	90.1	0.706
23-2	21W 10W 06AADD	83-11-16	935	7.9	526	139	5.23	68.6	0.563
23-2	" " "	84-01-27	2680						
23-2	" " "	84-11-02	5800						
23-2	" " "	85-04-05	5150						
25-2	23S 10W 06BBAB	83-02-22	66100	7.2	44070	3235	122.4	91.4	0.666
25-2	" " "	84-11-05	65000						
25-2	" " "	85-04-05	65100						
26-2	23S 10W 01AAAA	83-11-21	34500	7.3	22850	1922	82.9	90.4	0.662
27-2	23S 09W 01ADAA	83-11-21	2800	7.6	1580	334	11.4	75.5	0.564
28-2	25S 09W 01ADDA	81-10-01	769	7.7	452	110	5.12	70.3	0.587
28-2	" " "	83-01-12	758	7.6	424	110	4.66	68.4	0.560
29-2	24S 10W 36AAAA	83-12-08	1500	7.6	818	100	11.8	84.1	0.545
29-2	" " "	85-04-04	1620	8.7					
30-2	23S 10W 36DAAA	83-01-17	1710	7.5	932	232	7.61	71.0	0.545
31-2	22S 09W 01ADAA	84-01-27	2170	8.4	1220	156	14.6	85.0	0.562
31-2	" " "	84-11-02	2350		1229	148	15.3	85.9	0.523
32-2	23S 09W 25DDDD	83-05-19	5300	7.8	3138	680	15.8	74.9	0.592
33-2	25S 12W 36CBBA	83-03-01	1980	7.6	1071	303	7.16	67.0	0.541
34-2	25S 09W 36DDCC	83-01-04	388	8.0	224	161	0.47	15.8	0.577
34-2	" " "	83-12-14	395	7.8		180	0.45	14.4	0.000
34-2	" " "	84-10-31	408						
34-2	" " "	85-04-04	402						

Appendix D. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L CaCO3	Sodium adsorp-tion ratio	Soluble Soluble sodium, %	T.D.S./ Sp.C.[b]
35-2	26S 10S 31CCCB	83-03-08	2670	7.6	1476	249	13.2	80.4	0.552
36-2	27S 12W 06BAAB	83-03-07	46600	7.3	30750	1943	112.5	92.6	0.659
38-2	26S 12W 36ADDA	83-03-07	6620	7.6	3556	404	26.6	86.7	0.537
39-2	26S 10W 01AAAA	83-01-04	930	7.7	520	236	2.74	46.9	0.559
40-2	26S 09W 31CDDD	83-03-09	1610	7.6	850	210	7.26	71.2	0.528
41-2	26S 09W 35ADAD	83-01-04	879	7.8	498	171	3.85	59.2	0.566
42-2	28S 13W 01CBAA	83-04-26	14200	7.9	8745	1546	32.1	80.2	0.615
44-2	29S 13W 35ABBA	82-12-02	400	7.9	242	140	0.94	28.0	0.606
45-2	29S 11W 01DADA	82-12-09	477	7.8	297	180	1.03	27.6	0.623
46-2	29S 11W 06AAAB	82-12-10	610	8.0	361	145	2.70	52.1	0.593
47-2	29S 13W 12ABBA	83-04-26	470	7.8	292	169	1.37	34.0	0.623
48-2	29S 12W 36DCCD	82-12-07	374	8.0	239	131	1.09	31.8	0.640
48-2	" " "	84-01-04	309						
49-2	27S 12W 35AAAA	82-11-23	3830	7.6	2098	364	14.8	79.1	0.547
50-1	21S 13W 06BCCC	87-08-20	1040	8.0					
51-1	21S 14W 36DDDA	87-08-19	4980	7.8	2813	317	23.7	86.7	0.564
52-1	23S 13W 06BBBC	87-08-06	940	7.8	514	189	3.91	58.0	0.547

---

[a] Specific conductance in u-siemens/cm (same values as umhom/cm) at 25 °C.

[b] Specific conductance/calculated total dissolved solids

Appendix E. Concentration of Major Dissolved Constituents in Observation Well Waters from Near the Aquifer Base. All concentrations are in mg/L.

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
1-2	23S 12W 12BAAA	78-10-25	21	103	32	1390	223	234	2060
1-2	" " "	84-11-08	29	118	37	1335	207	224	1980
3-1	23S 13W 36DCCC	78-10-23	20	76	12	252	244	44	382
3-1	" " "	83-01-14	25	82	12	242	241	45	361
4-2	23S 14W 36DDCD	78-10-24	28	72	24	615	271	122	958
4-2	" " "	82-11-29	35	67.3	25.6	584	271	109	869
5-2	23S 12W 06BBBA	78-10-26	22	515	242	14600	223	2670	21700
5-2	" " "	83-01-20	50	563	244	13800	226	2231	20700
6-2	25S 13W 06BCBC	78-10-24	23	152	31	940	197	165	1660
6-2	" " "	83-01-18	24.2	65	12	272	217	54	396
7-2	24S 13W 36DDDD	78-10-25	19	29	4.7	197	253	49	174
7-2	" " "	83-01-18	22.4	30	4.6	180	248	35	159
8-2	25S 12W 11AAAD	79-10-30		61	8.9	236	247	57	288
8-2	" " "	83-01-11	25	58	8.6	228	247	58	287
9-2	24S 10W 31CBCB	79-10-31		173	29	757	214	166	1250
9-2	" " "	83-01-11	26	203	33	858	210	200	1482
10-2	24S 10W 06DCCC	79-11-01		150	38	858	295	189	1360
10-2	" " "	83-02-25	48	132	38	878	273	187	1340
12-2	29S 11W 36ACCC	82-12-07	18.4	42.2	6.2	18.1	181	18	7.8
13-2	29S 14W 36AAAD	80-11-12	26.5	46	6.3	35	190	25	15
13-2	" " "	83-06-22	28	50	7.0	30	189	21	13
14-2	29S 14W 12ABBB	80-11-12	25.5	46	5.1	31	182	21	20
14-2	" " "	83-06-21	27	49	5.8	31	172	18	22
14-2	" " "	84-01-04		50	4.3	31	167	19	21
15-2	28S 11W 01AAAD	82-12-14	23.5	134	12.8	137	211	24	318
16-2	21S 12W 31CCCB	81-09-28	35	905	432	21000	278	3570	32000
16-2	" " "	83-01-24	72	948	449	20700	279	3429	31500
16-2	" " "	84-01-24						3830	31100
16-2	" " "	84-05-14		829	416	20700	271	3710	30810
17-2	21S 12W 36DDCC	81-09-28	30	315	129	5960	268	1080	9020
17-2	" " "	83-01-21	39	305	134	5740	271	1008	8750
18-2	21S 11W 07BBBA	81-09-30	33	421	223	7070	396	1360	11400

Appendix E. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
18-2	21S 11W 07BBBA	83-01-24	41	379	218	6740	390	1347	10670
19-2	25S 13W 36DCCC	83-03-02	23	63	7.7	218	199	45	300
20-2	25S 13W 31DDAA	83-12-13	23	36	5.7	213	216	47	230
21-2	26S 11W 01DDDA	83-06-15	28	152	32	1610	222	249	2320
22-2	21S 12W 06CCBC	81-09-29	34	732	478	16800	581	3700	26500
22-2	" " "	83-01-24	65	751	514	17100	586	3690	26200
23-2	21W 10W 06AADD	83-11-16	29	44	7.1	142	173	26	184
23-2	" " "	84-01-27						19	594
23-2	" " "	84-11-02						2.9	985
23-2	" " "	85-04-05						16	1017
25-2	23S 10W 06BBAB	83-02-22	51	755	328	16000	196	2590	24200
25-2	" " "	84-11-05							24920
25-2	" " "	85-04-05						2763	24934
26-2	23S 10W 01AAAA	83-11-21	22	526	148	8350	225	1320	12360
27-2	23S 09W 01ADAA	83-11-21	25	111	14	480	314	70	719
28-2	25S 09W 01ADDA	81-10-01	25	38	3.9	124	157	24	142
28-2	" " "	83-01-12	26	37	4.5	113	154	25	135
29-2	24S 10W 36AAAA	83-12-08	25	35	3.2	272	74	40	386
29-2	" " "	85-04-04					16	47	445
30-2	23S 10W 36DAAA	83-01-17	25	75	11	267	273	50	362
31-2	22S 09W 01ADAA	84-01-27	22	49	8.4	419	281	84	496
31-2	" " "	84-11-02	22	45	8.7	427	249	82	518
32-2	23S 09W 25DDDD	83-05-19	56	190	50	949	269	274	1476
33-2	25S 12W 36CBBA	83-03-01	23	97	15	287	209	63	467
34-2	25S 09W 36DDCC	83-01-04	25	56	5.2	14	124	59	2.5
34-2	" " "	83-12-14		63	5.6	14	121	23	2.4
34-2	" " "	84-10-31							2.9
34-2	" " "	85-04-04						26	4.0
35-2	26S 10S 31CCCB	83-03-08	26	75	15	478	248	59	689
36-2	27S 12W 06BAAB	83-03-07	40	495	172	11400	181	1666	16850
38-2	26S 12W 36ADDA	83-03-07	25	119	26	1230	205	205	1834
39-2	26S 10W 01AAAA	83-01-04	28	83	7.1	97	215	28	158
40-2	26S 09W 31CDDD	83-03-09	25	66	11	242	239	57	319

