A BIBLIOGRAPHY AND REVIEW OF WATER QUALITY STUDIES IN THE UPPER GILA RIVER WATERSHED, ARIZONA

by
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CONTENTS

LIST OF FIGURES ii

LIST OF TABLES iii

INTRODUCTION 1

BIBLIOGRAPHY OF WATER QUALITY STUDIES AND DATA 1

WATER QUALITY IN THE UPPER GILA RIVER 5

- Hem, 1950 5
- Baldys and others, 1995 5
- Safford Agricultural Center 7

GROUNDWATER QUALITY IN THE SAFFORD BASIN 13

- General 13
- Hem, 1950 13
- Safford Agricultural Center 13
- U.S. Geological Survey data 22
- Study of Muller and others (1973) and Muller (1973) 51
  - *Groundwater quality trends* 51
  - *Discussion of well data* 52
  - *Evaluation of Muller study* 59

REFERENCES 61

LIST OF FIGURES

Figure 1. Location of upper Gila River watershed in Arizona. 2

Figure 2. Well numbering system used in Arizona. 3

Figure 3. Water quality of Gila River at San Jose. 10

Figure 4. Water quality in the Safford Agricultural Center well. 18

Figure 5. Water quality in well D(10-27)28dcd. 25

Figure 6. Water quality in well D(9-26)18dda. 29

Figure 7. Water quality in well D(7-26)15bcc. 33

Figure 8. Water quality in well D(6-25)36cbb. 38

Figure 9. Water quality in well D(6-24)13abd. 42

Figure 10. Water quality in well D(5-24)31aaa. 45

Figure 11. Water quality in well D(4-23)35ada. 48

Figure 12. Muller and others (1973) map of conductivity change, 1944-1972 57

Figure 13. Muller and others (1973) map of chloride change, 1944-1972 58

LIST OF TABLES

Table 1. Categories of water quality studies in the upper Gila region. 4

Table 2. Water quality trends in the upper Gila River. 6

Table 3. Water quality data for the Gila River at San Jose. 8

Table 4. Water quality data for the Safford Agricultural Center well. 15

Table 5. Water quality data for well D(10-27)28dcd 24

Table 6. Water quality data for well D(9-26)18dda 28

Table 7. Water quality data for well D(7-26)15bcc 32

Table 8. Water quality data for well D(6-25)36cbb 37

Table 9. Water quality data for well D(6-25)13cbb 41

Table 10. Water quality data for well D(5-24)31aaa1 44

Table 11. Water quality data for well D(4-23)35ada 48

Table 12. Well data in Muller and others (1973) Table 5 56

INTRODUCTION

This report presents a selected bibliography of water quality studies covering the upper Gila River watershed and discusses a few of the more important publications. Previously unpublished water quality data are reported for the Gila River and groundwater in the Safford basin. References cover the Gila River watershed between the Arizona-New Mexico border on the east and Coolidge Dam on the San Carlos Indian Reservation on the west. The watershed includes roughly 11,470 square miles, about half in Arizona and half in New Mexico.

The Gila River enters Arizona near the town of Duncan and flows to the northwest through the Duncan basin, then cuts across the northern Peloncillo Mountains to enter the middle of the Safford-San Simon Valley east of Safford. After flowing northwest to the north end of the Safford basin the river turns southwest, exiting the basin through a bedrock gorge cut at right angles to the Mescal and Dripping Spring Mountains.

The geologic history of the upper Gila region controls the hydrology and the chemistry of surface water and groundwater in the watershed. Both the Duncan and Safford basins are deep, sediment-filled structural troughs containing abundant lacustrine (lake) and playa sediments, reflecting long periods of closed-basin conditions (Harris, 1997). Soluble minerals such as halite, carbonates, gypsum, and anhydrite are common in the basin-fill sediments and contribute significant TDS to the groundwater of the basins and to the Gila River (Harris, 1999).

BIBLIOGRAPHY OF WATER QUALITY STUDIES AND DATA

Water quality in the upper Gila River watershed has been the subject of numerous studies. A bibliography of selected publications pertinent to water quality is presented in the references section of this report. Rather than annotate each citation individually, Table 1 provides a list of selected references grouped by subject. This bibliography is not meant to be comprehensive, but rather to provide a list of pertinent literature.

The most detailed reports, containing water-quality data for surface and groundwater specific to the upper Gila River watershed, are listed under the headings of "Detailed studies of water quality in the upper Gila watershed", "Water quality in the Gila River", and "Water quality data for springs." Other categories contain minor or no data on water quality, but discuss general factors that may influence water quality.

Not reported individually, but grouped as "USGS, annual" are the yearly reports on water quality titled "Water Resources Data, Arizona, Water Year YYYY." These reports, such as Smith and others (1997), are the U.S. Geological Survey Water-Data Report series, with each year numbered as Report AZ-YY-1, where YY is the year for the data. Contained in the reports are detailed data from the US Geological Survey surface- and groundwater data-collection network in Arizona, including water chemistry, streamflow and groundwater levels.

The reports of Muller (1973) and Muller and others (1973) are not included in the table because these reports are based on seriously flawed data and are of no value. A detailed discussion of these reports is included under the section "Groundwater quality in the Safford Basin".

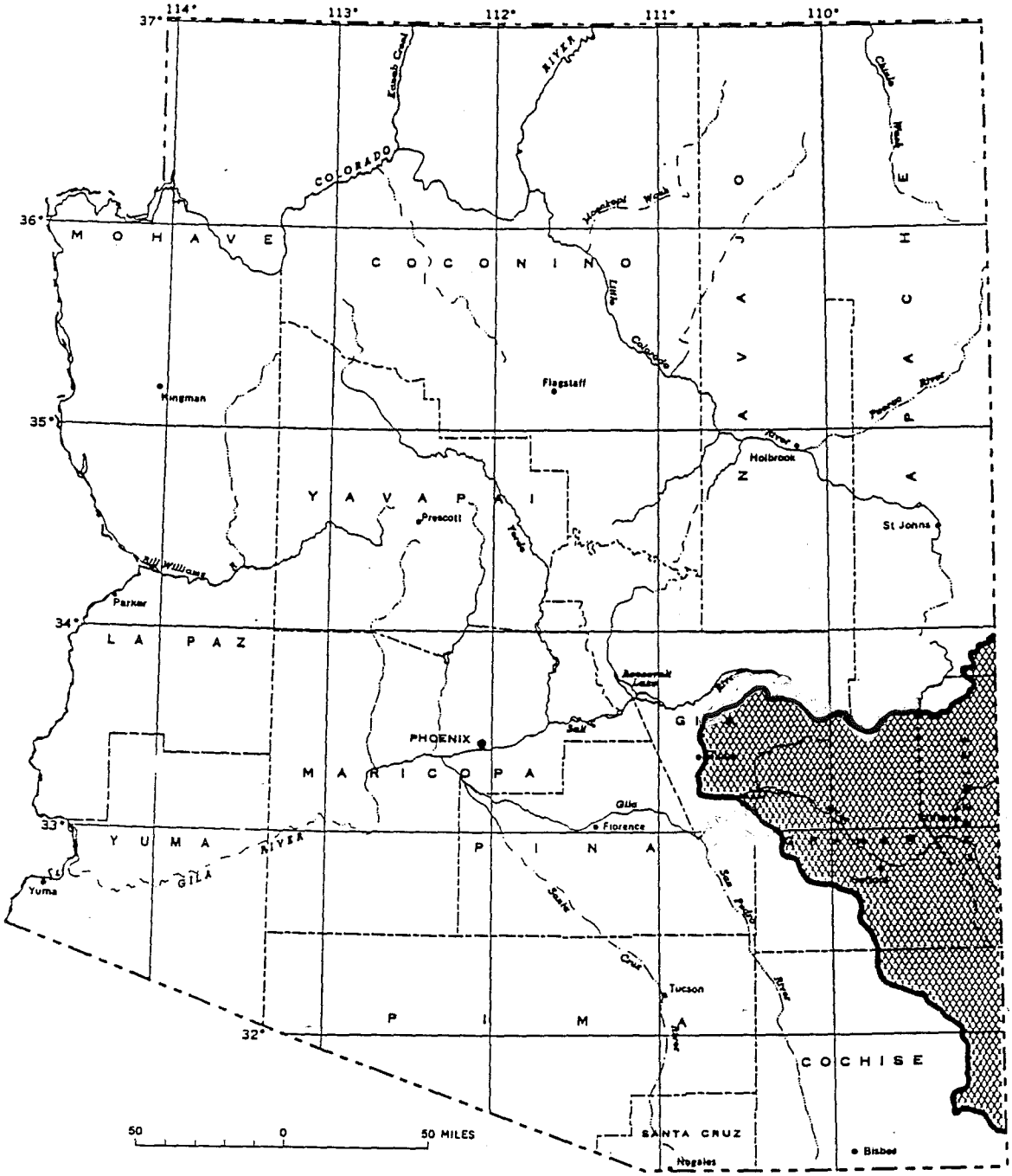
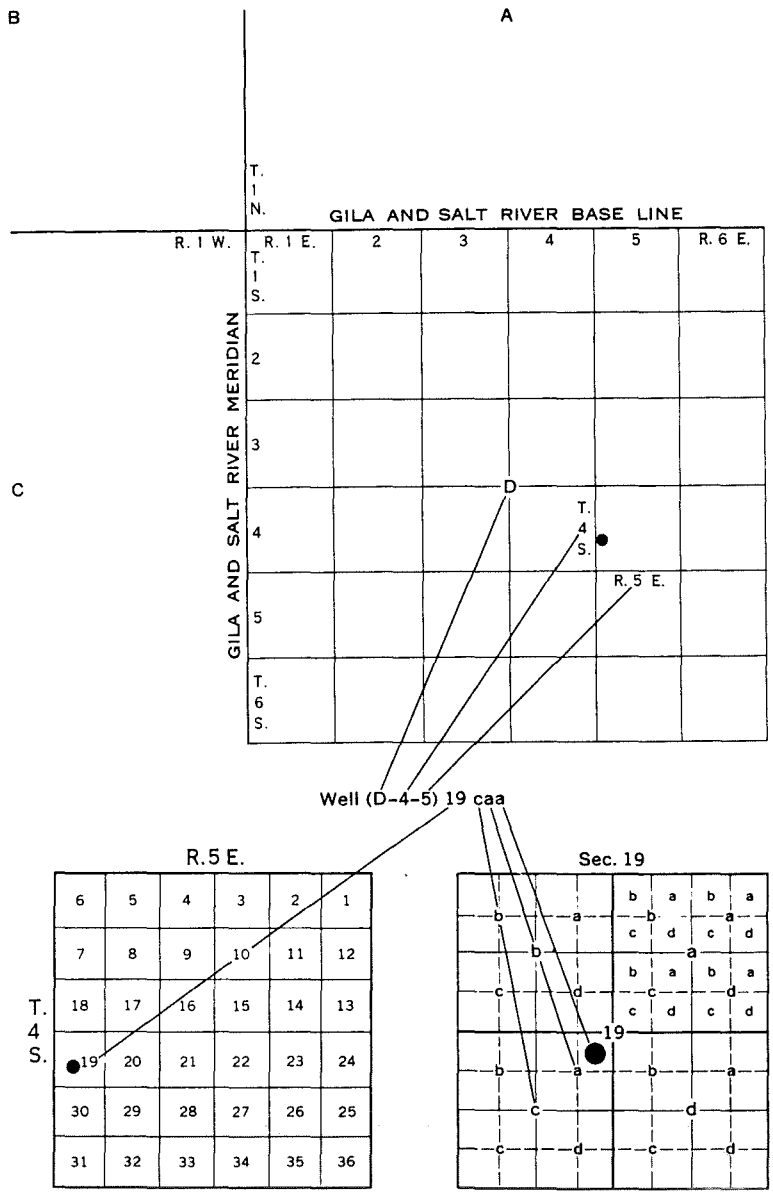


Figure 1. Location of upper Gila River watershed in Arizona.



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

Figure 2. Well numbering system used in Arizona.

Table 1. Categories of water quality studies in the upper Gila River region.

Detailed studies of water quality in the upper Gila watershed.

Barnes, 1991	Black, 1991	Brown, 1989
Catlin, 1926	Daniel, 1981	Dutt and McCreary, 1970
Feth and Hem, 1962; 1963	Follett, 1969	Grimm and Fisher, 1986
Hahman, 1979a	Hahman, 1979b	Halpenny et al., 1946
Halpenny et al., 1947	Halpenny et al., 1952	Harris, 1999
Hassemer et al., 1983a	Heindl and McCullough, 1961	Hem, 1950
Knechtel, 1938	Remick, 1989	Schwennesen, 1917
Schwennesen, 1919	Smalley, 1983	Smith, 1949
Smith et al., 1963	Smith et al., 1964	Stone and Witcher, 1982
Swanberg et al., 1977	Thompson et al., 1984	Turner et al., 1946
Wallin, 1999	White, 1963	Witcher, 1981a
Witcher, 1981b		

Water quality in the Gila River.

ADHS, 1976	Baldys et al., 1995	Ellingson and Sommerfeld, 1992
Follett, 1969	Gatewood et al., 1950	Harris, 1999
Hem, 1950	Hem, 1985	Schumann & Swanson, 1993

General Safford basin aquifer physical characteristics.

Hanson and Brown, 1972	Harbour, 1966	Hollander, 1960
Houser, 1990	Kruger et al., 1995	Marlowe, 1960; 1961
Norton et al., 1975	White and Hardt, 1965	

General studies of groundwater basins in Arizona - applicable to upper Gila.

Anderson, 1979; 1980; 1984; 1986a; 1986b; 1986c; 1995		Anderson et al., 1990
Anderson et al.,1992	Anderson et al., 1988	Bedinger et al., 1984a; 1984b
Bedinger et al., 1985	Freethy, 1986	Freethy and Anderson, 1986
Konieczki and Wilson, 1992	Langer et al., 1984	Mann, 1980
Robertson, 1986; 1991	Pool, 1984; 1986	Sargent and Bedinger, 1985
Thompson et al., 1984		

Water quality data for springs.

Eaton et al., 1972	Feth, 1954	Feth and Hem, 1962
Feth and Hem, 1963	Hahman, 1979a	Hahman, 1979b
Hassemer et al., 1983a	Hassemer et al., 1983b	Hem, 1950
Knechtel, 1935	Knechtel, 1938	Mariner et al., 1977
Stone and Witcher, 1982	Swanberg, 1978	Swanberg et al., 1977
Tellier, 1973; 1974	Witcher, 1981a	

Geothermal resources, with water quality data.

Hahman, 1979a	Hahman, 1979b	Mariner et al., 1977
Stone and Witcher, 1982	Witcher, 1981b	

Uranium and radon in water.

Duncan et al., 1993	Hassemer et al., 1983a	Hassemer et al., 1983b

Water use by phreatophytes, evapotranspiration.

Anderson, 1976	Burkham, 1976	Culler et al., 1970
Culler et al., 1972	Gatewood and others, 1950	Hanson and Dawdy, 1976
Hem, 1967	Jones, 1977	Kipple, 1977
Laney, 1977	McQueen and Miller, 1972	Park et al., 1978
Turner, 1974	Weist, 1971	

WATER QUALITY IN THE UPPER GILA RIVER

Hem, 1950

An extensive set of analytical data for the upper Gila River and tributaries is contained in Hem (1950). Hem's study covered the period of 1940 through 1944, and some of his data for the Gila River is also presented in Gatewood and others (1950).

Both of these studies show that water quality is highly variable and that TDS is inversely related to flow rate. Salinity in the river is low at the Arizona-New Mexico border and TDS shows only minor increases through the Duncan Valley. As the river passes Gillard Hot Springs, TDS and temperature show discernible increases, from the addition of spring water with TDS of 1200 to 1500 mg/l and temperatures as high as 82.6°C (181°F) (Witcher, 1981a).

One mile downstream from Gillard Hot Springs, the confluence with the San Francisco River adds significantly to the salt load in the Gila River. Most of the salt in the San Francisco River comes from hot springs near Clifton, which add more than 19,000 tons of salt per year. For perspective, 19,000 tons of salt would have accounted for 18% of the total salt load of 105,000 tons in the Gila River entering the San Carlos Indian Reservation during the time period of Hem's (1950) study.

TDS increases slowly in the Gila downstream from where it enters the Safford Valley until near the town of Pima, where salinity starts to increase markedly. Salinity reaches maximum values, typically as high as 3500 mg/l during lowest flow, in the Fort Thomas-Geronimo area and then slowly declines downstream.

Hem (1985, Figures 10 and 11) found a well defined, linear relationship of conductivity versus TDS, chloride, and sulfate in waters of the Gila River. The trends are so close to linear that the levels of these constituents can be estimated with reasonable accuracy from conductivity measurements alone. The relation of conductivity to TDS was determined to be 0.59xEC=TDS, where EC is electrical conductivity in microsiemens per centimeter (μS/cm) or micromhos (μmhos) and TDS is in mg/l or ppm.

Although detailed, the sampling by Hem (1950) does not represent a long-term study. As noted by Hem, seasonal variability related to flow rate is very large. Sampling was repeated two or three times per year at most sites, but the flow rate was not constant from one sampling to another.

Baldys and others, 1995

Baldys and others (1995) detail statistical methods for treatment of seasonally variable data and apply appropriate a flow rate adjustment to Gila River water quality analyses. Most of the variation in TDS of river water from one sampling to another is related to flow rate. During higher flow, the quality is better and as flow decreases, the water becomes more saline. Meaningful analyses of water quality trends in surface water must take into account this variation, in order to determine if TDS has intrinsically changed over time *for a given flow rate*. Table 2 summarizes the findings of Baldys and others (1995) for water quality trends in the Gila River system.

For most constituents, no statistically significant trend is seen, meaning there has been no real change in those water quality parameters over the sampling period. Only two statistically significant increases are noted: a 0.02 mg/l/ per year increase in total ammonia plus organic nitrogen in the San Francisco River at Clifton, and a 0.029 unit per year rise in pH at Calva. Explaining the increase in ammonia plus organic nitrogen is difficult as there is no agriculture upstream of Clifton. The slight rise in pH of the Gila River at Calva is accompanied by statistically significant decreases in TDS, sodium, chloride, sulfate, chloride, and phosphorus at that site.

Table 2. Water quality trends in the upper Gila River.

Gila River - Red Rock, NM

Constituent	Calculated change/year (mg/l)	Statistical Significance (p value)	Result
pH (std units)	0.056	0.1310	no trend
Turbidity (NTU)	-0.04	0.3418	no trend
Hardness	-0.03	0.2332	no trend
TDS	-0.45	0.0492	decrease
Sodium	-0.05	0.0002	decrease
Sulfate	-0.09	0.0013	decrease
Chloride	-0.07	0.0220	decrease
NH4+org N	-0.01	0.7041	no trend
Phosphorus	-0.01	0.1043	no trend
Boron	insufficient data		no trend

San Francisco River - Clifton

Constituent	Calculated change/year (mg/l)	Statistical Significance (p value)	Result
pH	<0.001	1.000	no trend
Turbidity	0.14	0.2301	no trend
Hardness	-0.04	0.3486	no trend
TDS	-0.2	0.4708	no trend
Sodium	-0.10	0.2648	no trend
Sulfate	-0.02	0.6058	no trend
Chloride	-0.01	0.8491	no trend
NH4+org N	0.02	0.0660	increase
Phosphorus	-0.05	0.0266	decrease
Boron	-0.24	0.5163	no trend

Gila River - Calva

Constituent	Calculated change/year (mg/l)	Statistical Significance (p value)	Result
pH	0.029	0.0234	increase
Turbidity	-0.02	0.9470	no trend
Hardness	-0.07	0.0088	decrease
TDS	-0.5	0.0439	decrease
Sodium	-0.04	0.0725	decrease
Sulfate	-0.05	0.0679	decrease
Chloride	-0.07	0.0054	decrease
NH4+org N	<0.01	0.9095	no trend
Phosphorus	-0.06	0.0333	decrease
Boron	-0.02	0.6235	no trend

Data from Baldys and others, 1995

Safford Agricultural Center

A detailed, long-term sampling program of Gila River water quality was undertaken from 1945 to 1985 by the University of Arizona's Safford Agricultural Center (SAC), formerly known as the Safford Experiment Station. This previously unpublished data set represents the most comprehensive sampling ever done in the upper Gila River. Analytical data are presented in Table 3. Sampling of river water was started in 1954, but prior to 1962 it is unclear if the sampling point was at the river diversion or at the delivery to the SAC farm. Groundwater is commonly added to the canal system, and in many years, canal water going to SAC was sampled at the San Jose canal diversion of the river, in the Montezuma canal (a spur of the main San Jose canal), and at SAC. Sampling data are not included for the period prior to 1962 because it is not explicit in the laboratory reports which of the three sites was sampled.

The SAC Gila River data in Table 3 have not been adjusted for flow-rate. As expected, a wide variation is seen in the analyses, with an apparent slight decrease in most parameters over time in the accompanying graphs (Figure 3). This decrease is probably due mostly to the timing of the sampling, that is, it is due to the flow rate at the time of the sampling. Adjusting for the flow rate is necessary before true trends in the TDS and other constituents can be determined.

As with the Gila River data of Hem (1950), the SAC conductivity versus TDS data show a slight concavity downward at the lower end. When TDS is plotted against conductivity, a relation of TDS = 0.59xEC (same as Hem, 1950) emerges if the least-squares regression line is forced to go through the origin (EC and TDS both zero). If that constraint is removed, the line, which is dominated by measurements in the EC range of about 700 to 1500 μS/cm, has a slope of 0.49 and crosses the TDS axis near 150. From these relations, TDS can be calculated with a fair degree of accuracy from EC measurements, or vice versa.

Note: Assumed sampling dates are given for 8/15/72 and 6/14/81, based on date of lab report. These samples should be omitted for any use where date-dependent flow rate adjustment is required.

Table 3. Water quality data for the Gila River at San Jose.

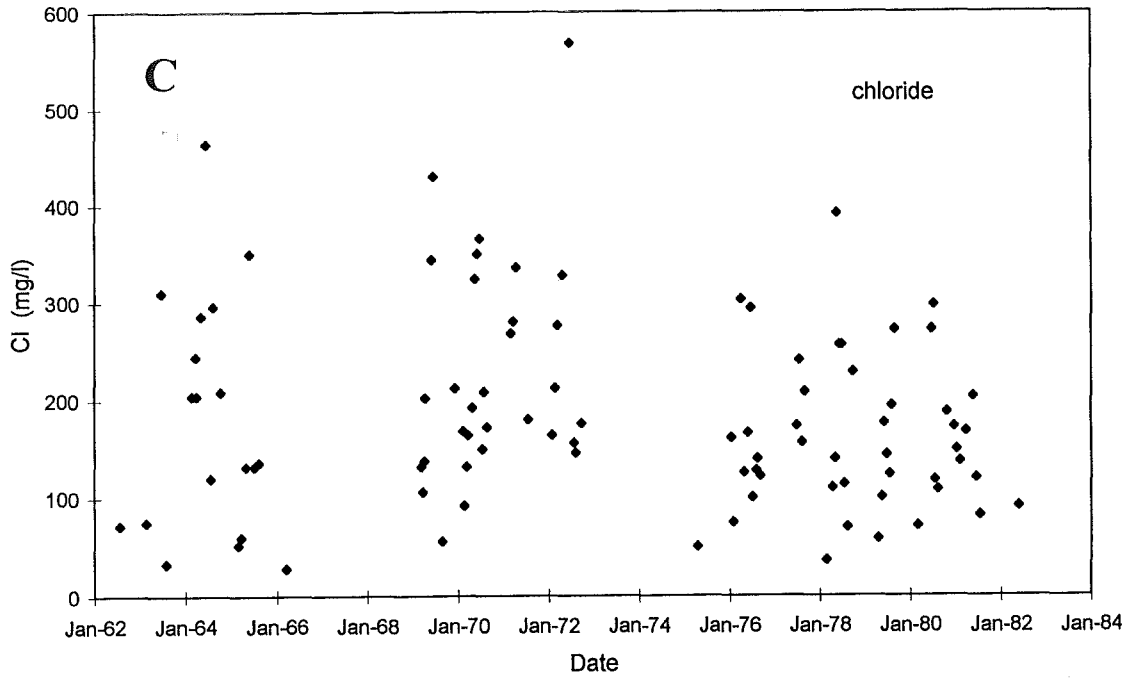
Date	EC	TDS	pH	Ca	Mg	Na	Cl	SO4	HCO3	CO3	Hard gr/gl	F	NO3 (N)
8/3/62	660	433		40	10	77	72	68	166	0	8.2		0
3/5/63	660	415		46	12	32	75	60	190	0	9.62		0.2
7/2/63	1920	989		76	16	221	310	163	200	1	20.2		0.28
8/16/63	450	311		42	7	38	33	48	142	0	7.74		0.23
3/12/64	1090	729		70	16	143	204	72	215	6	14		0.68
4/5/64	1250	771		72	26	141	244	54	232	0	16.7		0.45
4/17/64	1100	687		66	14	136	204	51	215	1	13.1		0
5/23/64	1400	779		75	14	169	286	42	181	10	14.3		0.45
7/2/64	1650	1079		93	17	262	464	71	166	4	17.7		0.45
8/7/64	700	531		51	14	94	120	71	181	0			0
8/27/64	1320	903		84	15	193	296	70	244	0	15.9		0.23
10/27/64	1000	726		70	13	145	208	56	234	0	13.4		0
3/15/65	480	332		38	9	47	52	40	146	0	7.8		0
4/7/65	500	357		37	10	55	60	34	161	0	7.73		0
5/14/65	800	535		56	12	95	132	50	186	4	11.1		0
6/14/65	1600	1152		90	15	278	350	220	192	6	16.7		0.23
7/21/65	750	505		54	10	90	132	34	183	0	10.4		0.45
8/26/65	840	548	7.8	80	22	55	136	44	209	0	17		0.45
4/4/66	320	227	8.2	30	7	24	28	22	115	0	6.2		0.23
3/27/69	750	540	8.4	62	10	92	132	52	185	7			0
4/11/69	690	483	7.8	48	12	74	106	46	195	0			0.45
4/19/69	880	554	7.7	64	9	92	138	46	205	0			0.11
4/29/69	900	574	7.3	60	18	62	202	60	166	6			0.07
6/17/69	1400	902	8.8	88	15	183	344	90	171	8			0.68
7/6/69	1750	1038	8.2	92	24	210	430	100	181	0			0.23
9/10/69	440	371	7.2	46	13	39	56	45	171	0			0.16
12/22/69	1210	716	7.8	68	15	138	212	50	229	0			0.84
3/1/70	1140	686	7.8	46	11	151	168	90	220	0			0.23
3/11/70	580	458	8.1	46	11	68	92	56	185	0			0.05
3/25/70	960	539	7.7	47	11	92	132	46	210	0			0.16
4/7/70	870	607	8.2	57	13	112	164	48	205	0			1.69
5/15/70	920	627	8	56	12	114	192	58	195	0			0.05
6/3/70	1420	864	8.1	73	17	193	324	62	190	0			1.22
6/22/70	1540	920	8.7	76	18	169	350	80	218	3.6			1.02
7/11/70	1800	967	8.4	72	21	212	366	75	171	3.6			3.05
7/31/70	850	539	8.8	51	15	97	150	40	183	0			0.68
8/18/70	1020	648	7.7	64	15	120	208	40	200	0			0.27
9/9/70	907	615	8.2	55	15	108	172	66	190	0			2.03
3/20/71	1260	800	8	68	16	168	268	72	200	0			1.87
4/10/71	1500	810	8.2	68	17	175	280	80	190	0			0.02
4/30/71	1500	919	7.7	70	17	231	336	60	185	0			4.4
8/6/71	1170	628	7.8	82	19	109	180	65	161	0			2.71
2/15/72	980	662	7.9	84	17	108	164	70	215	0			0.85
3/11/72	1130	757	8.15	90	18	134	212	80	215	2.4			1.35
3/31/72	1300	814	8.4	80	17	145	276	75	210	4.8			1.35
5/11/72	1500	898	8.3	82	19	166	328	80	220	0			0.68
7/11/72	2115	1291	8.1	112	35	302	568	90	176	0			1.69
8/15/72	910	672	7.3	88	13	100	156	60	244	0			2.54

Table 3. Water quality data for the Gila River at San Jose, continued.

Date	EC	TDS	pH	Ca	Mg	Na	Cl	SO4	HCO3	CO3	Hard gr/gl	F	NO3 (N)
8/25/72	850	603	7.8	61	15	103	146	55	215	0			1.69
10/15/72	1100	659	8.2	68	13	122	176	65	203	4.8			1.69
5/8/75	510	337	7.8	32	7.3	38	50	27	181	0		1.1	0.2
2/7/76	890	592	8.3	75	10.5	102	161	29	205	7.2		1.45	0.63
2/25/76	560	514	7.2	70	9.3	72	75	63	220	0		1.5	3.3
4/21/76	2940	1520	7.8	67	20	315	303	298	508	0		2.6	6.8
5/20/76	740	589	7.4	30	14.7	108	126	69	239	0		0.92	0.9
6/20/76	900	644	8.3	72	15.6	141	166	66	176	6		0.8	0.08
7/9/76	1550	810	8.5	87	20	198	294	87	185	9.6		0.65	0.07
7/30/76	690	498	7.6	33	9	56	100	45	254	0		0.2	0.85
8/26/76	830	551	7.5	79	12	93	128	18	220	0		0.82	0.16
9/3/76	940	595	7.7	70	10	96	140	72	205	0		1.25	0.9
9/27/76	820	548	7.7	65	12	86	122	66	195	0		1.2	0.55
7/21/77	958	704	7.1	35	11	100	173	297	185	0		0.9	0.75
8/8/77	1320	738	7.6	78	11.5	96	240	90	220	0		2.2	0.3
8/31/77	1010	583	7.5	72	12	100	156	33	210	0		1.5	0.15
9/21/77	1280	675	8	68	14	128	208	50	205	2.4		1.5	0.15
3/23/78	400	269	7.7	39	7	29	36	21	137	0		1.1	0.15
5/9/78	810	447	8.3	55	11	81	110	47	176	7.2		1.45	0.15
5/26/78	1210	599	7.9	63	13	100	140	78	205	0		1.4	0.05
6/8/78	3020	1630	7.9	84	20	408	392	258	468	0		2.27	7.1
7/1/78	1390	737	7.8	82	20	124	256	60	195	0		1.3	0.2
7/22/78	1500	767	8.2	82	15	136	256	78	190	6		1.95	0.05
8/11/78	1010	514	7.9	64	14	92	114	80	210	0		1.5	1.0
9/3/78	680	447	7.5	48	12	73	70	20	224	0		1.25	0.25
10/16/78	1330	687	8.4	86	16	114	228	36	200	7.2		1.55	0.05
5/9/79	470	339	8	42	7	46	58	47	137	2.4		1	0.2
6/13/79	660	458	7.95	49	9	85	100	30	185	0		1.33	0.05
6/29/79	950	593	7.7	34	16	132	176	27	206	1.2		1.27	0
7/19/79	720	519	7.6	50	12	93	144	30	190	0	1.85	1.85	1.51
8/9/79	690	469	7.5	50	13	82	124	24	176	0		1.25	1.1
8/31/79	980	743	7.8	80	13	157	194	75	224	0		0.24	1.25
9/21/79	1240	759	7.2	86	8.5	167	272	54	171	0		1.25	0.15
3/28/80	600	404	7.6	53	10.8	55	71	33	181	0		1.1	0.2
7/17/80	1350	819	7.1	92	12.4	165	272	72	205	0	16.4	1.43	1.5
7/31/80	1350	767	7.7	93	14.5	137	297	30	195	0		1.32	0.1
8/16/80	720	496	7.1	70	11.8	70	118	21	205	0		1.11	0.7
9/8/80	720	507	7.35	67	13.1	71	108	28.5	220	0		0.95	1.15
11/19/80	1022	705	7.5	85	12.2	136	187	69.3	215	0		1.35	0
1/16/81	955	635	7.6	48	11.3	127	172	67	210	0		1.5	0.41
2/5/81	1040	646	7.7	53	14.8	147	149	55	229	0		1.3	0.02
3/2/81	980	590	7.9	48	13.8	126	137	55	210	0		1.35	0.02
4/22/81	1090	597	8	49	14.2	136	167	55	166	9.6		1.2	0
6/14/81	1060	735	7.4	51.6	16.5	150	203	89	225	0	11.5	1.55	1.0
7/11/81	750	524	7.4	70	11.9	78	120	40	203	0	13.11	1	1.24
8/13/81	610	430	7.6	53	9.8	68	82	33	185	0	10.1	1.15	0.57
6/24/82	730	414	7.6	49	12	50	91	25	181	0	10	1.63	0.2

Data from Safford Agricultural Center

Figure 3. Water quality of Gila River at San Jose, continued.