Appendix E. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
41-2	26S 09W 35ADAD	83-01-04	25	55	8.3	116	227	25	148
42-2	28S 13W 01CBAA	83-04-26	18	420	121	2900	151	730	4470
44-2	29S 13W 35ABBA	82-12-02	25.2	46.2	6.2	25.9	180	26	16
45-2	29S 11W 01DADA	82-12-09	26.3	52.8	11.8	32	266	22	14
46-2	29S 11W 06AAAB	82-12-10	23.0	40.0	11.1	74.9	220	35	61
47-2	29S 13W 12ABBA	83-04-26	26	57	6.5	41	202	20	35
48-2	29S 12W 36DCCD	82-12-07	24.6	44.6	5.0	29	190	26	8.8
48-2	" " "	84-01-04						9.3	8.7
49-2	27S 12W 35AAAA	82-11-23	27.6	105	24.9	650	204	113	1064
50-1	21S 13W 06BCCC	87-08-20							158
51-1	21S 14W 36DDDA	87-08-19	23	84	26	971	307	201	1350
52-1	23S 13W 06BBBC	87-08-06	19	64	7.3	124	239	22	155

Appendix F. Concentration of Minor Dissolved Constituents in Observation Well Waters from Near the Aquifer Base. All concentrations are in mg/L.

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
1-2	23S 12W 12BAAA	78-10-25	4.6	1.3	0.4	4.3	0.21				
1-2	" " "	84-11-08	6.0	1.4		5.6					0.26
3-1	23S 13W 36DCCC	78-10-23	2.9	0.6	0.5	0.02	0.05				
3-1	" " "	83-01-14	3.4	0.6	0.4	<0.02	0.08	0.1	<0.01	0.14	0.10
4-2	23S 14W 36DDCD	78-10-24	5.7	1.3	0.9	0.05	1.23				
4-2	" " "	82-11-29	14.9	1.06	0.9	<0.01	0.05	0.12	<0.01	1.1	0.79
5-2	23S 12W 06BBBA	78-10-26	21	10	0.8	0.07	0.03				
5-2	" " "	83-01-20	42	9.1	0.8	0.02	0.04	0.4	<0.01	5.2	1.6
6-2	25S 13W 06BCBC	78-10-24	5.1	1.4	0.4	1.69	0.07				
6-2	" " "	83-01-18	3.0	0.6	0.4	1.49	0.03	<0.1	<0.01	0.13	0.10
7-2	24S 13W 36DDDD	78-10-25	2.1	0.3	0.6	3.4	0.05				
7-2	" " "	83-01-18	2.2	0.2	0.6	2.94	0.07	<0.1	<0.01	0.10	0.11
8-2	25S 12W 11AAAD	79-10-30	2.8	0.4	0.4	2.94	0.13			0.07	
8-2	" " "	83-01-11	2.9	0.4	0.4	0.95	0.06	0.1	<0.01	0.15	0.10
9-2	24S 10W 31CBCB	79-10-31	4.1	1.3	0.2	2.78	0.09			0.12	
9-2	" " "	83-01-11	6.2	1.6	0.2	0.95	0.06	0.1	<0.01	0.36	0.22
10-2	24S 10W 06DCCC	79-11-01	5.7	1.6	0.6	0.05	0.32			0.18	
10-2	" " "	83-02-25	7.4	1.5	0.6	0.02	0.06	0.1	<0.01	0.40	0.29
12-2	29S 11W 36ACCC	82-12-07	3.6	0.23	0.3	0.47	0.16	0.16	<0.01	0.05	0.03
13-2	29S 14W 36AAAD	80-11-12		0.33	0.6	1.74				0.05	
13-2	" " "	83-06-22	3.5	0.4	0.5	1.29	<0.03	0.1		0.05	0.05
14-2	29S 14W 12ABBB	80-11-12		0.32	0.3	2.12				0.04	
14-2	" " "	83-06-21	2.6	0.3	0.2	1.74	0.06	0.2		0.04	
14-2	" " "	84-01-04	2.4			5.4					0.07
15-2	28S 11W 01AAAD	82-12-14	3	0.54	0.3	1.00	0.05	0.06	<0.01	0.06	1.1
16-2	21S 12W 31CCCB	81-09-28	54	16	0.7	0.05				3.4	
16-2	" " "	83-01-24	90	16	0.8	0.02	0.09	0.7	<0.01	11	2.3
16-2	" " "	84-01-24									
16-2	" " "	84-05-14	25			0.04					4.0
17-2	21S 12W 36DDCC	81-09-28	18	4.8	0.5	0.05				0.8	
17-2	" " "	83-01-21	29	4.7	0.5	<0.1	0.04	0.2	<0.01	2.8	0.6
18-2	21S 11W 07BBBA	81-09-30	19	6.6	0.5	0.18				1.0	

Appendix F. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
18-2	21S 11W 07BBBA	83-01-24	29	6.6	0.5	0.34	0.03	<0.1	<0.01	2.7	1.0
19-2	25S 13W 36DCCC	83-03-02	3.4	0.4	0.3	2.71	0.08	<0.1	0.024	0.17	0.10
20-2	25S 13W 31DDAA	83-12-13	1.5	0.3	0.4	2.9	0.09	0.1		1.6	0.11
21-2	26S 11W 01DDDA	83-06-15	5.6	1.1	0.3	1.33	0.06	0.1		0.42	0.41
22-2	21S 12W 06CCBC	81-09-29	53	14	0.6	0.11				2.3	
22-2	" " "	83-01-24	63	14	0.5	0.02	0.09	1.8	<0.01	7.1	1.6
23-2	21W 10W 06AADD	83-11-16	1.7	0.3	0.3	1.64	0.12	<0.1		0.07	
23-2	" " "	84-01-27									
23-2	" " "	84-11-02				0.68					
23-2	" " "	85-04-05									0.13
25-2	23S 10W 06BBAB	83-02-22	38	13	0.3	0.02	0.16	0.5	<0.01	5.5	4.0
25-2	" " "	84-11-05									
25-2	" " "	85-04-05									2.3
26-2	23S 10W 01AAAA	83-11-21		7.2	0.3	0.69	0.73	0.1		1.2	2.2
27-2	23S 09W 01ADAA	83-11-21	2.7	0.6	0.3	0.72	0.10	0.1		0.11	0.22
28-2	25S 09W 01ADDA	81-10-01	2.3	0.16	0.4	3.4				0.04	
28-2	" " "	83-01-12	2.3	0.2	0.3	1.31	0.11	0.1	<0.01	0.04	0.08
29-2	24S 10W 36AAAA	83-12-08	8.7	1.4	0.4	2.26	0.03	0.2		0.04	0.10
29-2	" " "	85-04-04									
30-2	23S 10W 36DAAA	83-01-17	3.8	0.4	0.4	0.88	0.13	<0.1	<0.01	0.12	0.13
31-2	22S 09W 01ADAA	84-01-27	3.1	0.4		0.02	0.08	0.2		0.10	
31-2	" " "	84-11-02	3.2			0.20					0.13
32-2	23S 09W 25DDDD	83-05-19	9.0	1.9	0.4	0.09	0.06	0.1		0.18	0.28
33-2	25S 12W 36CBBA	83-03-01	3.2	0.7	0.3	2.94	0.09	0.1	<0.01	0.11	0.12
34-2	25S 09W 36DDCC	83-01-04	1.0	0.2	0.3	<0.02	0.07	0.1	<0.01	0.04	
34-2	" " "	83-12-14	0.8								
34-2	" " "	84-10-31									
34-2	" " "	85-04-04									0.08
35-2	26S 10S 31CCCB	83-03-08	3.6	0.5	0.4	1.81	0.04	<0.1	<0.01	0.17	0.17
36-2	27S 12W 06BAAB	83-03-07	28	8.0	0.5	1.40	0.14	0.2	<0.01	4.0	2.6
38-2	26S 12W 36ADDA	83-03-07	4.2	1.2	0.4	2.48	0.08	0.1	<0.01	0.41	0.31
39-2	26S 10W 01AAAA	83-01-04	2.3	0.3	0.3	2.48	0.08	0.1	<0.01	0.59	0.12
40-2	26S 09W 31CDDD	83-03-09	2.4	0.4	0.3	2.19	0.08	<0.1	<0.01	0.13	0.10

Appendix F. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
41-2	26S 09W 35ADAD	83-01-04	2.0	0.3	0.2	1.49	0.19	0.1	<0.01	0.05	0.11
42-2	28S 13W 01CBAA	83-04-26	6.3	5.5	0.4	0.02	0.16	0.1		0.47	0.33
44-2	29S 13W 35ABBA	82-12-02	3.2	0.28	0.3	1.1	0.18	0.02	<0.01	0.05	0.05
45-2	29S 11W 01DADA	82-12-09	1.9	0.43	0.3	1.2	0.20	<0.02	<0.01	0.05	0.08
46-2	29S 11W 06AAAB	82-12-10	3.4	0.40	0.5	0.98	0.13	<0.02	0.02	0.10	0.08
47-2	29S 13W 12ABBA	83-04-26	3.0	0.3	0.3	1.01	0.03	0.1		0.04	0.04
48-2	29S 12W 36DCCD	82-12-07	2.4	0.24	0.3	1.18	0.05	<0.02	0.02	0.05	0.04
48-2	" " "	84-01-04									0.07
49-2	27S 12W 35AAAA	82-11-23	7.2	0.91	0.3	1.1	0.05	0.14	<0.01	0.7	0.23
50-1	21S 13W 06BCCC	87-08-20									0.09
51-1	21S 14W 36DDDA	87-08-19	5.7	1.1	0.5	0.05	0.020	0.1		0.21	0.86
52-1	23S 13W 06BBBC	87-08-06	4.1	0.4	0.4	0.20	0.02	0.1		0.05	0.08

Appendix G. Chemical Properties of Observation Well Waters from the Upper Aquifer.

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./Sp.C.[b]
1-3	23S 12W 12BAAA	78-10-25	397	7.6	243	167	0.60	18.7	0.613
1-3	" " "	83-01-20	413	7.9	253	174	0.62	18.9	0.612
1-3	" " "	83-11-17	410						
2-2	23S 12W 36ABAB	78-10-25	693	7.5	400	181	2.29	45.5	0.577
2-2	" " "	83-01-14	875	7.7	508	286	1.93	36.0	0.581
2-2	" " "	83-11-23	900	7.4		267	2.31	41.1	0.000
2-2	" " "	84-05-10	920						
2-2	" " "	84-11-07	1020						
3-2	23S 13W 36DCCC	78-10-23	521	7.1	299	172	1.32	33.1	0.575
3-2	" " "	83-01-14	580	7.6	356	191	1.63	36.7	0.615
3-2	" " "	83-11-29	550						
3-2	" " "	84-10-25	578						
4-3	23S 14W 36DDCD	78-10-24	917	7.5	525	224	3.19	51.1	0.573
4-3	" " "	82-11-29	942	7.6	518	227	2.87	48.2	0.550
4-3	" " "	83-11-30	910						
4-3	" " "	84-11-01	1000						
5-3	23S 12W 06BBBA	78-10-26	693	7.5	386	264	0.82	20.0	0.557
5-3	" " "	83-01-20	795	7.8	445	318	0.78	17.8	0.560
5-3	" " "	83-11-17	760						
5-3	" " "	84-11-06	810						
6-3	25S 13W 06BCBC	78-10-24	695	7.8	404	129	3.68	61.2	0.582
6-3	" " "	83-01-18	1330	7.8	693	290	3.75	52.0	0.521
6-3	" " "	83-12-12	1400						
6-3	" " "	84-11-01	1442						
7-3	24S 13W 36DDDD	78-10-24	636	7.7	384	186	2.07	42.8	0.604
7-3	" " "	83-01-18	699	8.0	413	218	1.88	38.5	0.591
7-3	" " "	83-12-09	661						
7-3	" " "	84-10-26	690						
8-3	25S 12W 11AAAD	79-10-29	1290	7.6		194	6.47	69.6	
8-3	" " "	83-01-11	1280	7.9	710	177	6.53	70.6	0.555

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
8-4	25S 12W 11AAAD	79-10-29	1145	7.6		192	5.43	65.8	
8-4	" " "	83-01-11	1200	7.8	675	202	5.33	64.7	0.563
8-4	" " "	83-12-09	1210						
8-4	" " "	84-11-08	1190						
9-3	24S 10W 31CBCB	79-10-31	3170	7.6	1720	468	9.49	68.5	0.542
9-3	" " "	83-01-11	3190	7.6	1783	438	10.57	71.3	0.559
9-3	" " "	83-12-08	3150						
9-3	" " "	84-11-05	3210						
10-3	24S 10W 06DCCC	79-11-01	2700	7.8	1457	381	9.18	69.9	0.539
10-3	" " "	83-02-25	2410	7.6	1341	328	9.05	71.0	0.556
10-3	" " "	83-12-06	2420						
10-4	24S 10W 06DCCC	79-11-01	1020	7.5		297	2.19	38.5	
10-4	" " "	83-02-24	971	7.6	532	288	2.20	38.9	0.548
10-4	" " "	83-12-06	965						
10-4	" " "	84-11-05	1000						
11-2	22S 10W 06CBBB	79-11-02	4000	7.4	2183	690	9.57	64.4	0.545
11-2	" " "	83-11-15	3900	7.8	2165	660	9.87	65.7	0.555
11-2	" " "	84-11-14	4000						
12-3	29S 11W 36ACCC	80-11-11	450	7.7	277	186	0.89	24.6	0.615
12-3	" " "	82-12-07	455	7.7	283	217	0.37	11.1	0.623
12-3	" " "	84-01-04	391						
12-3	" " "	84-10-24	478						
13-3	29S 14W 36AAAD	80-11-12	421	7.6	250	185	0.47	15.0	0.595
13-3	" " "	82-11-30	404	7.5	245	188	0.29	9.56	0.608
13-3	" " "	84-01-04	385						
13-3	" " "	84-10-22	424						
14-3	29S 14W 12ABBB	83-06-22	185	8.8	126	39.8	1.10	38.1	0.684
14-3	" " "	84-10-26	640	8.0	366	178	1.89	40.9	0.572
15-3	28S 11W 01AAAD	82-12-14	461	7.6	278	216	0.36	10.9	0.604
15-3	" " "	83-12-16	490						

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
15-3	28S 11W 01AAAD	84-10-26	552						
16-3	21S 12W 31CCCB	81-09-28	529	7.5	316	233	0.62	16.7	0.597
16-3	" " "	83-01-24	500	7.8	293	207	0.66	18.3	0.587
16-3	" " "	83-11-16	480						
16-3	" " "	84-11-06	503						
17-3	21S 12W 36DDCC	81-09-28	712	7.3	430	271	1.00	23.2	0.604
17-3	" " "	83-01-20	685	7.8	407	252	1.26	28.2	0.595
17-3	" " "	83-11-16	670						
17-3	" " "	84-05-10	670						
17-3	" " "	84-11-06	710						
17-3	" " "	86-07-09	672						
18-3	21S 11W 07BBBA	81-09-30	890	7.5	481	333	0.73	16.6	0.541
18-3	" " "	83-01-24	665	7.9	343	243	0.75	19.1	0.515
18-3	" " "	83-11-14	441	7.9		177	0.75	21.5	
18-3	" " "	84-05-10	440	7.8		158	0.76	22.7	
18-3	" " "	84-11-06	371						
19-3	25S 13W 36DCCC	83-01-10	455	7.9	282	185	0.89	24.4	0.620
19-3	" " "	83-12-20	461						
19-3	" " "	84-10-25	495						
20-3	25S 13W 31DDAA	84-01-26	471	7.6	281	209	0.54	15.4	0.597
20-3	" " "	84-05-08	485						
20-3	" " "	84-11-08	875						
21-3	26S 11W 01DDDA	82-01-10	590	7.7	344	270	0.39	10.7	0.583
21-3	" " "	83-12-13	629						
21-3	" " "	84-05-14	623						
21-3	" " "	84-10-30	663						
21-3	" " "	86-08-25	821						
22-3	21S 12W 06CCBC	81-09-29	445	7.4	288	210	0.51	14.8	0.648
22-3	" " "	83-01-24	459	7.6	286	210	0.51	14.7	0.624
22-3	" " "	83-11-14	445						