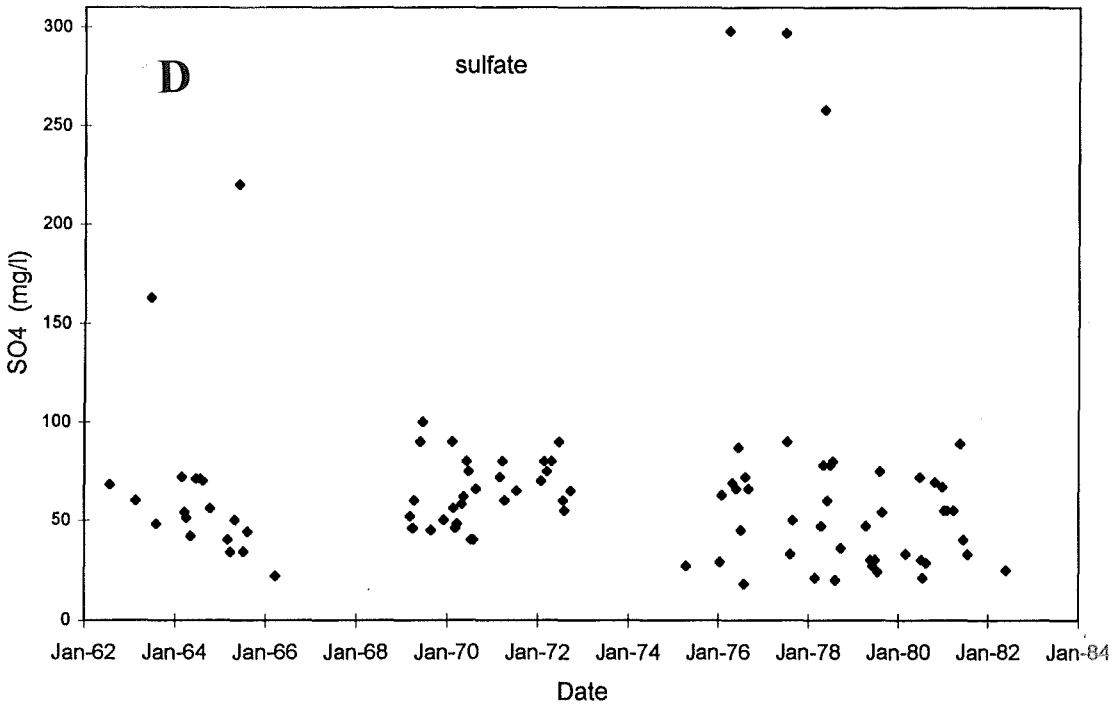
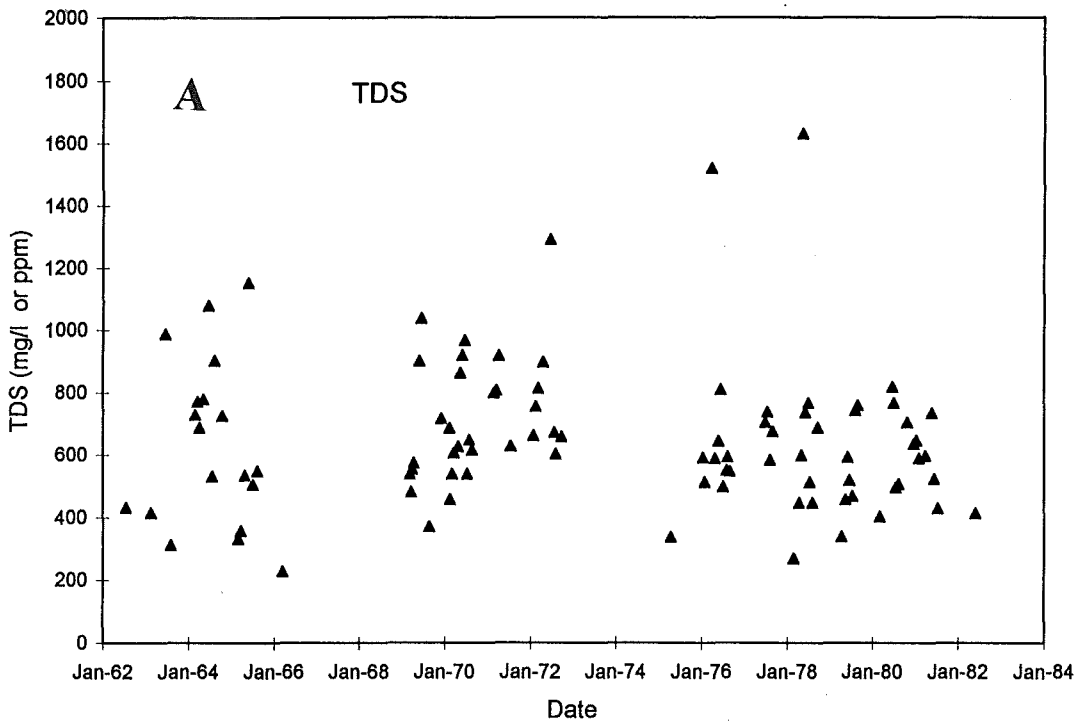


Figure 3. Water quality of Gila River at San Jose.



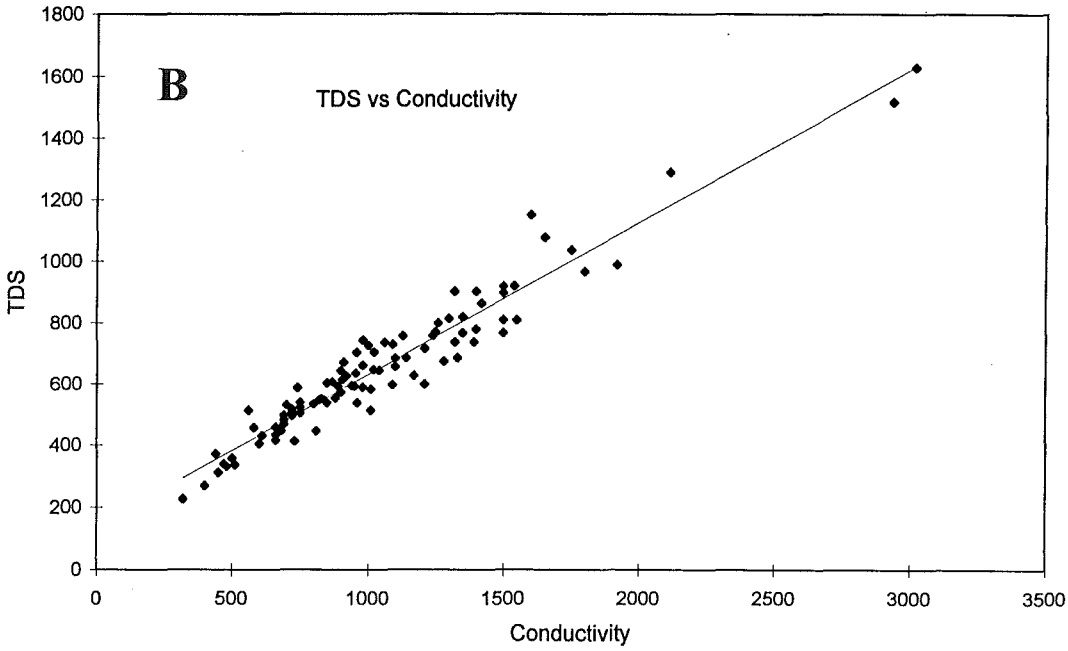
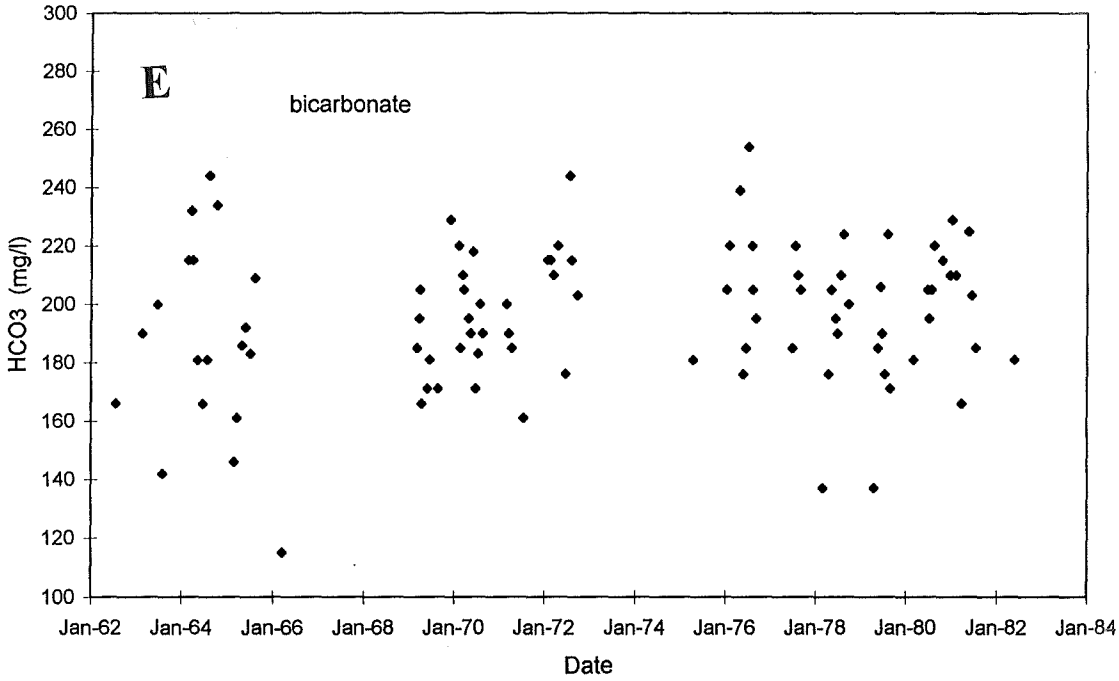
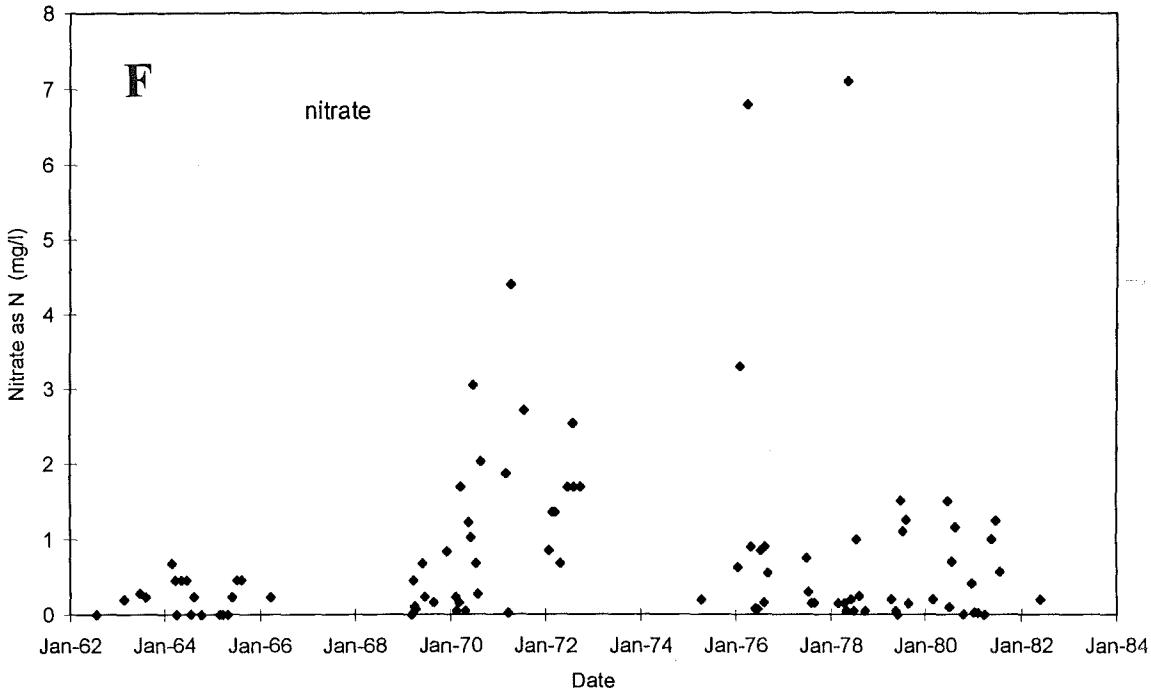


Figure 3. Water quality of Gila River at San Jose, continued.





GROUNDWATER QUALITY IN THE SAFFORD BASIN

General

Groundwater in the Safford Valley varies tremendously in TDS (Hem, 1950; Gatewood and others, 1950; Black, 1991). In general, TDS is higher north of Pima, and reaches a peak in the Fort Thomas-Geronimo area. This part of the valley is also where outcrops of salty clay and salty springs are most common. Additional salinity comes from natural artesian leakage of deep groundwater, suspected to be of a large magnitude (Hanson and Brown, 1972; Brown, 1989). A significant portion of the salinity in groundwater and in the Gila River may be introduced from the underlying basin-fill sediment in this manner.

Aquifer tests have indicated that water under artesian pressure is flowing upward from the basin-fill sediments into the valley-floor alluvial aquifer (Weist, 1971; Culler and others, 1982). Higher water levels in wells in basin fill versus levels in nearby wells producing from stream alluvium lead Brown (1989) to conclude that water is flowing from the basin fill into the stream aquifer. The magnitude of the vertical flow in the San Carlos Reservation part of the Gila River has been computed at 106,000 cubic feet per day (1.23 cfs) per mile of river length (Hanson and Brown, 1972). Water in some shallow wells in the Fort Thomas-Geronimo area temperatures as high as 97°F, 30° higher than the normal background for shallow wells (Hem, 1950, p.52). Water this warm most certainly is coming from artesian leakage of deep basin water and not from infiltration of Gila River water.

Hem, 1950

Hem (1950) reported 3999 chemical analyses of surface and groundwater samples taken during his study from 1940 through 1944. This collection represents the most ambitious study ever undertaken in the Upper Gila region. Although detailed, the study does not constitute a long-term study in the sense that, given the highly variable TDS over short periods of time in a single well, the typical two to four samples from any one well is not enough to distinguish a real long-term trend versus short-term natural variability.

Hem was able to construct 1,300 observation wells in the Safford Valley, most of them in the Gila River floodplain. In addition, hundreds of existing irrigation, stock, and residential wells were analyzed, along with seeps in the Gila River channel and springs. The density of measurements allowed the spatial distribution of TDS in groundwater to be mapped in great detail.

Safford Agricultural Center

Of all the wells in the Safford basin, none has a more extensive data set than that of the University of Arizona's Safford Agricultural Center (SAC), formerly the Safford Experiment Station [D(7-26)22b]. Spanning from 1945 to 1988, the record includes more than 120 chemical analyses (Table 4).

The SAC data confirm, as Hem (1950) reported, that groundwater quality in a well can change significantly over short periods of time. Levels of constituents in the SAC well typically vary by a factor of at least 2 or 3 over the course of several years. Calcium, for example, ranged from 31 to 128 mg/l from 1970 to 1972. Sodium varied from 144 to 441 mg/l, and chloride from 216 to 472 mg/l in the four samples taken during 1976.

An obvious trend of improved water quality over time is seen in this well (Figure 4). TDS, Na, Cl, and SO4 have all decreased to about half or less of their 1950s values. The reason for the decrease in salinity in this well is not easily explainable. The isotopic composition of water in the well does not match that of the Gila River (Harris,1999), so changes in water quality in the river (which are minuscule anyway) are not responsible. Oxygen and deuterium in the water reflect a high-elevation, low-temperature source area, such as Mt. Graham, rather than from the Gila River.

Isotopes of the TDS constituents show a significant contribution of salinity from natural evaporites in the basin sediments. Because isotopic analyses for this well and the river do not exist prior to 1998, the question of whether or not the source(s) of TDS or the water in this well has changed since monitoring began in 1945 cannot be answered.

As is seen in the graphs, a few of the sulfate analyses are obviously suspect. The values for these outliers are not only unreasonably higher than in other analyses, but exceed the chloride concentrations in the samples, a situation also unreasonable in the SAC well. Yet, without the large number of analyses available for this well, these points might not be recognized as outliers.

If two or three analyses out of the entire set were picked out at random, there is a chance that they would show an increase over time. Yet, the whole data set clearly shows a significant downward trend in every constituent with the possible exception of nitrate, which shows no clear trend.

Table 4. Water quality data for the Safford Agricultural Center well.