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.^{a}, uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hardness, mg/L $CaCO_3$	Sodium adsorption ratio	Soluble sodium, %	T.D.S./Sp.C.^{b}
22-3	21S 12W 06CCBC	84-11-06	460						
23-3	21S 10W 06AADD	83-01-25	895	7.6	503	139	4.76	66.4	0.562
23-3	" " "	83-11-14	875						
23-3	" " "	84-11-02	890						
24-2	22S 10W 01ADBC	83-05-11	1260	7.7	710	231	5.29	63.4	0.564
24-2	" " "	83-11-24	1280	7.2		205	6.02	67.5	
25-3	23S 10W 06BBAB	83-02-23	61500	7.2	41150	3097	116.51	91.2	0.669
25-3	" " "	83-11-18	61900						
25-3	" " "	84-05-14	62000						
25-3	" " "	85-04-05	61300						
26-3	23S 10W 01AAAA	83-02-17	3170	7.9	1721	97.0	28.39	93.2	0.543
26-3	" " "	83-11-21	3180						
26-3	" " "	84-11-03	3160						
27-3	23S 09W 01ADAA	84-01-26	2590	7.4	1572	650	4.67	47.3	0.607
27-3	" " "	84-05-14	2680						
27-3	" " "	84-11-02	2800						
27-3	" " "	86-08-04	2790						
28-3	25S 09W 01ADDA	81-10-01	370	7.0	253	102	1.76	46.0	0.684
28-3	" " "	83-01-12	275	7.2	197	95.5	0.84	29.8	0.716
28-3	" " "	83-12-06	275						
28-3	" " "	84-10-31	280						
29-3	24S 10W 36AAAA	81-10-01	484	7.5	307	133	2.00	45.9	0.636
29-3	" " "	83-01-12	372	7.5	246	137	0.85	26.4	0.661
29-3	" " "	83-12-08	362						
29-3	" " "	84-05-14	358						
29-3	" " "	84-11-03	482						
30-3	23S 10W 36DAAA	83-02-17	381	7.7	243	86.8	2.05	51.7	0.640
30-3	" " "	83-11-21	354	7.7		96.8	2.12	51.4	
30-3	" " "	84-11-03	470						
31-3	22S 09W 01ADAA	83-01-26	1590	8.0	894	137	10.68	81.7	0.562

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
31-3	22S 09W 01ADAA	83-11-14	1500						
31-3	" " "	84-11-02	1600						
32-3	23S 09W 25DDDD	83-01-13	5700	7.7	3186	413	22.73	84.6	0.559
32-4	23S 09W 25DDDD	83-01-13	2020	7.8	1072	173	11.68	81.3	0.530
32-4	" " "	83-11-18	1900						
32-4	" " "	84-11-02	1950						
33-3	25S 12W 36CBBA	83-03-01	471	7.6	294	184	0.83	23.3	0.625
33-3	" " "	83-12-13	469						
33-3	" " "	84-11-05	488						
35-3	26S 10W 31CCCB	83-03-07	440	7.6	276	202	0.45	13.8	0.629
35-3	" " "	83-12-15	438						
35-3	" " "	84-05-09	445						
35-3	" " "	84-10-30	451						
36-3	27S 12W 06BAAB	83-03-07	921	7.6	508	165	4.16	61.3	0.551
36-4	27S 12W 06BAAB	82-12-23	475	7.6	296	155	1.52	37.3	0.623
36-4	" " "	83-12-14	503						
36-4	" " "	84-10-30	495						
37-3	27S 13W 05CABB	83-03-03	385	7.8	240	138	0.99	29.2	0.625
37-4	27S 13W 05CABB	83-03-03	411	7.1	265	174	0.56	17.1	0.646
37-4	" " "	83-12-16	417						
37-4	" " "	84-05-07	430						
37-4	" " "	84-10-29	443						
38-3	26S 12W 36ADDA	82-12-23	335	8.3	219	74.3	1.84	47.0	0.654
38-3	" " "	83-12-14	225			42.7	1.92	53.8	
38-3	" " "	84-10-30	218						
39-3	26S 10W 01AAAA	83-01-04	710	7.6	440	281	0.88	20.7	0.620
39-3	" " "	83-12-14	718						
39-3	" " "	84-05-09	750						
39-3	" " "	84-11-13	932						
39-3	" " "	86-08-26	1100						

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
40-3	26S 09W 31CDDD	83-03-08	448	7.6	284	207	0.30	9.41	0.634
40-3	" " "	83-12-15	493						
40-3	" " "	84-05-09	460						
40-3	" " "	84-10-30	462						
41-3	26S 09W 35ADAD	82-12-24	328	7.2	227	111	1.08	32.8	0.693
41-3	" " "	83-12-15	371	7.3		140	1.06	30.6	
41-3	" " "	84-05-09	330						
41-3	" " "	84-10-30	346						
42-3	28S 13W 01CBAA	83-04-26	650	8.0	387	191	2.17	43.7	0.595
42-3	" " "	83-12-16	675	7.7		191	2.14	43.2	
42-3	" " "	84-10-26	660						
43-2	27S 13W 31DDDD	82-12-22	421	7.6	265	140	1.24	33.7	0.630
43-2	" " "	83-12-16	445						
43-2	" " "	84-01-25	410						
43-2	" " "	84-11-14	460						
44-3	29S 13W 35ABBA	82-12-02	389	7.7	243	134	1.07	31.0	0.624
44-3	" " "	82-12-07	374	7.9	222	131	1.12	32.5	0.595
44-3	" " "	84-10-22	370						
45-3	29S 11W 01DADA	82-12-09	450	7.6	283	217	0.37	11.3	0.630
45-3	" " "	84-01-03	450						
45-3	" " "	84-10-24	462						
46-3	29S 11W 06AAAB	82-12-10	471	7.5	292	217	0.38	11.4	0.620
46-3	" " "	84-01-03	430						
46-3	" " "	84-10-24	470						
47-3	29S 13W 12ABBA	82-12-14	409	7.7	257	180	0.56	17.0	0.630
47-3	" " "	84-01-03	398						
47-3	" " "	84-10-24	425						
48-3	29S 12W 36DCCD	84-01-04	361	7.8	259	164	0.71	21.5	0.718
48-3	" " "	84-05-07	365						
48-3	" " "	84-10-22	370						

Appendix G. (continued)

Site-well	Location	Sample date	Sp.C.[a], uS/cm	pH, lab	Total dissolved solids, calculated mg/L	Hard-ness, mg/L $CaCO_3$	Sodium adsorp-tion ratio	Soluble sodium, %	T.D.S./ Sp.C.[b]
49-3	27S 12W 35AAAA	82-11-23	2270	7.7	1230	170	13.43	83.3	0.542
49-4	27S 12W 35AAAA	82-11-22	519	7.8	299	91.3	3.21	62.2	0.577
49-4	" " "	83-12-16	480						
49-4	" " "	84-10-26	458						
50-2	21S 13W 06BCCC	87-08-20	600	8.0					
50-3	" " "	87-08-19	600	7.8	360	244	0.75	19.1	0.600
51-2	" " "	87-08-06	500	7.8	303	193	1.06	27.2	0.607
52-2	23S 13W 06BBBC	87-08-06	440	7.9	264	183	0.73	21.0	0.600

[a] Specific conductance in u-siemens/cm (same values as umhom/cm) at 25 °C.

[b] Specific conductance/calculated total dissolved solids

Appendix H. Concentration of Major Dissolved Constituents in Observation Well Waters from the Upper Aquifer. All concentrations are in mg/L.

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
1-3	23S 12W 12BAAA	78-10-25	19	59	4.7	18	203	9.7	12
1-3	" " "	83-01-20	22	62	4.8	19	206	11	14
1-3	" " "	83-11-17						4.8	14
2-2	23S 12W 36ABAB	78-10-25	20	64	5.2	71	263	22	72
2-2	" " "	83-01-14	25	101	8.1	75	290	41	103
2-2	" " "	83-11-23		94	7.9	87	290	34	105
2-2	" " "	84-05-10						37	109
2-2	" " "	84-11-07							127
3-2	23S 13W 36DCCC	78-10-23	16	60	5.4	40	245	18	36
3-2	" " "	83-01-14	19	67	5.8	52	245	23	66
3-2	" " "	83-11-29						19	48
3-2	" " "	84-10-25						18	46
4-3	23S 14W 36DDCD	78-10-24	22	70	12	110	260	35	143
4-3	" " "	82-11-29	26.2	70.5	12.5	99.8	255	33	145
4-3	" " "	83-11-30						32	146
4-3	" " "	84-11-01							165
5-3	23S 12W 06BBBA	78-10-26	20	94	7.2	31	224	16	92
5-3	" " "	83-01-20	24	114	8.0	32	239	22	104
5-3	" " "	83-11-17						18	100
5-3	" " "	84-11-06						22	98
6-3	25S 13W 06BCBC	78-10-24	20	43	5.2	96	195	23	99
6-3	" " "	83-01-18	22.9	98.2	11	147	132	15	329
6-3	" " "	83-12-12						9.7	347
6-3	" " "	84-11-01							338
7-3	24S 13W 36DDDD	78-10-24	22	64	6.3	65	252	23	53
7-3	" " "	83-01-18	26	76	7.0	64	260	24	65
7-3	" " "	83-12-09						22	55
7-3	" " "	84-10-26						24	56
8-3	25S 12W 11AAAD	79-10-29		64	8.2	207	267	52	244
8-3	" " "	83-01-11	25	58	7.9	200	244	50	242
8-4	25S 12W 11AAAD	79-10-29		66	6.5	173	252	45	201
8-4	" " "	83-01-11	24	69	7.1	174	244	47	225

Appendix H. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
8-4	25S 12W 11AAAD	83-12-09						49	214
8-4	" " "	84-11-08							201
9-3	24S 10W 31CBCB	79-10-31		151	22	472	228	119	824
9-3	" " "	83-01-11	25	141	21	509	272	120	820
9-3	" " "	83-12-08						122	794
9-3	" " "	84-11-05							787
10-3	24S 10W 06DCCC	79-11-01		118	21	412	277	87	677
10-3	" " "	83-02-25	56	100	19	377	261	73	581
10-3	" " "	83-12-06						69	598
10-4	24S 10W 06DCCC	79-11-01		101	11	87	231	20	192
10-4	" " "	83-02-24	16	99	10	86	227	23	181
10-4	" " "	83-12-06						17	178
10-4	" " "	84-11-05							179
11-2	22S 10W 06CBBB	79-11-02		222	33	578	270	93	1116
11-2	" " "	83-11-15	23	215	30	583	266	92	1087
11-2	" " "	84-11-14							1066
12-3	29S 11W 36ACCC	80-11-11	23.6	65	5.9	28	248	9.7	8.1
12-3	" " "	82-12-07	25.3	75.7	6.8	12.6	256	19	6.3
12-3	" " "	84-01-04						4.2	6.4
12-3	" " "	84-10-24							6.8
13-3	29S 14W 36AAAD	80-11-12	22.5	63	6.8	15	222	9.2	7.7
13-3	" " "	82-11-30	23.3	67.2	4.9	9.3	204	18	9.0
13-3	" " "	84-01-04						6.2	8.9
13-3	" " "	84-10-22							11
14-3	29S 14W 12ABBB	83-06-22	19	14	1.2	16	51	12	17
14-3	" " "	84-10-26	26	61	6.2	58	172	27	79
15-3	28S 11W 01AAAD	82-12-14	23.5	77.9	5.2	12.2	243	22	9.3
15-3	" " "	83-12-16						6.6	13
15-3	" " "	84-10-26							25
16-3	21S 12W 31CCCB	81-09-28	21	85	5.0	22	259	13	35
16-3	" " "	83-01-24	21	76	4.3	22	262	14	20
16-3	" " "	83-11-16						8.8	21
16-3	" " "	84-11-06							22

Appendix H. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
17-3	21S 12W 36DDCC	81-09-28	29	95	8.2	38	265	25	39
17-3	" " "	83-01-20	27	89	7.2	46	273	18	56
17-3	" " "	83-11-16						25	34
17-3	" " "	84-05-10						17	51
17-3	" " "	84-11-06						43	17
17-3	" " "	86-07-09						35	28
18-3	21S 11W 07BBBA	81-09-30	23	122	6.8	31	106	15	199
18-3	" " "	83-01-24	23	89	5.0	27	110	15	123
18-3	" " "	83-11-14		65	3.6	23	114	10	55
18-3	" " "	84-05-10		58	3.3	22	115	13	52
18-3	" " "	84-11-06							31
19-3	25S 13W 36DCCC	83-01-10	23	63	6.7	28	222	21	21
19-3	" " "	83-12-20						8.1	26
19-3	" " "	84-10-25							25
20-3	25S 13W 31DDAA	84-01-26	21	73	6.4	18	230	7.5	18
20-3	" " "	84-05-08						16	18
20-3	" " "	84-11-08							77
21-3	26S 11W 01DDDA	82-01-10	28	97	6.7	15	265	23	29
21-3	" " "	83-12-13						14	40
21-3	" " "	84-05-14						15	38
21-3	" " "	84-10-30						16	48
21-3	" " "	86-08-25						17	92
22-3	21S 12W 06CCBC	81-09-29	25	75	5.6	17	235	18	7
22-3	" " "	83-01-24	24	75	5.6	17	241	19	6.9
22-3	" " "	83-11-14						13	8.5
22-3	" " "	84-11-06							8.7
23-3	21S 10W 06AADD	83-01-25	33	43	7.6	129	179	26	169
23-3	" " "	83-11-14						24	167
23-3	" " "	84-11-02							159
24-2	22S 10W 01ADBC	83-05-11	31	76	10	185	206	35	267
24-2	" " "	83-11-24		68	8.5	198	218	36	278
25-3	23S 10W 06BBAB	83-02-23	50	726	312	14900	218	2600	22400
25-3	" " "	83-11-18						2680	23600

Appendix H. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
25-3	23S 10W 06BBAB	84-05-14						2590	23100
25-3	" " "	85-04-05						2770	23049
26-3	23S 10W 01AAAA	83-02-17	24	28	6.6	643	324	73	780
26-3	" " "	83-11-21						79	789
26-3	" " "	84-11-03							762
27-3	23S 09W 01ADAA	84-01-26	19	246	8.6	274	383	117	483
27-3	" " "	84-05-14						126	488
27-3	" " "	84-11-02						139	479
27-3	" " "	86-08-04						201	389
28-3	25S 09W 01ADDA	81-10-01	29	33	4.8	41	122	25	28
28-3	" " "	83-01-12	29	31	4.4	19	105	22	8.8
28-3	" " "	83-12-06						13	8.4
28-3	" " "	84-10-31						14	8.9
29-3	24S 10W 36AAAA	81-10-01	26	46	4.4	53	164	23	45
29-3	" " "	83-01-12	28	48	4.2	23	144	23	20
29-3	" " "	83-12-08						16	17
29-3	" " "	84-05-14						16	16
29-3	" " "	84-11-03						23	52
30-3	23S 10W 36DAAA	83-02-17	26	30	2.9	44	145	18	13
30-3	" " "	83-11-21		34	2.9	48	141	13	12
30-3	" " "	84-11-03						21	36
31-3	22S 09W 01ADAA	83-01-26	20	44	6.5	287	283	67	321
31-3	" " "	83-11-14						58	308
31-3	" " "	84-11-02							295
32-3	23S 09W 25DDDD	83-01-13	25	121	27	1062	281	210	1597
32-4	23S 09W 25DDDD	83-01-13	26	55	8.6	353	293	27	452
32-4	" " "	83-11-18						58	443
32-4	" " "	84-11-02							412
33-3	25S 12W 36CBBA	83-03-01	26	64	5.8	26	193	16	26
33-3	" " "	83-12-13						12	24
33-3	" " "	84-11-05						13	27
35-3	26S 10W 31CCCB	83-03-07	23	72	5.3	15	219	16	11
35-3	" " "	83-12-15						9.9	9.4