Date	EC	TDS	pH	Ca	Mg	Na	Cl	SO4	HCO3	Hard gr/gal	F	NO3 (N)
12/18/45		2184				585	646					
6/30/47		3147				943	1250					
3/10/48		3957				1409	1350					
8/21/48		4091				1176	1253					
4/19/49		3672				1150	1370					
11/30/49		3150				782	980					
3/2/50		2362				749	844					
5/16/50		4116				1240	1276					
4/3/51		4039				1140	1260					
6/12/51		4017				1134	1270					
6/22/52		3922				989	1374					
2/26/54		3995		158	23	1170	1240	550	854			
4/23/54		3208		352	8	737	1146	406	559	53.36		
4/26/54		3364		120	11	1058	1320	330	525	20.26		
5/11/54		3062		135	11	773	1188	425	530	22.45		
6/24/54		3203		53	11	658	1398	697	383	10.48	3	
8/14/54		3534		210	11	1057	1120	600	534	33.39	2	
9/1/54		2721		126	42	466	1170	380	537	28.88		
9/20/54		2406		120	15	264	1160	315	531	21.5		
2/4/55		3196		82	23	989	1080	410	610	20	2.5	
2/12/55		3072		100	23	934	1078	360	573	20.34	4	
4/28/55		3709		110	36	1151	1260	550	602			
6/9/55	3800	3647		110	22	1136	1290	528	591	22		
6/13/55	3800	3706		108	29	1148	1300	560	561	23		
8/23/55		3558		157	19	1065	1440	340	537			
10/14/55		3334		120	23	880	1164	635	512			
1/15/56		3124		110	18	950	1080	380	586	20.5		
2/15/56		3146		82	24	976	1070	420	574	18		
4/11/56		3474		92	25	1095	1200	525	537	19.6		
5/3/56		3472		110	26	998	1210	580	548	22.5		
6/9/56	3800	3647		110	22	1136	1290	528	591	22		
6/13/56	3800	3706		108	29	1148	1300	560	561	23		
7/19/56		3467		72	43	1077	1260	405	610	21.2		
11/15/56		3530		110	18	945	1230	690	537	20.5	5	
4/2/57		3735		125	32	1132	1260	625	561	26.2		
4/2/57		3698		148	37	1081	1220	675	537	30.9		
4/9/57		3202		127	28	1139	1280	580	548	25.6		
4/26/57		3788		116	34	1067	1310	700	561	25.4		
7/10/57		3811		113	29	1179	1300	665	525	23.8		
5/28/58		3503		118	19	1063	1083	696	522	22	1.6	
3/6/59		3518		174	47	982	1263	540	512	36		
4/6/59		3709		139	33	1102	1273	600	542	28.2		4.5
4/28/59		3473		130	35	887	1275	600	527	27.4		4.29
5/3/59		3701		126	36	1110	1277	600	532	27		4.5
5/14/59		3614		130	33	1083	1269	560	517	27.2		4.97
5/26/59		3599		128	38	1077	1280	560	516	28.2		
6/10/59		4823		322	46	1257	1320	1400	498	58.5		
6/23/59		4906		245	71	1317	1296	1450	527	53.5		6.1
10/21/59		3420		115	30	1030	1174	525	522	24.3		5.42
11/11/59		3268		115	31	970	1104	490	527	24.5		7
3/29/60		3334		156	41	923	1100	550	527	32.6		8.35

Table 4. Water quality data for the Safford Agricultural Center well, continued.

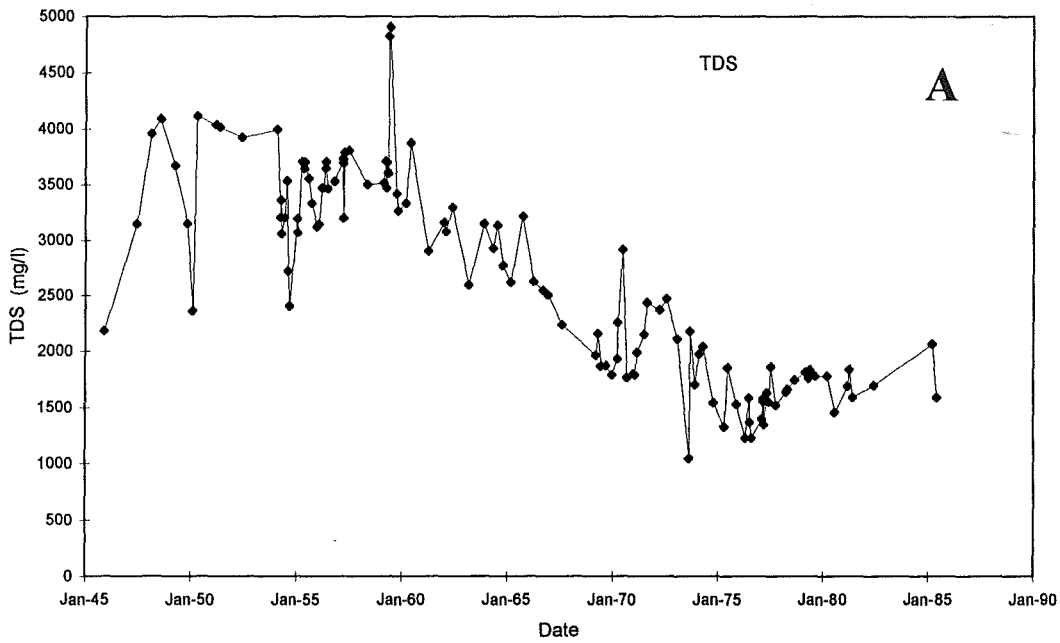
Date	EC	TDS	pH	Ca	Mg	Na	Cl	SO4	HCO3	Hard gr/gal	F	NO3 (N)
6/22/60		3877		248	53	845	1152	563	537	49		6.55
4/25/61		2903		206	53	696	942	418	588	42.8	2.4	
1/26/62	4450	3165		94	36	930	950	540	585			6.77
2/28/62	4300	3081		96	33	899	903	533	576	22		9.26
6/13/62	4600	3298		256	48	777	1012	510	649	49		10.4
3/25/63	4200	2596		62	32	802	922	435	435	16.8		7.9
12/20/63	4300	3150		220	41	779	970	520	566	42		12.2
5/22/64	4300	2929		132	32	822	970	390	542	27.2		9.26
8/6/64	4500	3136		136	32	893	1028	475	527			10.16
11/4/64	3850	2772		112	26	789	864	370	552	22.5		13.32
3/24/65	3800	2619		121	30	723	856	300	552	25		8.35
10/12/65	4300	3216	7.7	132	24	919	896	670	534	25.3		9.26
4/22/66	3800	2626	7.5	154	33	685	862	316	532	30.4	2	9.48
10/3/66	3200	2547	7.5	136	32	665	822	360	483		2.4	10.4
12/29/66	3500	2506	7.4	216	40	512	688	330	590	41.3	1.4	6.55
8/30/67	3200	*2240*	7.5	136	32	665	882	360	483		2.4	10.4
4/2/69	2500	1966	7.4	130	22	437	472	270	585			11.29
5/12/69	2800	2160	7.8	128	22	550	540	320	571			6.55
6/30/69	2200	1872	7.3	120	18	397	384	240	649			14.44
9/30/69	2250	1874	7	96	17	484	440	230	566			9.26
1/12/70	2680	1793	7.6	98	18	450	400	210	566			11.51
4/9/70	2410	1931	7.6	96	20	480	468	260	547			13.54
4/24/70	2600	2260	7.6	84	19	474	468	220	542			11.51
7/9/70	4260	2915	7.5	268	73	610	920	550	455			8.8
9/29/70	2500	1767	8.1	31	19	545	500	216	390			14.9
1/20/71	2700	1803	7.6	94	18	470	480	210	483			10.84
2/17/71	2700	1792	7.4	90	19	470	480	204	490			8.8
3/20/71	3060	1991	7.8	80	23	550	560	250	468			13.54
7/26/71	3100	2154	7.5	80	26	600	640	350	417			9.31
9/7/71	3200	2439	7.5	112	28	665	732	390	454			13.07
4/15/72	3500	2373	7.8	106	24	610	746	330	525			7.28
8/15/72	3500	2474	7.7	218	28	660	740	340	527			11.5
2/15/73	3100	2113	7.5	112	24	550	600	250	512	22	2	14.22
9/11/73	1500	1050	7.5	28	11	280	250	310	163		3.4	1.01
9/26/73	3000	2179	7.7	126	27	517	648	300	522			8.8
12/20/73	3010	1705	7.5	64	28	502	420	240	405		2.9	7.09
2/21/74	2940	1977	7.6	96	23	460	528	290	537		2.35	9.03
4/30/74	2710	2044	7.6	98	19	500	630	260	532		2.4	0.72
10/30/74	2230	1543	8.4	28	13	405	432	284	322		2.3	9.03
5/8/75	2530	1332	7.8	60	14	288	312	143	486		2.23	6.09
7/8/75	2480	1856	7.9	82	13	369	320	756	273		2.54	9.14
12/1/75	2430	1531	7.7	66	14	369	363	192	498		2.45	6.13
5/10/76	2190	1230	7.8	80	24	261	243	225	390		3	4.5
7/9/76	2460	1587	7.7	63	24	441	303	255	498		1.4	1.7
7/30/76	2520	1368	8	37	15	308	472	248	278		1.64	6.15
8/26/76	2520	1231	7.7	97	28	144	216	240	498		2.37	10.25
2/28/77	2340	1400	7.6	85	15	368	240	189	495		2.4	5.9
3/9/77	2450	1553	7.8	6.2	14	432	300	199	537		2.23	6.4
3/14/77	2560	1579	7.5	60	16	528	320	186	459		2.33	7.6
3/24/77	2610	1568	7.4	56	17	464	320	222	478		2.3	8.8
4/1/77	2560	1350	7.5	39	17	336	348	168	444		2.31	5.4

Table 4. Water quality data for the Safford Agricultural Center well, continued.

Date	EC	TDS	pH	Ca	Mg	Na	Cl	SO4	HCO3	Hard gr/gal	F	NO3 (N)
5/7/77	2910	1572	7.8	63	18	272	496	234	478		2.3	8.5
5/23/77	3010	1635	7.6	55	18	352	508	243	447		2.57	9.1
6/22/77	3070	1551	7.3	67	18	272	452	245	488		2.8	6.65
7/28/77	3020	1863	7.3	80	20	352	672	246	483		2.35	7.5
10/18/77	3040	1522	7.6	86	20	376	428	168	444		0.16	1.5
4/13/78	3080	1642	7.6	90	19	432	448	180	473		2.75	7.25
5/10/78	2910	1663	7.6	82	20	408	476	204	473		2.7	5.8
9/18/78	2920	1747	7.7	86	22	512	468	180	473		2.75	6.7
3/23/79	2960	1816	7.4	100	20	449	564	180	503		2.42	5.55
5/11/79	2710	1761	7.5	81	11	450	560	192	473		2.5	4.2
6/6/79	2780	1835	7.2	95	20	466	570	189	495		2.92	12
9/4/79	2730	1783	7.5	100	18	449	542	186	448		0.2	1.2
4/5/80	2730	1780	7.4	112	16	432	514	198	508		2.5	5.9
8/11/80	2430	1458	7.1	108	18	347	435	72	478		2.13	9.1
3/20/81	2330	1692	7.8	78	16	485	418	230	458		2.45	8.08
4/22/81	2440	1840	7.7	86	17	509	495	230	503		2.65	1.98
6/14/81	2330	1591	7.3	63	22	462	386	194	456	14.4	2.3	7.9
6/24/82	2290	1698	7.5	170	18	348	504	155	488	29.2	2.45	8.7
4/2/85	2090	2067	7.8	97.1	19	536	433	589	327	18.7	2.16	5.68
6/14/85	2210	1591	7.4	78	14	415	334	200	483	14.7	<0.8	6.48
12/24/86	2800											4.1
4/3/87	2200											5.3
4/15/87	1800											4.6
3/28/88	2000											5

Note: Assumed sampling dates are given for 1/15/56; 11/15/56; 8/15/72; 2/15/73; and 6/14/81, based on date of lab report.

Figure 4. Water quality in the Safford Agricultural Center well.



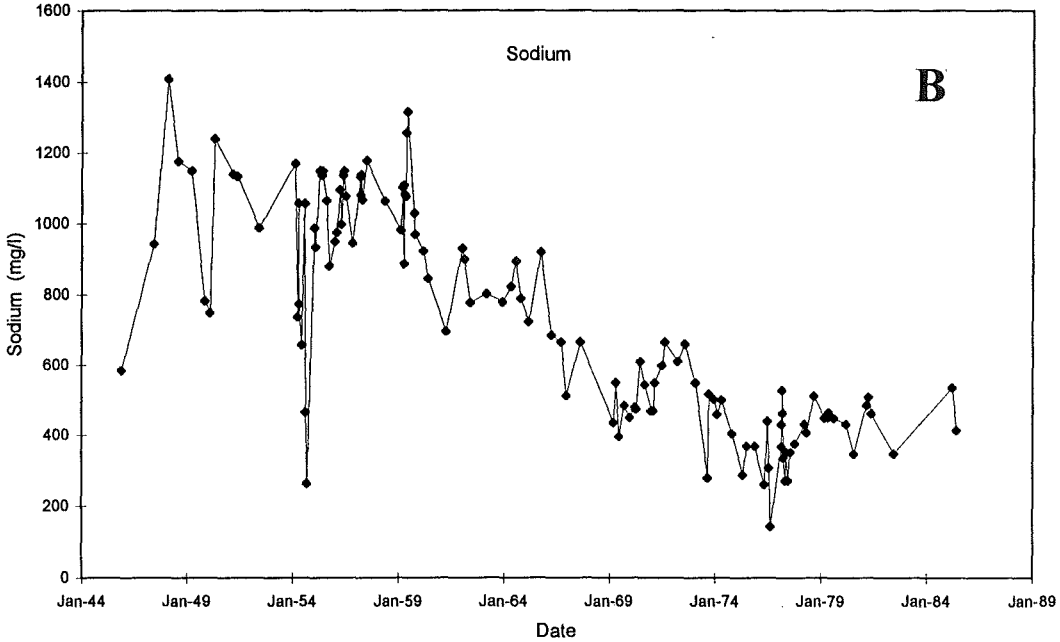
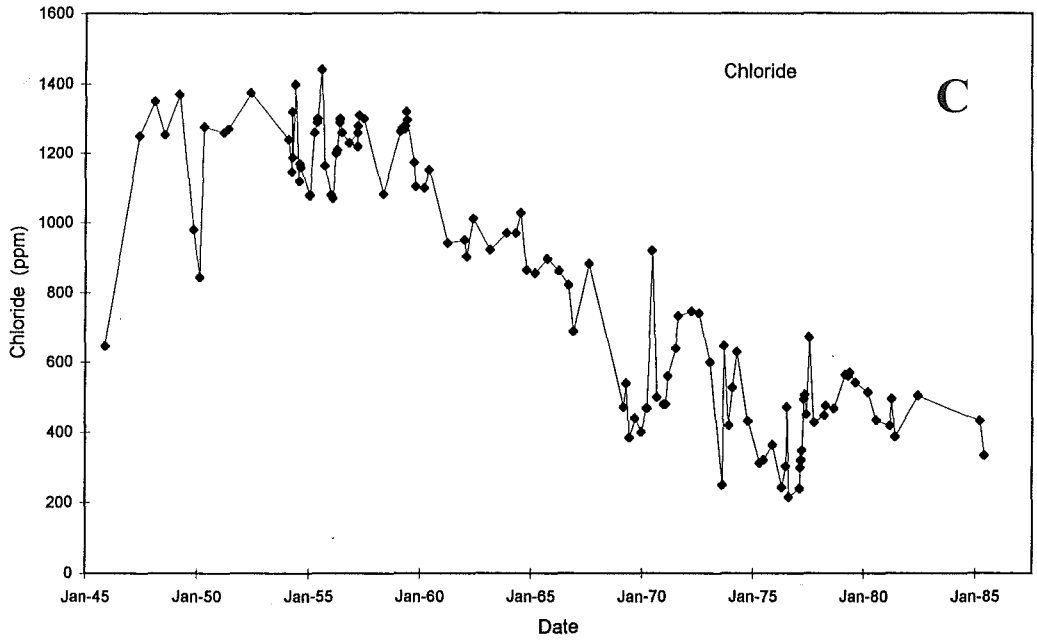


Figure 4. Water quality in the Safford Agricultural Center well, continued.