Appendix H. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
35-3	26S 10W 31CCCB	84-05-09							9.6
35-3	" " "	84-10-30							10
36-3	27S 12W 06BAAB	83-03-07	22	57	5.6	123	188	26	172
36-4	27S 12W 06BAAB	82-12-23	24.8	54.9	4.4	43.6	223	22	29
36-4	" " "	83-12-14						10	29
36-4	" " "	84-10-30							30
37-3	27S 13W 05CABB	83-03-03	23	49	3.9	27	185	11	19
37-4	27S 13W 05CABB	83-03-03	28	62	4.7	17	185	14	13
37-4	" " "	83-12-16						9.9	14
37-4	" " "	84-05-07							15
37-4	" " "	84-10-29						10	16
38-3	26S 12W 36ADDA	82-12-23	22.1	26.3	2.1	36.6	151	24	16
38-3	" " "	83-12-14		14	1.9	29	73	7.9	18
38-3	" " "	84-10-30						7.1	19
39-3	26S 10W 01AAAA	83-01-04	24	100	7.6	34	191	28	66
39-3	" " "	83-12-14						25	49
39-3	" " "	84-05-09							76
39-3	" " "	84-11-13						41	82
39-3	" " "	86-08-26						51	55
40-3	26S 09W 31CDDD	83-03-08	26	74	5.4	10	202	15	3.0
40-3	" " "	83-12-15						12	3.2
40-3	" " "	84-05-09							4.1
40-3	" " "	84-10-30						10	4.8
41-3	26S 09W 35ADAD	82-12-24	31.1	36.8	4.6	26.2	164	26	17
41-3	" " "	83-12-15		47	5.4	29	181	6.7	18
41-3	" " "	84-05-09							17
41-3	" " "	84-10-30							19
42-3	28S 13W 01CBAA	83-04-26	28	66	6.3	69	188	29	77
42-3	" " "	83-12-16		66	6.4	68	189	27	77
42-3	" " "	84-10-26							84
43-2	27S 13W 31DDDD	82-12-22	25.4	49.0	4.3	33.8	169	26	35
43-2	" " "	83-12-16						12	36
43-2	" " "	84-01-25						11	36

Appendix H. (continued)

Site-well	Location	Sample date	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl
43-2	27S 13W 31DDDD	84-11-14							37
44-3	29S 13W 35ABBA	82-12-02	25.4	45.3	5.0	28.5	192	22	13
44-3	" " "	82-12-07	22.9	46.0	3.9	29.7	177	24	4.6
44-3	" " "	84-10-22							14
45-3	29S 11W 01DADA	82-12-09	24.4	75.7	6.8	12.8	258	20	6.3
45-3	" " "	84-01-03						6.1	6.0
45-3	" " "	84-10-24							5.9
46-3	29S 11W 06AAAB	82-12-10	26.7	74.3	7.6	13.1	262	20	8.1
46-3	" " "	84-01-03						5.4	8.0
46-3	" " "	84-10-24							8.7
47-3	29S 13W 12ABBA	82-12-14	26.8	63.9	5.0	17.3	205	24	11
47-3	" " "	84-01-03						8.0	12
47-3	" " "	84-10-24							12
48-3	29S 12W 36DCCD	84-01-04	25	58	4.8	21	183	12	2.8
48-3	" " "	84-05-07							2.4
48-3	" " "	84-10-22						9.2	3.1
49-3	27S 12W 35AAAA	82-11-23	25.2	52.2	9.7	403	210	67	560
49-4	27S 12W 35AAAA	82-11-22	24.5	30.8	3.5	70.5	161	20	63
49-4	" " "	83-12-16						14	47
49-4	" " "	84-10-26							48
50-2	21S 13W 06BCCC	87-08-20							37
50-3	" " "	87-08-19	26	82	9.6	27	213	17	42
51-2	" " "	87-08-06	20	68	5.7	34	242	20	20
52-2	23S 13W 06BBBC	87-08-06	21	65	5.1	23	223	11	17

Appendix I. Concentration of Minor Dissolved Constituents in Observation Well Waters from the Upper Aquifer. All concentrations are in mg/L.

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
1-3	23S 12W 12BAAA	78-10-25	2.5	0.2	0.5	4.1	0.09				
1-3	" " "	83-01-20	2.4	0.2	0.4	3.6	0.08	0.1	<0.01	0.04	
1-3	" " "	83-11-17									0.10
2-2	23S 12W 36ABAB	78-10-25	3.1	0.3	0.4	2.9	0.09				
2-2	" " "	83-01-14	3.9	0.4	0.3	1.90	0.08	0.1	<0.01	0.16	
2-2	" " "	83-11-23	3.3			5.6					
2-2	" " "	84-05-10				5.9					
2-2	" " "	84-11-07									0.18
3-2	23S 13W 36DCCC	78-10-23	2.8	0.3	0.4	0.05	0.17				
3-2	" " "	83-01-14	2.9	0.3	0.4	<0.02	0.07	0.1	<0.01	0.03	0.07
3-2	" " "	83-11-29									
3-2	" " "	84-10-25									0.10
4-3	23S 14W 36DDCD	78-10-24	3.6	0.6	0.6	0.23	0.03				
4-3	" " "	82-11-29	4.6	0.57	0.6	0.15	0.33	<0.02	<0.01	0.08	0.13
4-3	" " "	83-11-30									
4-3	" " "	84-11-01									0.11
5-3	23S 12W 06BBBA	78-10-26	4.0	0.4	0.3	2.5	0.05				
5-3	" " "	83-01-20	4.0	0.4	0.3	4.3	0.04	<0.1	<0.01	0.06	
5-3	" " "	83-11-17									0.30
5-3	" " "	84-11-06				5.9					0.26
6-3	25S 13W 06BCBC	78-10-24	2.7	0.3	0.6	4.3	0.04				
6-3	" " "	83-01-18	3.8	0.6	0.5	0.20	0.03	<0.1	<0.01	0.13	
6-3	" " "	83-12-12									
6-3	" " "	84-11-01									0.63
7-3	24S 13W 36DDDD	78-10-24	2.7	0.3	0.4	5.4	0.06				
7-3	" " "	83-01-18	2.9	0.4	0.3	4.5	0.04	<0.1	<0.01	0.08	
7-3	" " "	83-12-09									
7-3	" " "	84-10-26				5.6					0.13
8-3	25S 12W 11AAAD	79-10-29	2.7	0.4	0.4	3.0	0.35			0.06	
8-3	" " "	83-01-11	2.7	0.4	0.4	0.99	0.03	0.1	<0.01	0.07	0.08
8-4	25S 12W 11AAAD	79-10-29	3.2	0.3	0.4	3.5	0.20			0.06	
8-4	" " "	83-01-11	3.7	0.4	0.4	1.20	0.07	0.1	<0.01	0.12	

Appendix I. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
8-4	25S 12W 11AAAD	83-12-09									
8-4	" " "	84-11-08									0.09
9-3	24S 10W 31CBCB	79-10-31	3.3	1.0	0.2	3.5	0.08			0.10	
9-3	" " "	83-01-11	5.0	0.9	0.3	1.69	0.06	0.1	<0.01	0.11	
9-3	" " "	83-12-08									
9-3	" " "	84-11-05									0.18
10-3	24S 10W 06DCCC	79-11-01	3.9	1.0	0.6	0.14	0.11			0.10	
10-3	" " "	83-02-25	5.2	0.8	0.6	0.02	0.11	0.2	<0.01	0.20	
10-3	" " "	83-12-06									0.42
10-4	24S 10W 06DCCC	79-11-01	3.7	0.6	0.4	0.32	0.05			0.04	
10-4	" " "	83-02-24	4.3	0.6	0.4	0.18	0.04	0.1	<0.01	0.09	
10-4	" " "	83-12-06									
10-4	" " "	84-11-05									0.38
11-2	22S 10W 06CBBB	79-11-02	4.8	1.6	0.1	0.50	0.08			0.09	
11-2	" " "	83-11-15	1.6	1.4	0.1	0.43	0.06	0.1		0.12	
11-2	" " "	84-11-14									0.16
12-3	29S 11W 36ACCC	80-11-11		0.26	0.3	3.2				0.03	
12-3	" " "	82-12-07	1.9	0.24	0.3	2.2	0.14	<0.02	<0.01	0.03	0.06
12-3	" " "	84-01-04									
12-3	" " "	84-10-24									0.05
13-3	29S 14W 36AAAD	80-11-12		0.28	0.2	3.8				0.02	
13-3	" " "	82-11-30	2.7	0.20	0.2	2.4	0.09	<0.02	<0.01	0.03	0.08
13-3	" " "	84-01-04									
13-3	" " "	84-10-22									0.07
14-3	29S 14W 12ABBB	83-06-22	13	0.4	0.2	1.99	<0.03	0.3		0.03	
14-3	" " "	84-10-26	3.8			4.7					0.08
15-3	28S 11W 01AAAD	82-12-14	1.1	0.24	0.3	1.7	0.06	0.09	<0.01	0.02	0.05
15-3	" " "	83-12-16									
15-3	" " "	84-10-26									0.05
16-3	21S 12W 31CCCB	81-09-28	4.8	0.31	0.4	0.50				0.04	
16-3	" " "	83-01-24	4.7	0.3	0.4	0.54	0.06	<0.1	<0.01	0.05	
16-3	" " "	83-11-16									
16-3	" " "	84-11-06									0.10

Appendix I. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
17-3	21S 12W 36DDCC	81-09-28	2.1	0.3	0.2	14.2				0.03	
17-3	" " "	83-01-20	2.6	0.3	0.3	6.1	0.04	<0.1	<0.01	0.07	
17-3	" " "	83-11-16									
17-3	" " "	84-05-10				7.0					
17-3	" " "	84-11-06				19.6					
17-3	" " "	86-07-09				14.7					0.10
18-3	21S 11W 07BBBA	81-09-30	5.3	0.4	0.2	6.1				0.04	
18-3	" " "	83-01-24	4.5	0.3	0.2	0.45	0.10	<0.1	<0.01	0.04	0.07
18-3	" " "	83-11-14	4.1			6.5					
18-3	" " "	84-05-10	3.9			6.3				0.28	
18-3	" " "	84-11-06									
19-3	25S 13W 36DCCC	83-01-10	2.8	0.9	0.3	1.40	0.04	0.1	<0.01	0.04	
19-3	" " "	83-12-20									
19-3	" " "	84-10-25									0.09
20-3	25S 13W 31DDAA	84-01-26	5.7	0.3		4.1	0.39	0.3		0.04	
20-3	" " "	84-05-08				4.1	0.85	0.16			0.06
20-3	" " "	84-11-08									
21-3	26S 11W 01DDDA	82-01-10	1.3	0.3	0.3	2.9	0.06	0.1	<0.01	0.03	
21-3	" " "	83-12-13									
21-3	" " "	84-05-14				8.6					
21-3	" " "	84-10-30				8.1					0.04
21-3	" " "	86-08-25				9.5					0.06
22-3	21S 12W 06CCBC	81-09-29	2.4	0.3	0.5	5.0				0.04	
22-3	" " "	83-01-24	2.8	0.3	0.5	3.8	0.08	<0.1	<0.01	0.04	
22-3	" " "	83-11-14									
22-3	" " "	84-11-06									
23-3	21S 10W 06AADD	83-01-25	2.9	0.2	0.3	0.93	0.11	<0.1	<0.01	0.07	
23-3	" " "	83-11-14									
23-3	" " "	84-11-02									0.08
24-2	22S 10W 01ADBC	83-05-11	1.2	0.4	0.2	0.86	0.13	<0.1		0.04	
24-2	" " "	83-11-24	1.8			1.08					0.14
25-3	23S 10W 06BBAB	83-02-23	39	12	0.3	0.09	0.16	0.6	<0.01	11	
25-3	" " "	83-11-18									3.6

Appendix I. (continued)

Site-well	Location	Sample date	K	Sr	F	NO$_3$-N	PO$_4$-P	NH$_4$-N	NO$_2$-N	B	Br
25-3	23S 10W 06BBAB	84-05-14									
25-3	" " "	85-04-05									2.2
26-3	23S 10W 01AAAA	83-02-17	4.2	0.2	0.6	0.61	0.33	0.1	0.015	0.28	
26-3	" " "	83-11-21									
26-3	" " "	84-11-03									0.50
27-3	23S 09W 01ADAA	84-01-26	11	0.9		50.8	0.08	0.1		0.06	0.90
27-3	" " "	84-05-14				56.2					0.94
27-3	" " "	84-11-02				59.8					0.95
27-3	" " "	86-08-04				73.2					0.79
28-3	25S 09W 01ADDA	81-10-01	1.9	0.2	0.3	6.8				0.02	
28-3	" " "	83-01-12	1.6	0.2	0.2	6.6	0.14	0.1	<0.01	0.02	
28-3	" " "	83-12-06									
28-3	" " "	84-10-31				7.2					0.05
29-3	24S 10W 36AAAA	81-10-01	2.2	0.2	0.4	6.1				0.02	
29-3	" " "	83-01-12	1.8	0.1	0.2	6.1	0.12	0.1	<0.01	0.03	
29-3	" " "	83-12-08									
29-3	" " "	84-05-14				6.3					
29-3	" " "	84-11-03				5.4					0.04
30-3	23S 10W 36DAAA	83-02-17	2.0	0.1	0.4	8.2	0.17	0.1	<0.01	0.05	
30-3	" " "	83-11-21	1.6			8.4					
30-3	" " "	84-11-03				7.9					0.05
31-3	22S 09W 01ADAA	83-01-26	2.8	0.2	0.5	1.49	0.06	<0.1	<0.01	0.12	
31-3	" " "	83-11-14									
31-3	" " "	84-11-02									0.13
32-3	23S 09W 25DDDD	83-01-13	4.6	1.1	0.5	0.02	0.05	0.1	<0.01	0.29	0.20
32-4	23S 09W 25DDDD	83-01-13	2.8	0.3	0.4	0.63	0.06	0.1	<0.01	0.14	
32-4	" " "	83-11-18									
32-4	" " "	84-11-02									0.14
33-3	25S 12W 36CBBA	83-03-01	2.2	0.2	0.3	7.4	0.17	0.1	<0.01	0.04	
33-3	" " "	83-12-13									
33-3	" " "	84-11-05				6.6					0.10
35-3	26S 10W 31CCCB	83-03-07	1.5	0.2	0.3	5.6	0.10	0.1	<0.01	0.03	
35-3	" " "	83-12-15									

Appendix I. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
35-3	26S 10W 31CCCB	84-05-09				5.9					0.04
35-3	" " "	84-10-30									0.05
36-3	27S 12W 06BAAB	83-03-07	2.9	0.3	0.4	1.49	0.12	<0.1	<0.01	0.10	0.09
36-4	27S 12W 06BAAB	82-12-23	3.2	0.21	0.3	0.89	0.10	0.08	<0.01	0.05	0.08
36-4	" " "	83-12-14									
36-4	" " "	84-10-30									0.10
37-3	27S 13W 05CABB	83-03-03	3.2	0.2	0.4	2.9	0.17	0.2	<0.01	0.04	0.05
37-4	27S 13W 05CABB	83-03-03	3.7	0.2	0.2	7.2	0.09	0.1	0.025	0.04	
37-4	" " "	83-12-16									
37-4	" " "	84-05-07				8.1					0.08
37-4	" " "	84-10-29				8.4					0.07
38-3	26S 12W 36ADDA	82-12-23	12.0	1.44	0.5	0.90	0.07	0.25	0.04	0.03	0.05
38-3	" " "	83-12-14	8.9			4.3	0.04	0.2			
38-3	" " "	84-10-30				4.1					0.04
39-3	26S 10W 01AAAA	83-01-04	1.9	0.3	0.3	19.0	0.06	0.1	<0.01	0.07	
39-3	" " "	83-12-14									
39-3	" " "	84-05-09				13.6					0.10
39-3	" " "	84-11-13				35.5					0.08
39-3	" " "	86-08-26				50.8					0.07
40-3	26S 09W 31CDDD	83-03-08	1.9	0.2	0.2	11.1	0.10	0.1	<0.01	0.04	
40-3	" " "	83-12-15									
40-3	" " "	84-05-09				16.7					
40-3	" " "	84-10-30				11.7					0.05
41-3	26S 09W 35ADAD	82-12-24	4.5	0.18	0.2	0.01	0.13	0.09	<0.01	0.02	0.04
41-3	" " "	83-12-15	2.9								
41-3	" " "	84-05-09				0.09					0.06
41-3	" " "	84-10-30									0.03
42-3	28S 13W 01CBAA	83-04-26	2.0	0.3	0.3	3.8	0.06	0.1		0.04	
42-3	" " "	83-12-16	2.7								
42-3	" " "	84-10-26									0.08
43-2	27S 13W 31DDDD	82-12-22	3.5	0.21	0.4	1.10	0.20	0.08	<0.01	0.04	0.06
43-2	" " "	83-12-16									
43-2	" " "	84-01-25									

Appendix I. (continued)