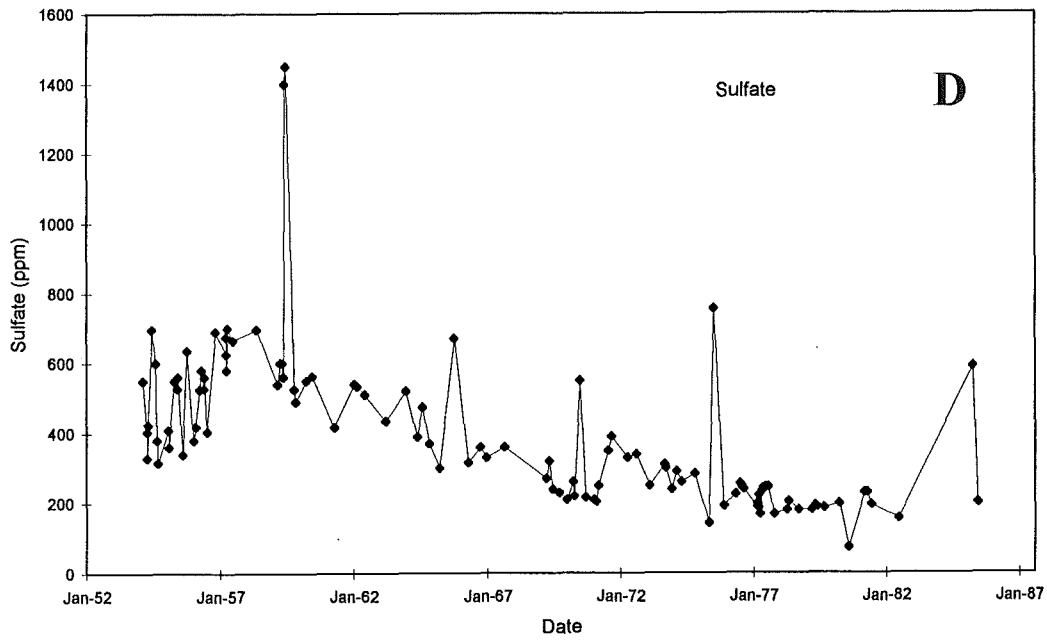
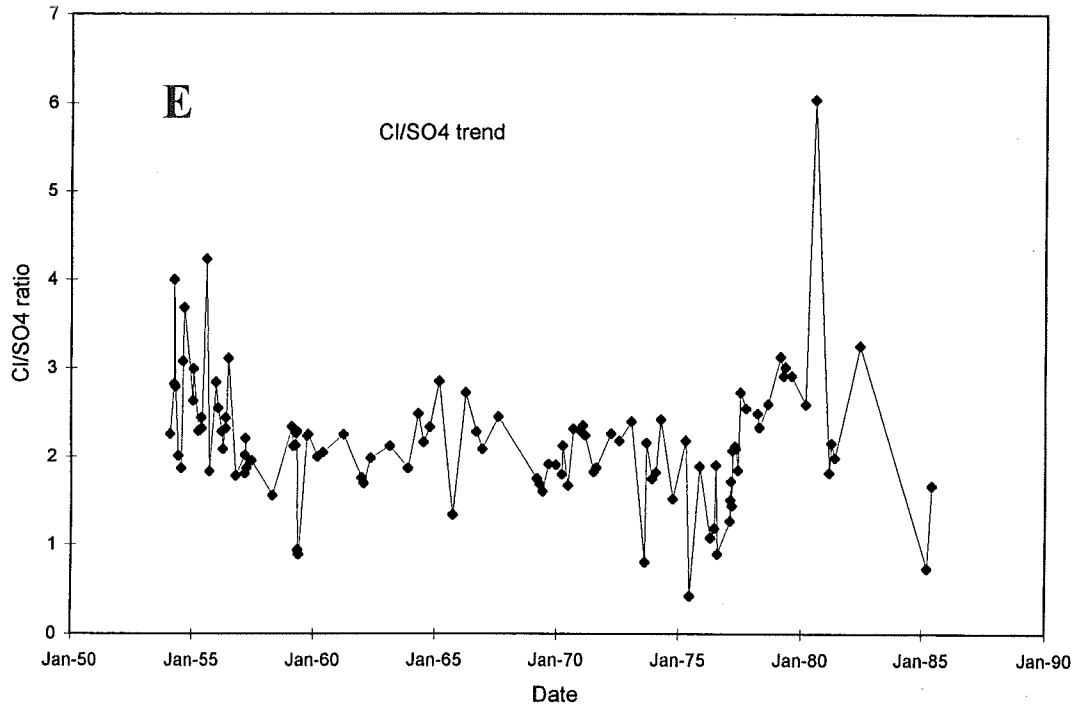


Figure 4. Water quality in the Safford Agricultural Center well, continued.



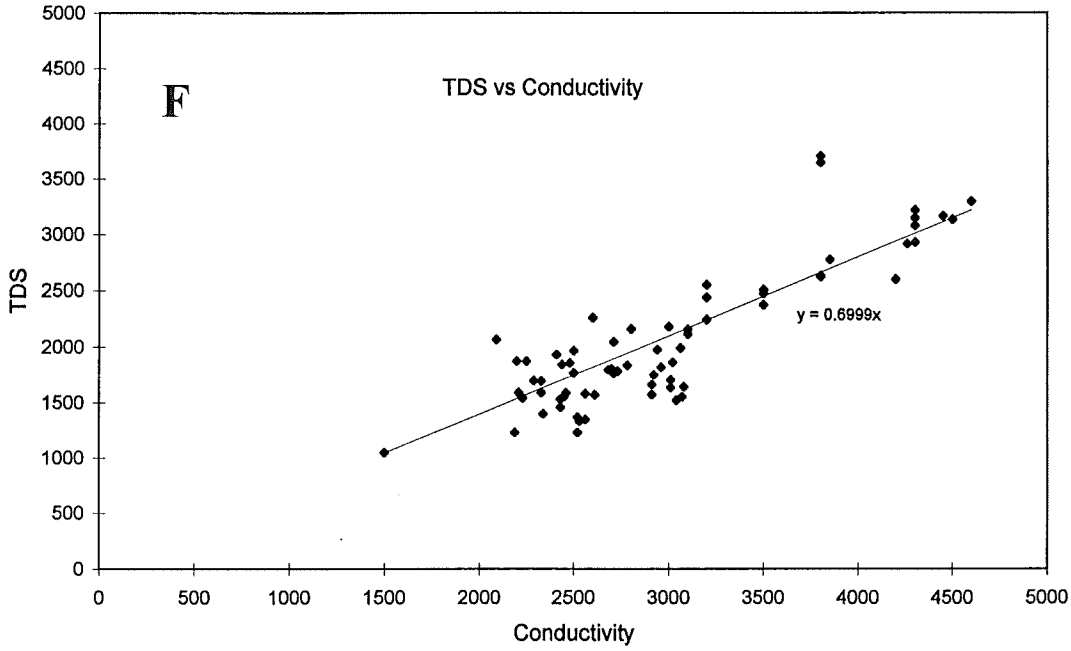
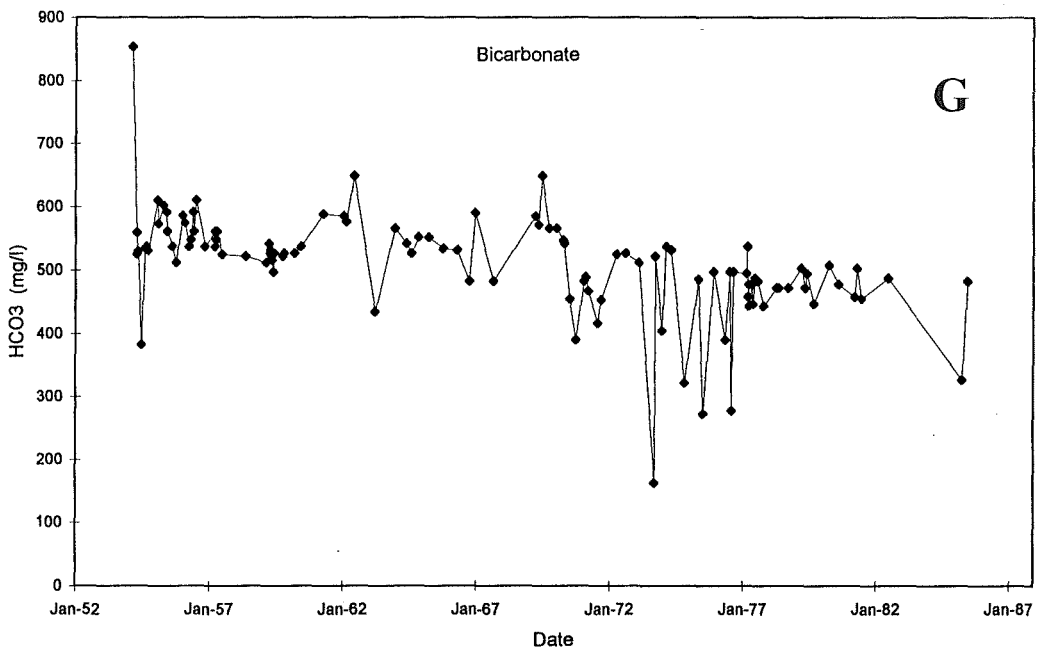
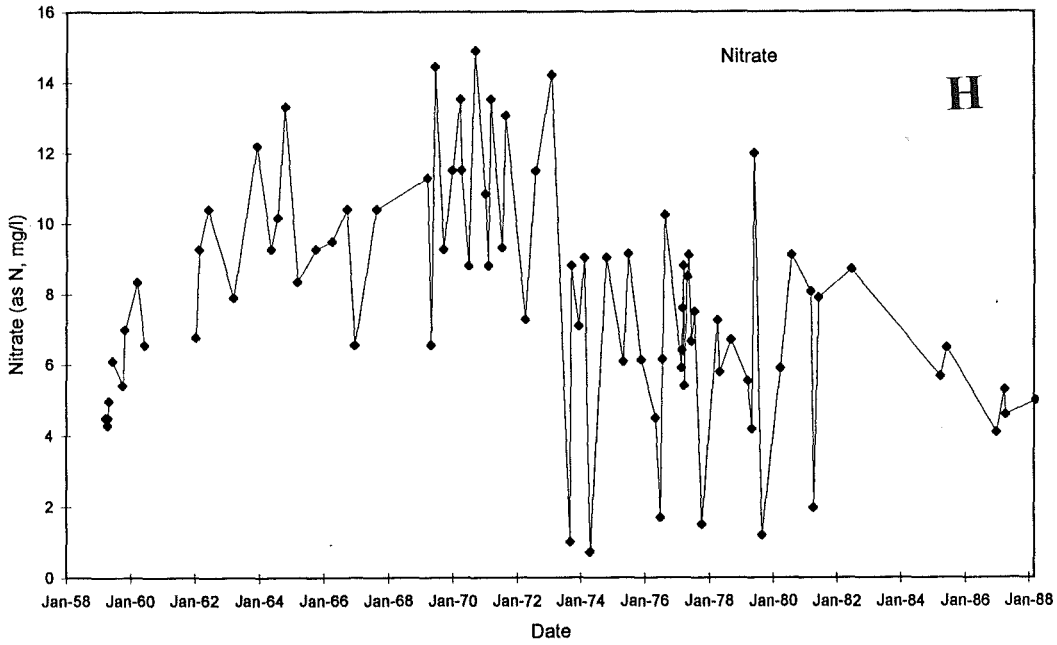


Figure 4. Water quality in the Safford Agricultural Center well, continued.





US Geological Survey data

Analytical data for groundwater in Arizona are recorded in a database available from the US Geological Survey Water Resources Division in Tempe. Data from numerous springs and thousands of wells are recorded and the database can be searched for desired parameters.

Data from wells with the longest monitoring periods were requested from the USGS and seven wells were selected by them that fit the criteria. USGS data for the wells are presented in Tables 5 through 11, and graphs showing the chemistry of water in the wells are shown in Figures 5 through 11. Statistical analysis of water quality trends has not been performed and any reference to discernible trends is based on visual inspection only. The wells are listed from south to north.

Well D(10-27)28dcd

Well D(10-27)28dcd is a stock well located about six miles SW of Tanque. The well head is at an elevation of 3760 feet (the USGS database figure of 3726' is the elevation of the nearest section corner, ¼ east). With a maximum TDS of 240 mg/l, the water is of excellent quality and is much lower in dissolved solids than wells closer to Safford. No obvious trend in water quality is seen in the graphs. Data for the well are given in Table 5 and are plotted in Figure 5.

Well D(9-26)18dda

Well D(9-26)18dda is located about four miles south of Artesia, near the east front of the Pinaleño Mountains. No depth is reported for the well, which is at an elevation of 3495 feet. Water in the well is quite low in dissolved solids, with a maximum reported TDS of 216 mg/l. A slight increase in TDS is due to an increase in sulfate, with other constituents showing no obvious trends. Table 6 lists chemical data for the well and this data is plotted in Figure 6.

Well D(7-26)15bcc

Well D(7-26)15bcc is just east of the town of Safford, about one mile north of the SAC well. The well is 86 feet deep with a surface elevation of 2939 feet. Water quality is variable in the well (Table 7). The data can be interpreted to show either an overall decrease in TDS, or a moderate decrease in the earlier samples followed by a slight increase in the later samples (Figure 7). With as much variability as is shown in the data, ten sampling events over 14 years may not be adequate to define a long-term trend.

Well D(6-25)36cbb

Formerly known as the Mt. Graham Mineral Bath well, this 2161 foot-deep well was drilled in 1957. A flood in 1978 destroyed the spa, and the artesian water from the well then flowed freely at a rate of 500 to 600 gpm into the Gila River. Water from the Smithville well was hot (46°C, 115°F) and contained 5500 to 8292 mg/l TDS. Water quality (Table 8; Figure 8) was variable over the sampling period, despite the depth of the well. The well was plugged and abandoned in 1997 by the Smithville Canal company, owner of the well.

Well D(6-24)13abd

Well D(6-24)13abd is the 3,767 foot-deep Underwriters Syndicate #1 Mack oil exploration well, also known as the Mary Mack, drilled in 1927-1929. A detailed account of the history of this well, northwest of Pima, is spelled out in the Safford *Graham Guardian* and other regional newspapers. Chemical analyses for the well are presented in Table 9 and are graphed in Figure 9.

TDS was measured by Knechtel (1938) at 3351 ppm and by Hem (1950) at 3400 to 3530 ppm, with a water temperature of 59°C (138°F). Records show a decrease in the flow rate in the Mary Mack over time, part of which is probably the result of loss of integrity of its casing. In

1933, several years after abandonment, the well was flowing at 5 cfs (2250 gpm)(Knechtel, 1935, 1938). Hem reports artesian flow of 1550 gpm in 1940, and USGS measurements indicate a flow rate of 1550 gpm in 1952 to 1000 gpm in 1957. Calculations based on flow rate and salinity put the salt load from this well at about 12,000 tons of TDS per year when the well was flowing. Assuming all of this salt ended up in the Gila River, this one well would have accounted for 11.4% of the total salt load of 105,000 tons in the Gila River at Bylas for the year 1944, reported in Gatewood and others (1950, p.64)

The well was drilled starting July 26, 1927 and was completed to a depth of 3,767 feet in the spring of 1929, at which time the well was abandoned and left flowing. According to USGS data, the flow in the Mary Mack well decreased over time to about 1000 gpm by the 1970s. When the well was temporarily capped and then uncapped, sometime before 1979, the artesian flow stopped (Witcher, 1981b; Stone and Witcher, 1982).

Well D(5-24)31aaa

Well D(5-24)31aaa is immediately south of Eden road, west of the Gila River. The well is 58 feet deep with a surface elevation of 2740 feet. Water chemistry in the well is quite variable, making determination of trend difficult. Data is given in Table 10 and plotted in Figure 10.

Well D(4-22)35ada

Located southwest of Geronimo, this well is 75 feet deep, with a surface elevation of 2858 feet. Water data are presented in Table 11 and are plotted in Figure 11. Water quality was fairly constant until after 1961 when an upward trend began. The last sample, taken in 1975, shows a leveling-off or downward trend in dissolved constituents. The reason for the increase in TDS in the 1960s, followed by an apparent end or reversal of the increase is unknown.

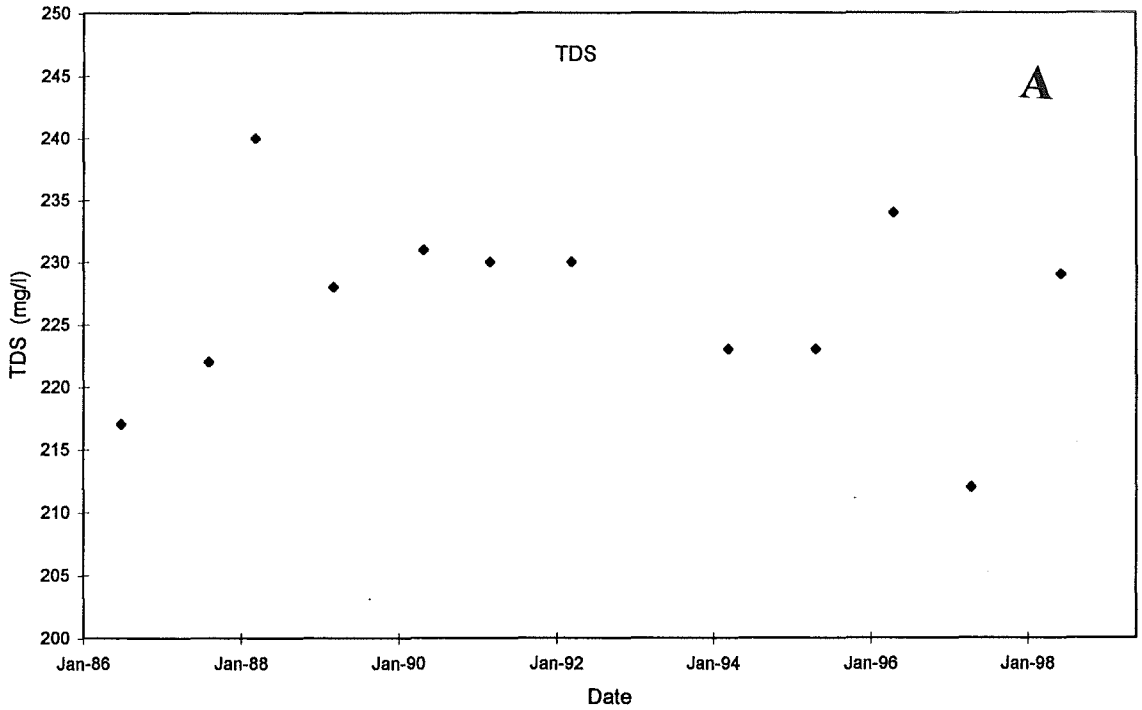
Table 5. Water quality data for well D(10-27)28dcd.

DATE	T (C)	Spec Cond	TDS	pH	ANC CaCO3	HCO3	PO4	ANC noncarb hard	Ca	Mg	Na	K	Cl	SO4	F	SiO2	ug/l B	Fe	NH4
7/2/86	26.5	345	217	9	126		0.06	126	2.3	0.07	73	0.7	9.3	17	4.9	34	190	35	
8/11/87	27	350	222	8.9	137			138	2.3	0.04	77	0.7	8.7	16	4	36	220	180	
3/15/88	25	360	240	8.8	143		0.06	141	2.2	0.02	81	0.8	8.3	16	6.4	39	240	23	
3/9/89	26	358	228	8.7			0.09	127	2.7	0.11	75	0.8	12	29	3.6	28	130	66	
5/2/90	23	330	231	9.1	138		0.06	133	2.4	0.15	76	0.5	10	18	3.4	38	190	35	
3/5/91	25	350	230	9.1	137	140	0.06	135	2.2	0.1	81	0.8	9.8	13	5.4	35	220	14	0.01
3/17/92	24	340	230	9.1	138	130	0.06	142	2	0.14	76	0.7	9.9	14	6.6	37	240	14	
3/17/94	25.5	340	223	9.1	139	140	0.09	135	2.3	0.09	73	0.8	9.7	14	5.2	35	190	31	0.03
4/25/95	24.5	340	223	9	137	140	0.09	140	2.1	0.08	75	0.7	10	11	6.6	35	200	27	0.04
4/17/96	26	342	234	9.1	136	140	0.09	139	2.1	0.08	81	0.7	7.8	13	6.3	41	230	19	0.04
4/15/97	23	351	212	8.8	130	120	0.08	129	2.2	0.08	73	0.71	11	18	4	34	174	57	0.03
6/3/98	26.5	353	229	8.9	136	140	0.12	140	2.1	0.08	78	0.57	8	13	5.1	40	228	30	0.04

Depth 520 feet Lat 32-31'38" Lon 109-35'07" *Data from U.S. Geological Survey*

Note: Analysis of 180 mg/l Fe on 8/11/87 believed to be a typographical error - not included on graphs.

Figure 5. Water quality in well D(10-27)28dcd.



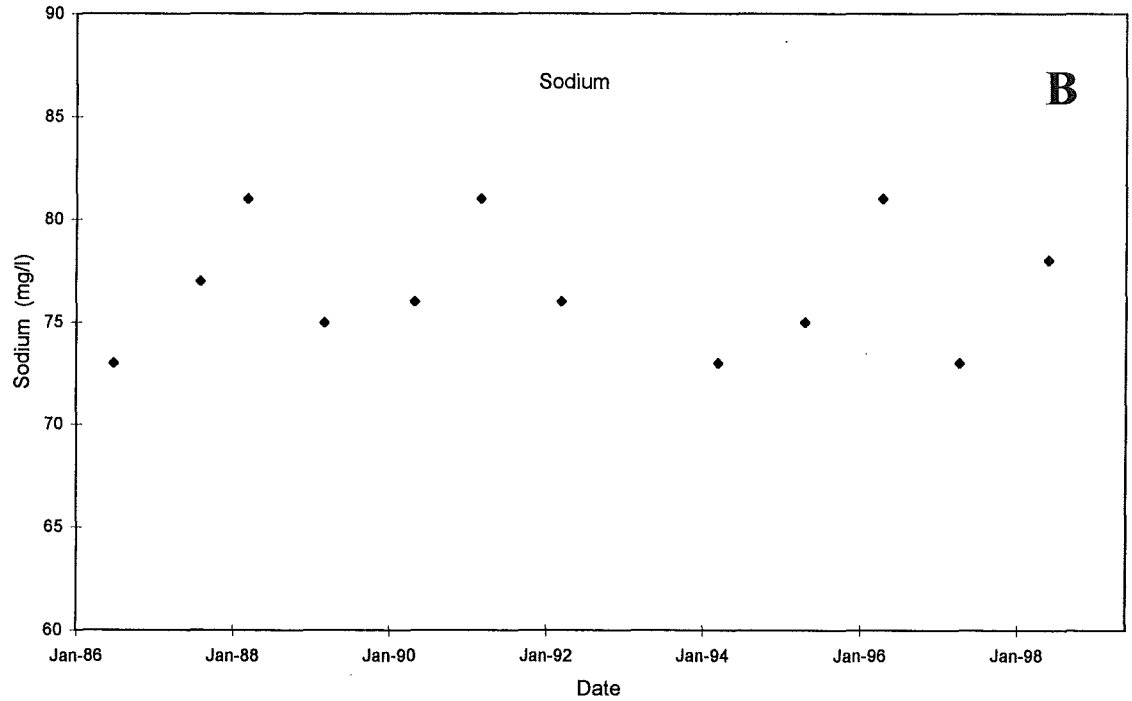
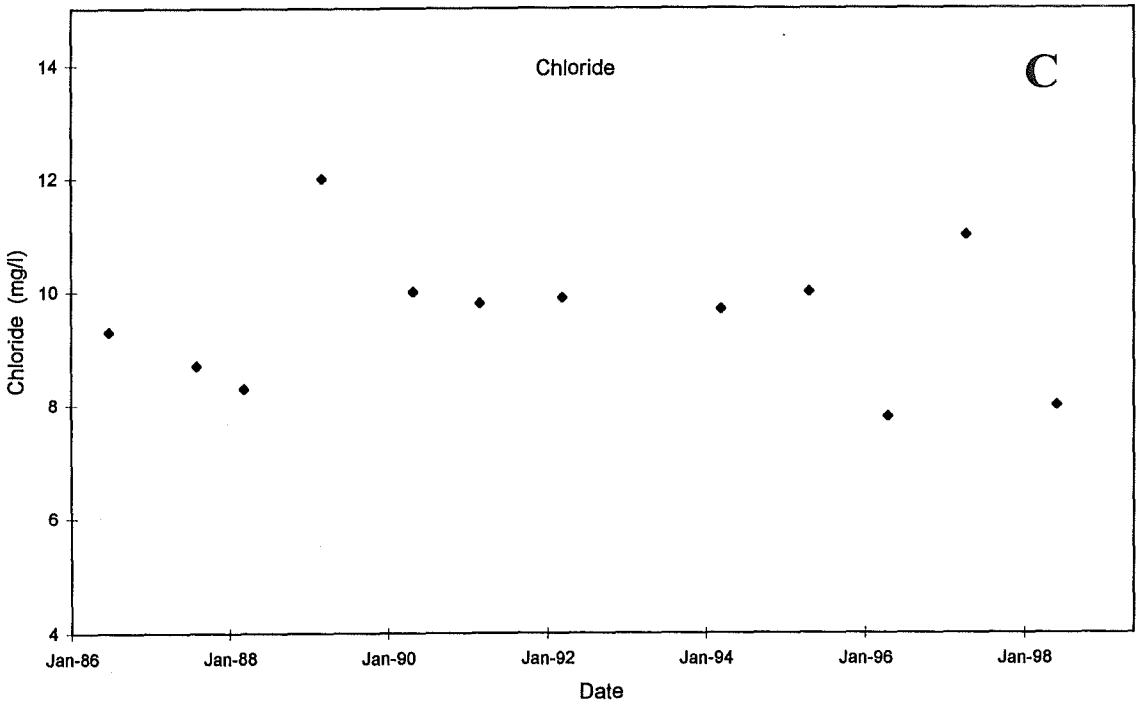


Figure 5. Water quality in well D(10-27)28dcd, continued.



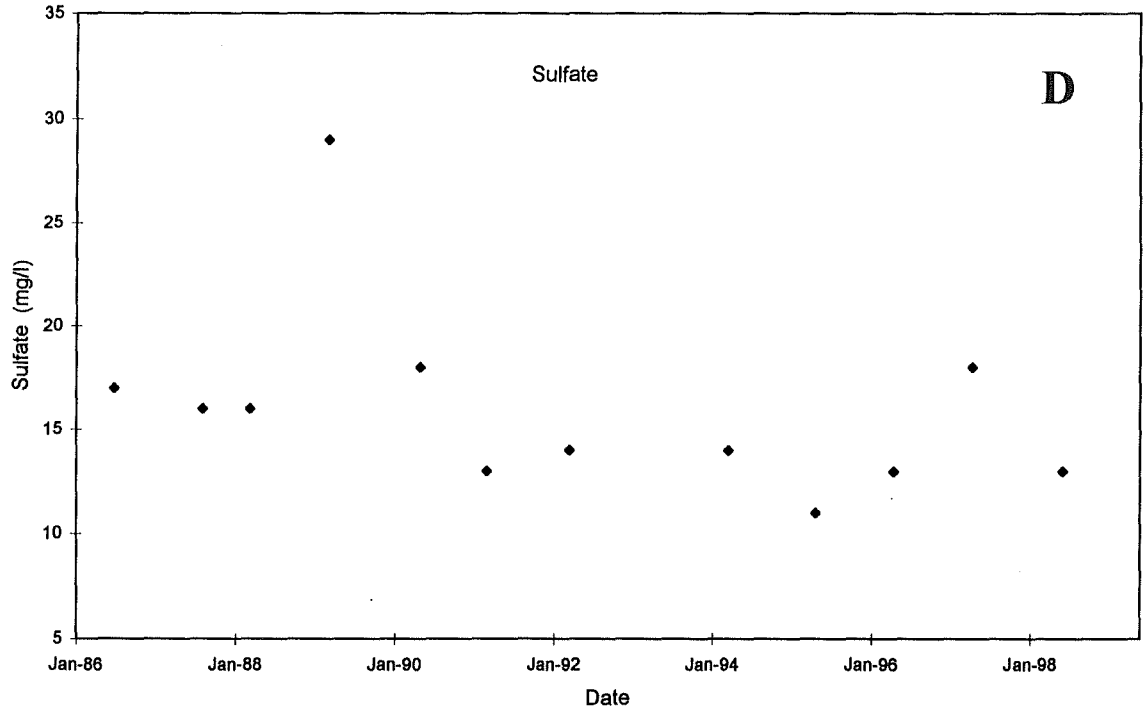
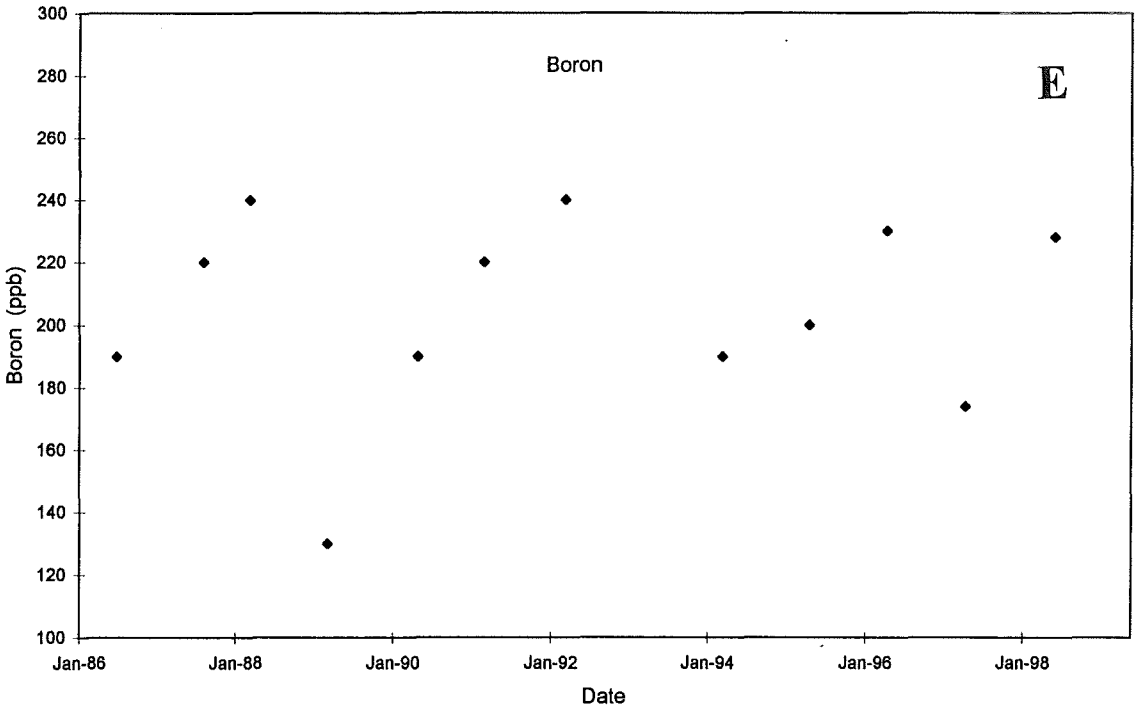


Figure 5. Water quality in well D(10-27)28dcd, continued.