Site-well	Location	Sample date	K	Sr	F	NO_3-N	PO_4-P	NH_4-N	NO_2-N	B	Br
43-2	27S 13W 31DDDD	84-11-14									0.04
44-3	29S 13W 35ABBA	82-12-02	3.5	0.23	0.3	1.2	0.31	0.02	<0.01	0.05	0.05
44-3	" " "	82-12-07	2.5	0.19	0.3	0.33	0.14	0.02	0.02	0.04	0.04
44-3	" " "	84-10-22									0.06
45-3	29S 11W 01DADA	82-12-09	1.5	0.28	0.2	2.0	0.05	<0.02	<0.01	0.04	0.07
45-3	" " "	84-01-03									
45-3	" " "	84-10-24									0.04
46-3	29S 11W 06AAAB	82-12-10	2.9	0.31	0.2	2.3	0.04	0.03	<0.01	0.04	0.08
46-3	" " "	84-01-03									
46-3	" " "	84-10-24									0.07
47-3	29S 13W 12ABBA	82-12-14	2.4	0.21	0.3	1.4	0.07	0.06	<0.01	0.04	0.08
47-3	" " "	84-01-03									
47-3	" " "	84-10-24									0.08
48-3	29S 12W 36DCCD	84-01-04	2.1	0.3	0.3	9.7	0.03	0.1		0.03	0.05
48-3	" " "	84-05-07				6.3					0.06
48-3	" " "	84-10-22				6.3					0.04
49-3	27S 12W 35AAAA	82-11-23	4.4	0.38	0.3	1.2	0.07	0.02	<0.01	0.7	0.13
49-4	27S 12W 35AAAA	82-11-22	1.4	0.15	0.3	1.38	0.15	<0.02	0.02	0.04	0.04
49-4	" " "	83-12-16									
49-4	" " "	84-10-26									0.05
50-2	21S 13W 06BCCC	87-08-20									0.09
50-3	" " "	87-08-19	4.1	0.3	0.3	10.6	0.15	0.1		0.03	0.10
51-2	" " "	87-08-06	4.1	0.3	0.4	2.7	0.026	0.1		0.05	0.07
52-2	23S 13W 06BBBC	87-08-06	4.1	0.3	0.4	1.76	0.144	0.1		0.04	0.03

Appendix J. Additional Data for Sulfate, Chloride, and Nitrate Concentrations in Observation Well Waters Analyzed by GMD5. Concentrations are in mg/L.

Site-well	Location	Sample date	SO_4	Cl	NO_3-N
Samples from wells in bedrock					
1-1	23S 12W 12BAAA	04-24-90	-	13700	-
6-1	25S 13W 06BCBC	07-07-86	5200	43200	-
7-1	24S 13W 36DDDD	07-25-86	-	35200	-
11-1	22S 10W 06CBBA	07-09-86	613	5680	-
12-1	29S 11W 36ACCC	07-15-86	49	71	-
15-1	28S 11W 01BBBA	07-11-86	99	453	1.8
16-1	21S 12W 31CCCB	04-23-90	-	35200	-
22-1	21S 12W 06CCBC	07-06-92	-	33100	-
25-1	23S 10W 06ADBC	07-09-86	2300	17600	-
27-1	23S 09W 01ADAA	08-23-91	-	2140	-
28-1	25S 09W 01ADDA	08-08-86	400	860	1.3
41-1	26S 09W 35ADAD	08-27-86	190	1240	1.2
44-1	29S 13W 35ABBA	07-03-86	-	26	2.5
45-1	29S 11W 01DAAD	07-15-86	18	57	-
46-1	29S 11W 06AAAB	07-07-86	-	340	-
48-1	29S 12W 36DCCD	07-03-86	-	23	2.0
Samples from wells at or near base of aquifer					
1-2	23S 12W 12BAAA	07-02-86	-	1910	-
1-2	23S 12W 12BAAA	04-16-90	-	1860	-
16-2	21S 12W 31CCCB	04-23-90	-	31500	-
16-2	21S 12W 31CCCB	07-06-92	-	32500	-
22-2	21S 12W 06CCBC	04-24-90	-	25800	-
23-2	21S 10W 06AADD	08-04-86	-	1000	-
25-2	23S 10W 06ADBC	07-08-86	2940	25500	-
27-2	23S 09W 01ADAA	08-23-91	-	525	-
34-2	25S 09W 36CDCD	08-25-86	-	4	-
50-1	21S 13W 06CCB	11-00-86	-	109	-
51-1	21S 14W 36DDD	11-00-86	-	1915	-
52-1	23S 13W 06BBB	11-00-86	-	43	-
Samples from wells in middle to upper part of aquifer					
1-3	23S 12W 12BAAA	06-25-86	-	15	-
1-3	23S 12W 12BAAA	04-16-90	-	14	-
2-2	23S 12W 36ABAB	06-25-86	-	129	-
2-2	23S 12W 36ABAB	07-19-91	-	198	-
4-3	23S 14W 36DDCD	08-05-86	-	155	-
5-3	23S 12W 06BBBA	06-26-86	-	97	-
6-3	25S 13W 06BCBC	07-02-86	-	216	-
7-3	24S 13W 36DCDD	06-12-86	-	53	-
7-3	24S 13W 36DDDD	07-25-86	-	45	-
8-4	25S 12W 11AAAD	06-12-86	-	192	-
9-3	24S 10W 31CBCB	08-26-86	128	840	-
10-4	24S 10W 06DCCC	07-08-86	-	186	-
11-2	22S 10W 06CBBA	07-09-86	-	1050	-

Appendix J. (continued)

Site-well	Location	Sample date	SO_4	Cl	NO_3-N
12-3	29S 11W 36ACCC	07-15-86	-	7	-
13-3	29S 14W 36AAAD	07-03-86	-	10	-
14-3	29S 14W 12ABBB	07-18-86	-	18	-
15-3	28S 11W 01BBBA	07-11-86	-	37	-
16-3	21S 12W 31CCCB	06-27-86	-	22	-
16-3	21S 12W 31CCCB	04-23-90	-	53	-
16-3	21S 12W 31CCCB	07-06-92	-	31	-
17-3	21S 12W 36DDDC	07-09-86	43	22	15
19-3	25S 13W 36DCCC	07-21-86	-	22	-
19-3	25S 13W 36DCCC	07-19-91	-	39	-
20-3	25S 13W 31DDAA	07-25-86	-	27	-
21-3	26S 11W 01DDDA	07-11-86	18	88	9.5
21-3	26S 11W 01DDDA	08-25-86	19	91	12
22-3	21S 12W 06CCBC	06-27-86	-	16	-
22-3	21S 12W 06CCBC	04-24-90	-	17	-
23-3	21S 10W 06AADD	08-04-86	-	129	-
25-3	23S 10W 06ADBC	07-08-86	2800	23700	-
26-3	23S 10W 01AAAA	08-06-86	-	870	-
27-3	23S 09W 01ADAA	08-04-86	-	430	-
27-3	23S 09W 01ADAA	03-26-90	-	268	-
27-3	23S 09W 01ADAA	08-23-91	-	290	-
28-3	25S 09W 01ADDA	08-26-86	-	8	-
29-3	24S 10W 36AAAA	08-06-86	-	15	7.3
30-3	23S 10W 36DAAA	07-08-86	-	20	-
31-3	22S 09W 01ADAA	08-04-86	-	304	-
32-4	23S 09W 25DDDD	08-06-86	-	380	-
33-3	25S 12W 36CBBA	07-14-86	-	45	-
35-3	26S 10W 31CCCB	08-25-86	-	12	-
36-4	27S 12W 06BAAB	07-11-86	-	39	-
37-4	27S 13W 05CABB	07-18-86	-	12	7.4
38-3	26S 12W 36ADDA	08-25-86	-	20	-
39-3	26S 10W 01AAAA	08-26-86	68	60	57
40-3	26S 09W 31CDDD	08-25-86	14	13	14
41-3	26S 09W 35ADAD	08-27-86	-	18	-
42-3	28S 13W 01CBAA	07-18-86	-	98	4.7
43-2	27S 13W 31DDDD	07-18-86	-	40	3.0
44-3	29S 13W 35ABBA	07-03-86	-	14	-
45-3	29S 11W 01DAAD	07-15-86	-	5	-
46-3	29S 11W 06AAAB	07-15-86	-	6	-
47-3	29S 13W 12ABBA	08-28-86	-	14	-
48-3	29S 12W 36DCCD	07-03-86	-	3	-
49-4	27S 12W 35AAAA	08-19-86	-	48	-
50-2	21S 13W 06CCB	11-00-86	-	30	-
50-3	21S 13W 06CCB	11-00-86	-	35	-
51-2	21S 14W 36DDD	11-00-86	-	8	-
52-2	23S 13W 06BBB	11-18-86	-	5	-