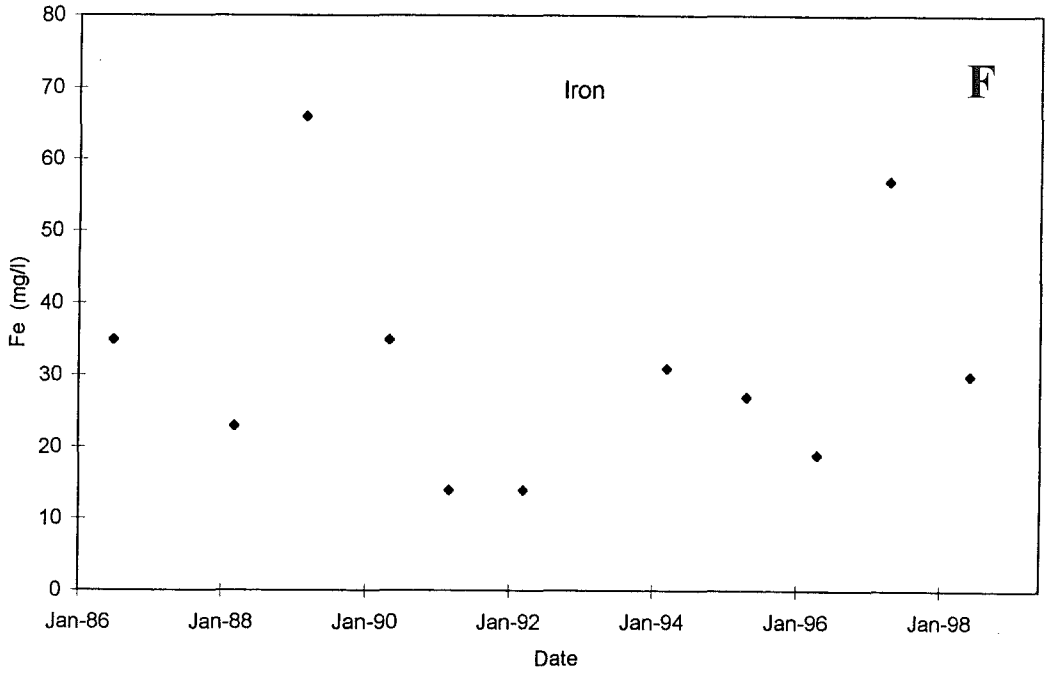
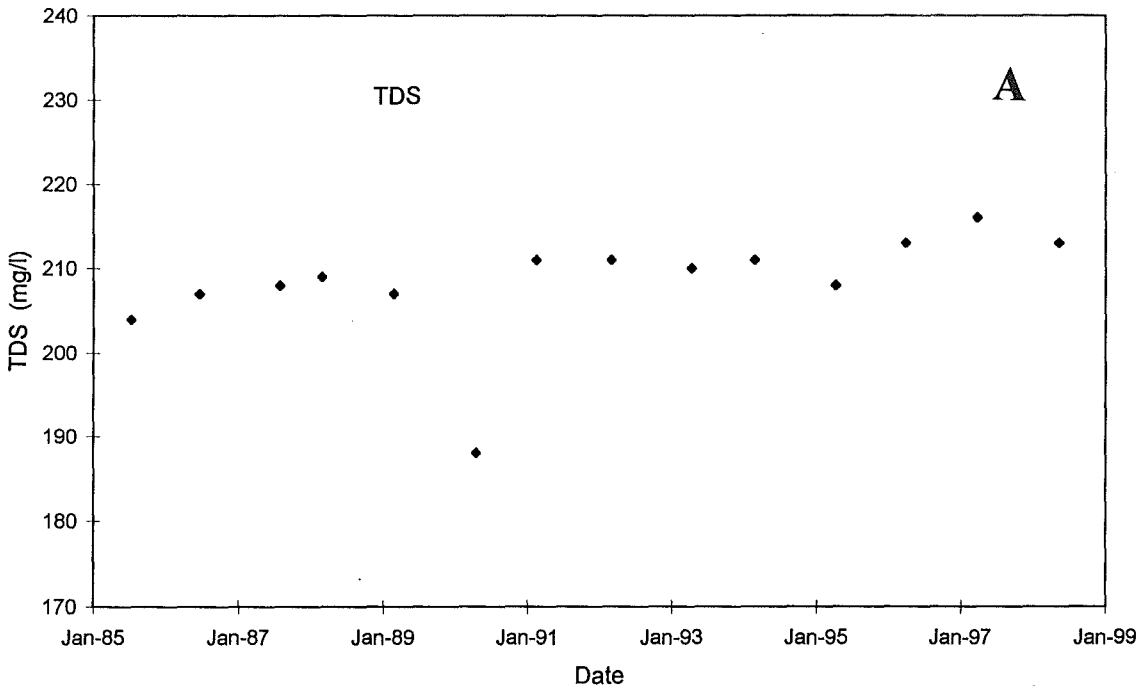


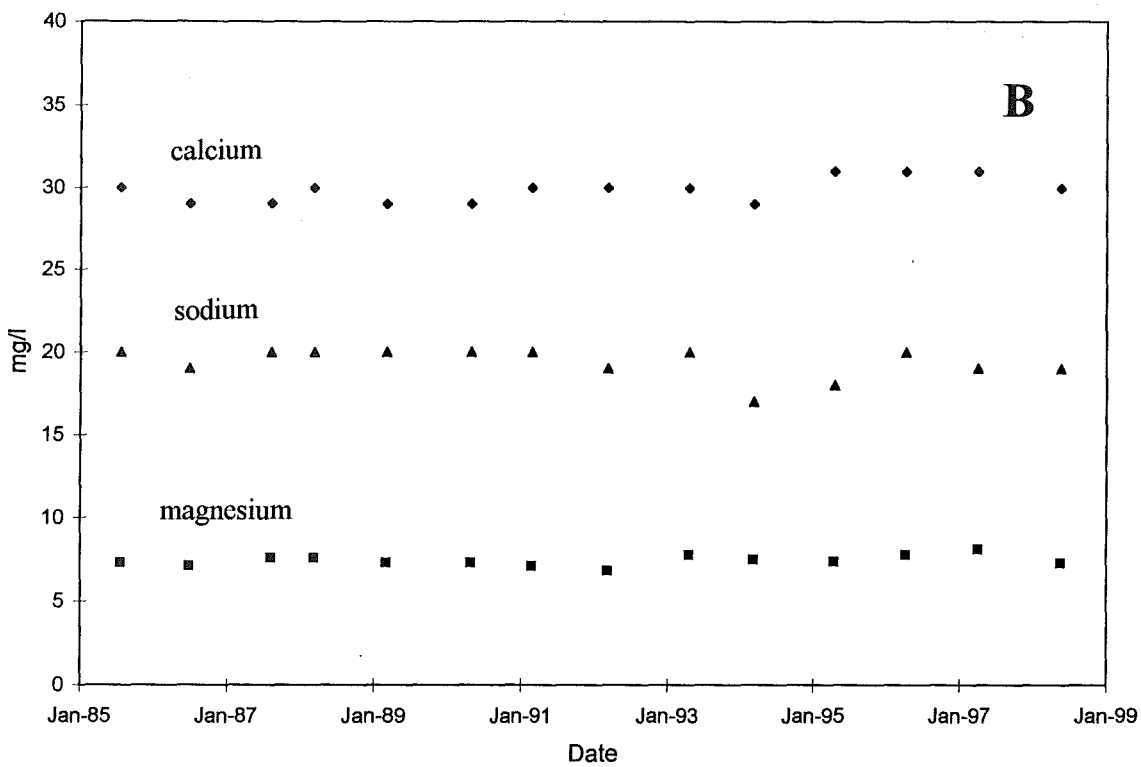
Table 6. Water quality data for well D(9-26)18dda.

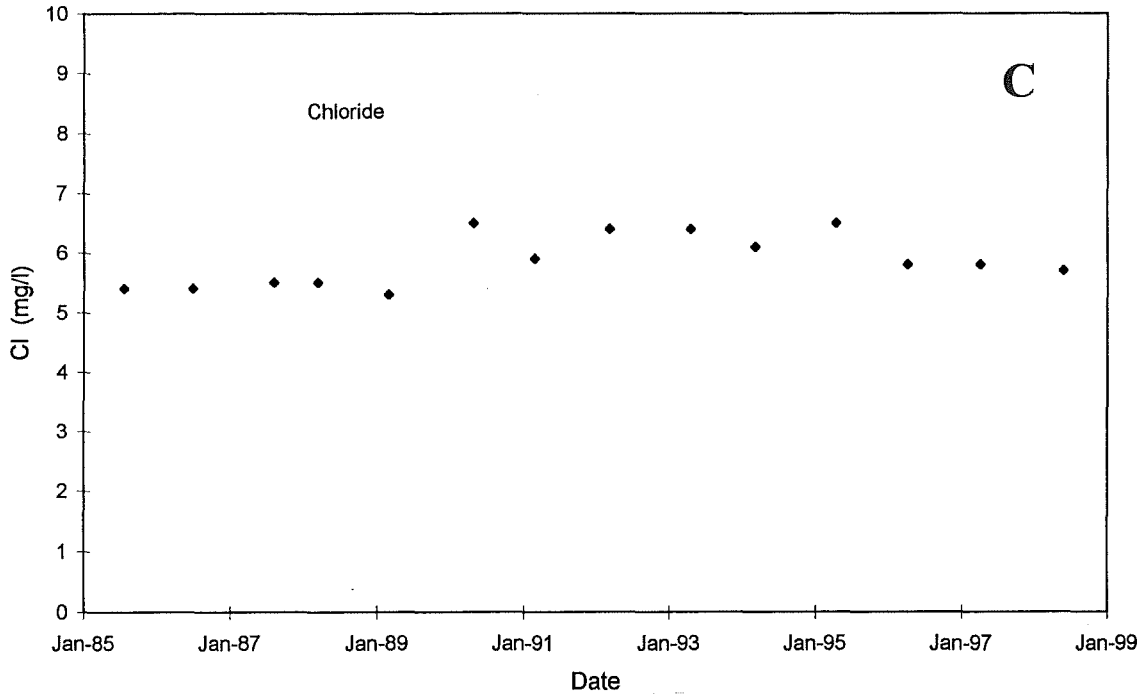
	T (C)	Cond	TDS	pH	ANC CaCO3	NH4 (N)	NO2 (N)	NO3 (N)	NO2+ NO3-N	PO4	Hard CaCO3	Ca	Mg	Na	K	Cl	SO4	F	SiO2	ug/l B	Fe	Mn	ug/l Zn
7/23/85	22	323	204	7.3	88				2.2		100	30	7	20	1	5.4	39	1	38	10	8	<1.0	
7/2/86	22	310	207	7.3	88				2.2	0	100	29	7	19	0.9	5.4	44	0.8	38	20	11	2	73
8/11/87	21	310	208	7.3	83				2.2		100	29	8	20	1	5.5	48	0.8	36	20	23	3	
3/15/88	21	310	209	7.0	83				2.2		110	30	8	20	1	5.5	46	0.8	39	20	11	6	
3/8/89	21.5	312	207						2.1		100	29	7	20	1.1	5.3	45	0.7	37	20	12	1	
5/2/90	22	280	188	7.1	80				2.2		100	29	7	20	0.8	6.5	26	0.4	40	20	6	1	
3/4/91	21.5	303	211	7.2	86	<.010	<.010		2.2		100	30	7	20	1	5.9	48	0.7	37	20	15	1	
3/17/92	21	300	211	7.1	85	<.010	<.010		2.1		100	30	7	19	1	6.4	49	0.7	38	20	14	1	
4/28/93	21.7	313	210	7.2	81	<.010	<.010		2		110	30	8	20	0.9	6.4	49	0.7	38	20	5	1	40
3/16/94	21	300	211	7.2	80	0.02	<.010		2		100	29	8	17	1	6.1	53	0.8	40	20	35	2	57
4/25/95	22	300	208	7.1	79	<.015	<.010		2	0.1	110	31	7	18	0.9	6.5	51	0.9	36	10	13	1	53
4/17/96	21.5	308	213	7.2	77	<.015	<.010		1.9		110	31	8	20	1	5.8	54	0.8	38	10	43	19	70
4/15/97	21.5	309	216	7.1	81	<.015	<.010		2.05	0	110	31	8	19	0.98	5.8	54	0.8	39	20	9.5	2.5	17
6/4/98	21	305	213	7.0	80	0.04	0.02	1.96	1.98	0	100	30	7	19	0.81	5.7	53	0.9	39	18	<10	<4.0	<20

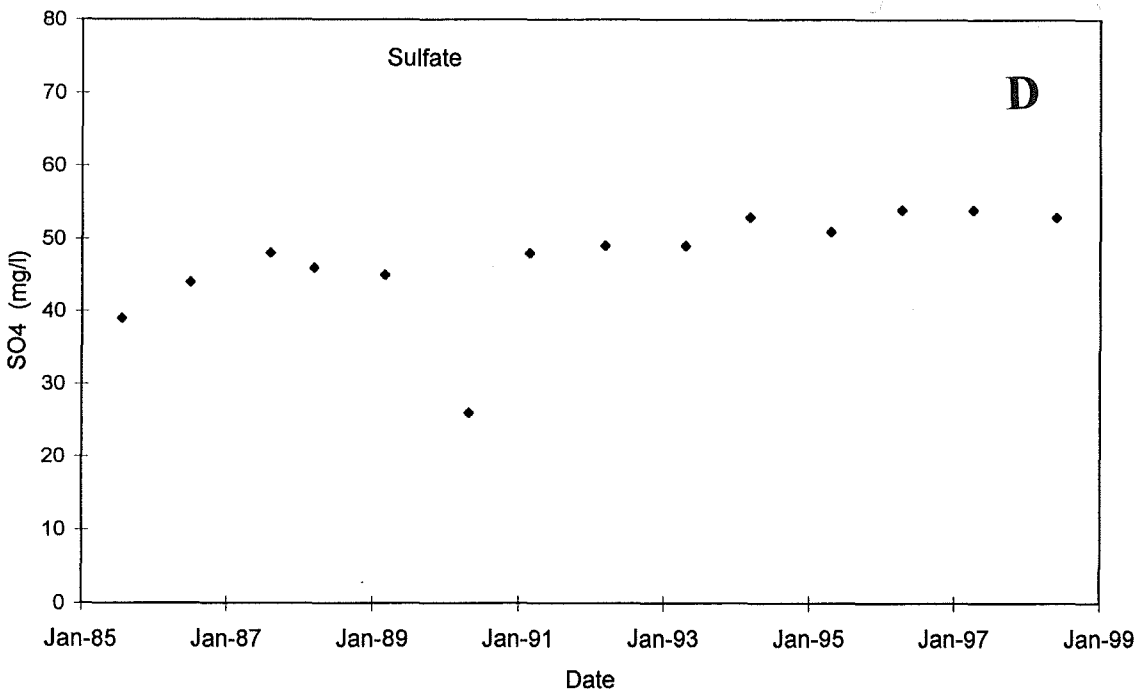
No depth reported Lat 32-38'50" Lon 109-43'07" *Data from U.S. Geological Survey*

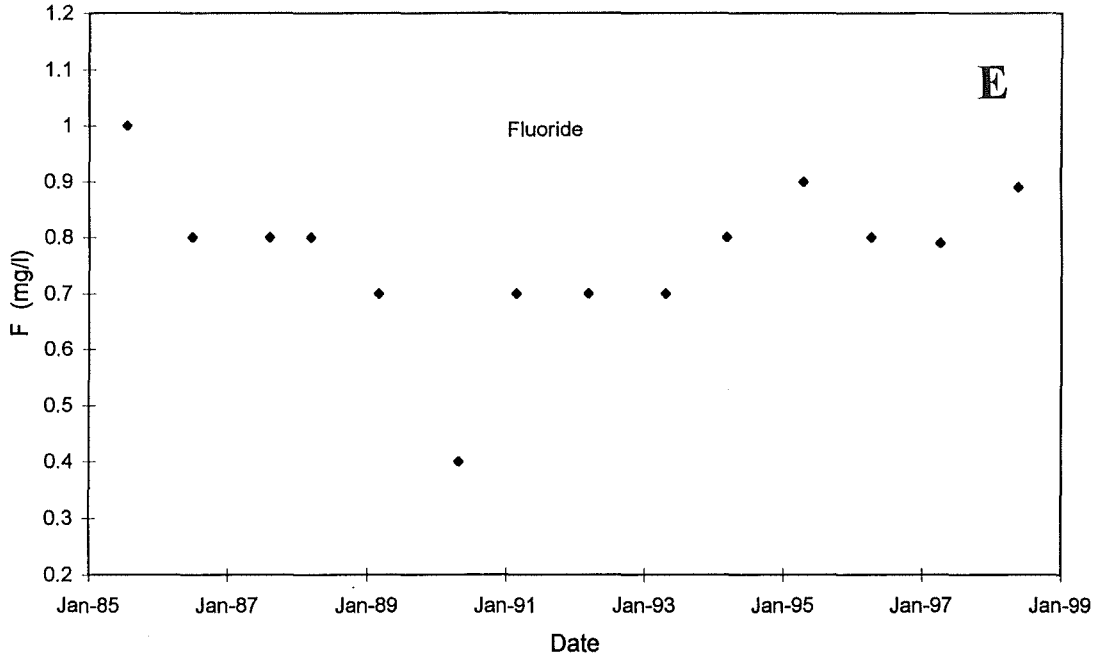
Figure 6. Water quality in well D(9-26)18dda.






C
Chloride
Cl (mg/l)
10
9
8
7
6
5
4
3
2
1
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


D
Sulfate
SO4 (mg/l)
80
70
60
50
40
30
20
10
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date


E
Fluoride
F (mg/l)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

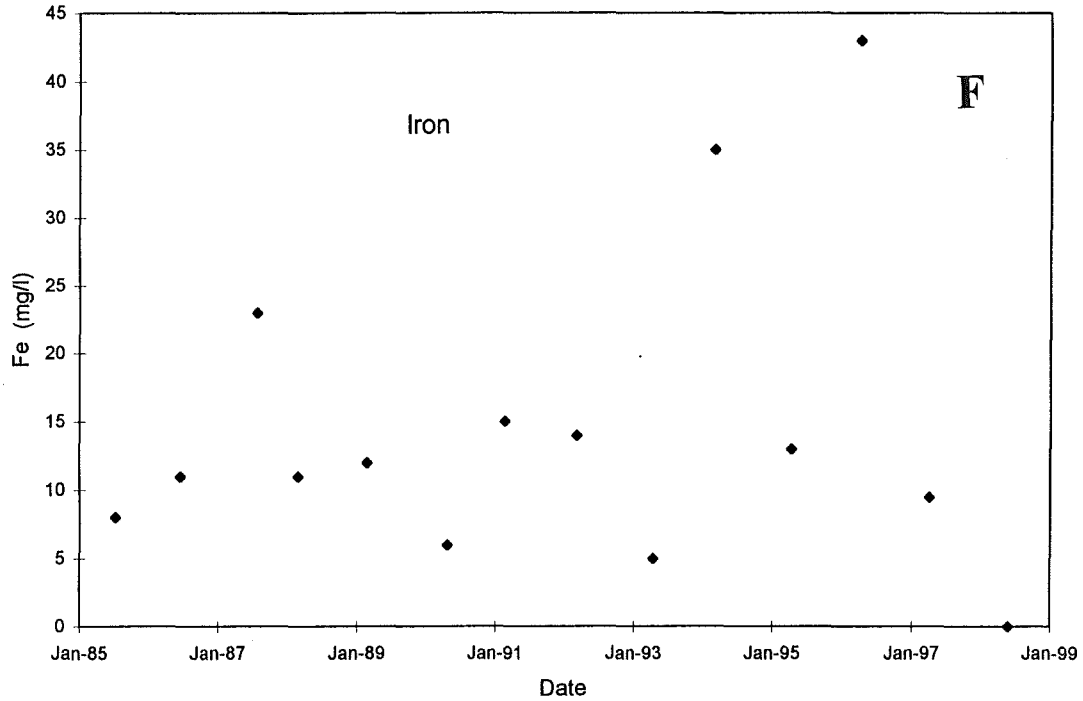
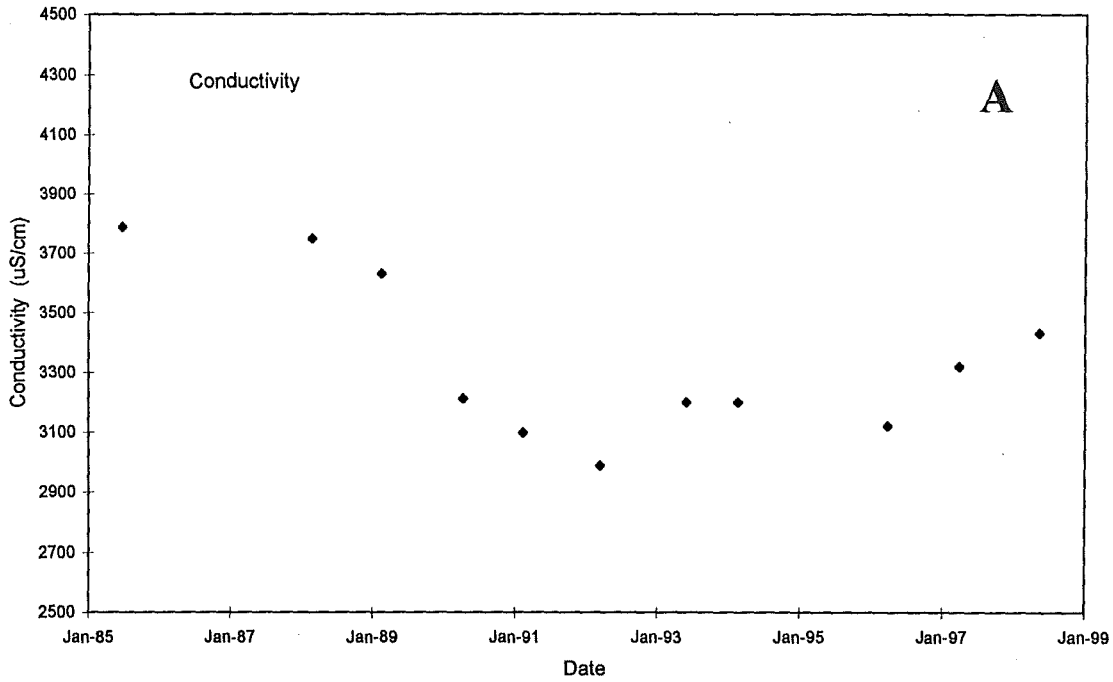

F
Iron
Fe (mg/l)
45
40
35
30
25
20
15
10
5
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Date

Table 7. Water quality data for well D(7-26)15bcc.

DATE	T (C)	Spec Cond	TDS	pH	ANC CaCO3	HCO3	PO4	P	Total Hard	ANC noncarb hard	Ca	Mg	Na	K	Cl	SO4	F	SiO2	B	Fe	N-NH4	NO3
7/16/85	19.5	3790	2310	7.4	463		0.09	0.03	420	451	120	29	720	7.4	680	380	4.2	56	440	<9.0		
3/15/88	19.5	3750	2110	7.3	455		0.12	0.04	350	463	100	25	660	7.7	540	420	4	50	750	20		
3/8/89	19.5	3630	2290	7.4			0.12	0.04	350	461	98	25	680	7	670	430	4.2	57	690	20		
5/1/90	19	3210	2060	7.5	459		0.12	0.04	320	448	89	23	640	6	590	350	2.6	55	740	20		
3/5/91	19	3100	1890	7.5	435	530	0.15	0.05	260	437	71	19	600	6.3	490	350	5	53	700	20		
4/3/92	19.5	2990	1810	7.1	419	510	0.15	0.05	270	415	75	20	550	6.3	500	330	4.7	43	700	<10	0.03	
6/23/93	19	3200	1950	7.5	417		0.12	0.04	280	346	79	20	590	6.3	550	360	4.9	52	770	10		
3/15/94	19	3200	2080	7.3	441		0.15	0.05	310	450	87	23	650	6.9	580	370	4.4	58	720	20	0.04	36
4/16/96	19	3120	1940	7.3	412		0.12	0.04	270	424	78	19	590	6	560	340	4.6	55	670	14		
4/15/97	19	3320	2060	7.3	434		0.16	0.05	330	443	92	24	618	6.5	580	370	4.1	55	714	21	0.02	
6/3/98	19	3430	2100	7.3	427		0.18	0.06	300	440	84	21	623	30	610	380	3.9	58	685	39	0.05	38

Depth 86 feet Lat 32-49'26" Lon 109-40'52" Data from U.S. Geological Survey

Figure 7. Water quality in well D(7-26)15bcc.



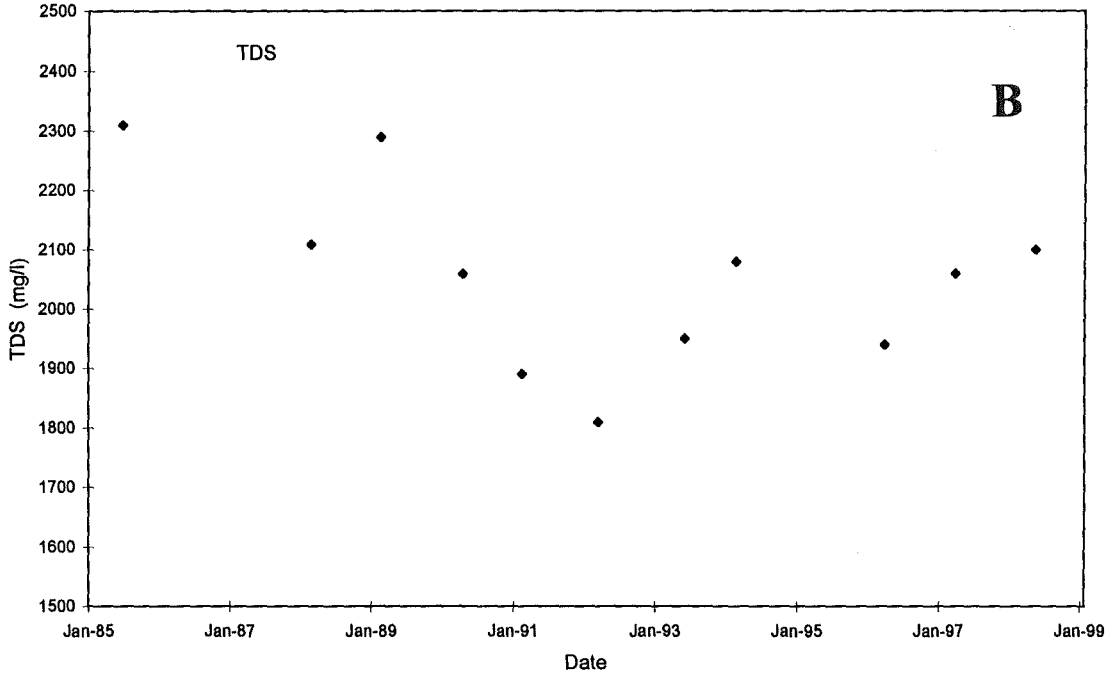
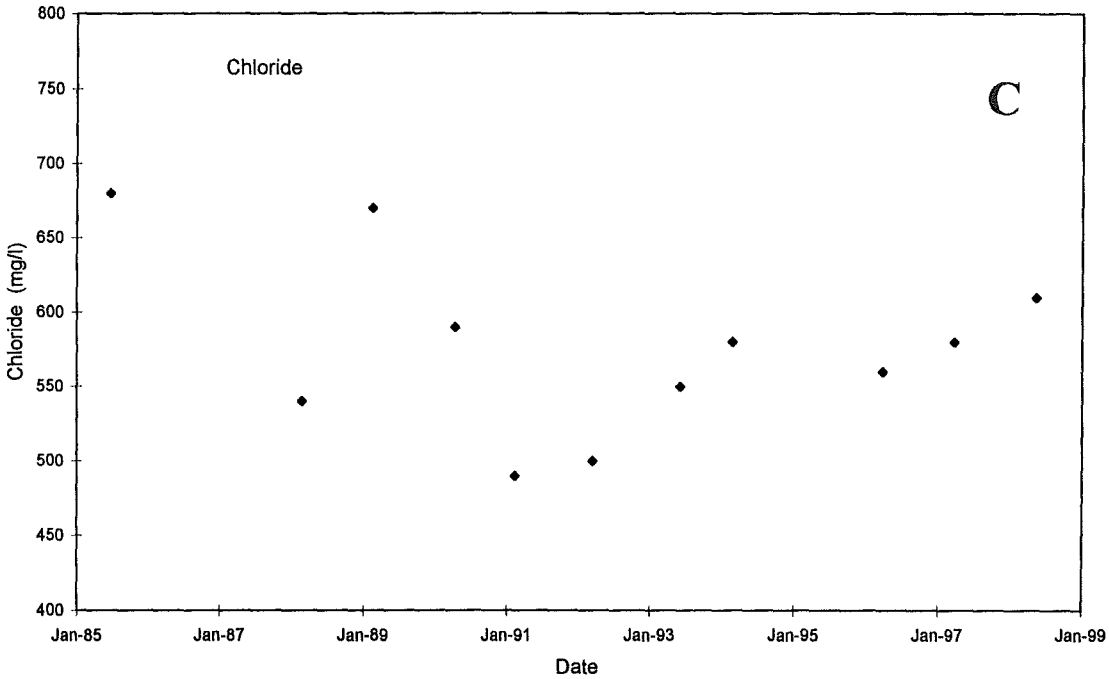


Figure 7. Water quality in well D(7-26)15bcc, continued.



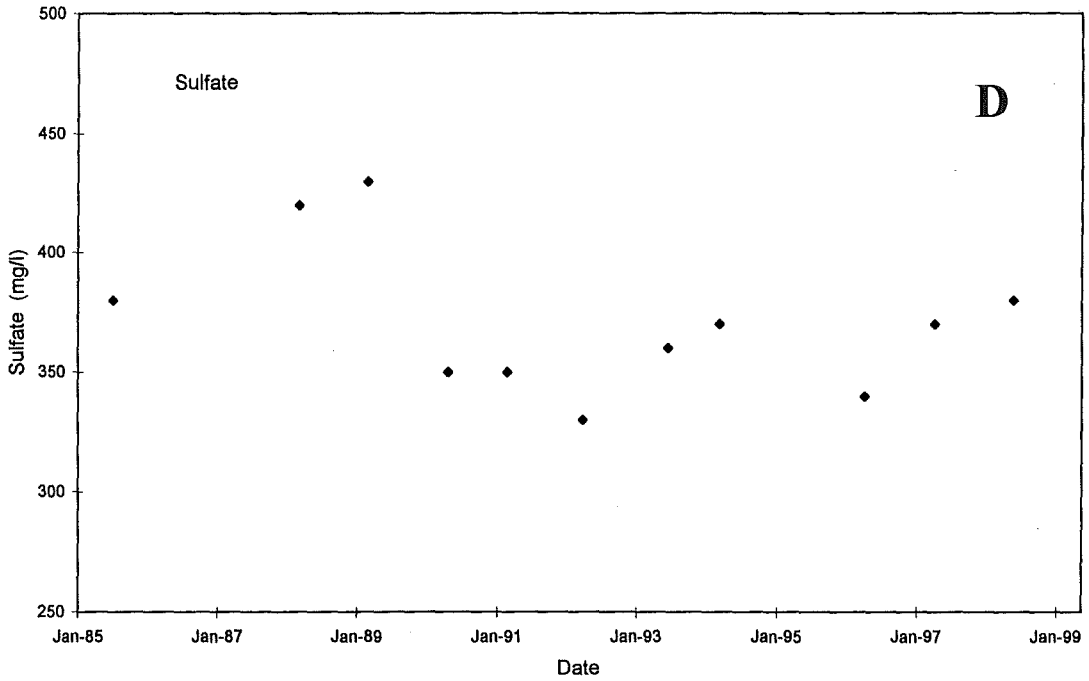
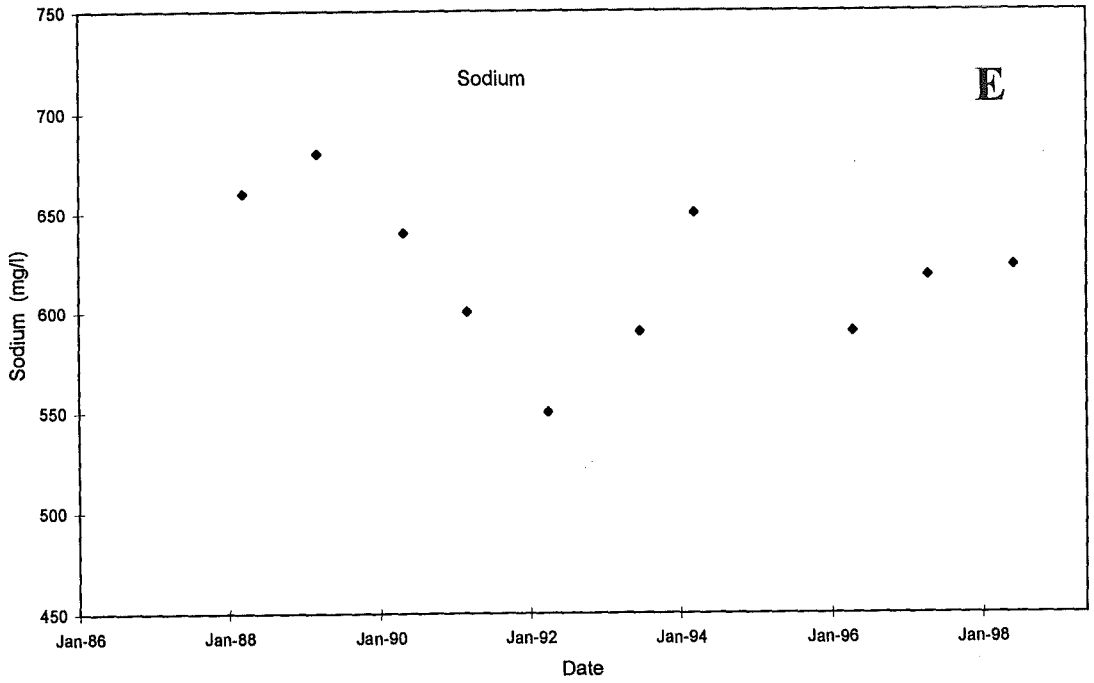


Figure 7. Water quality in well D(7-26)15bcc, continued.



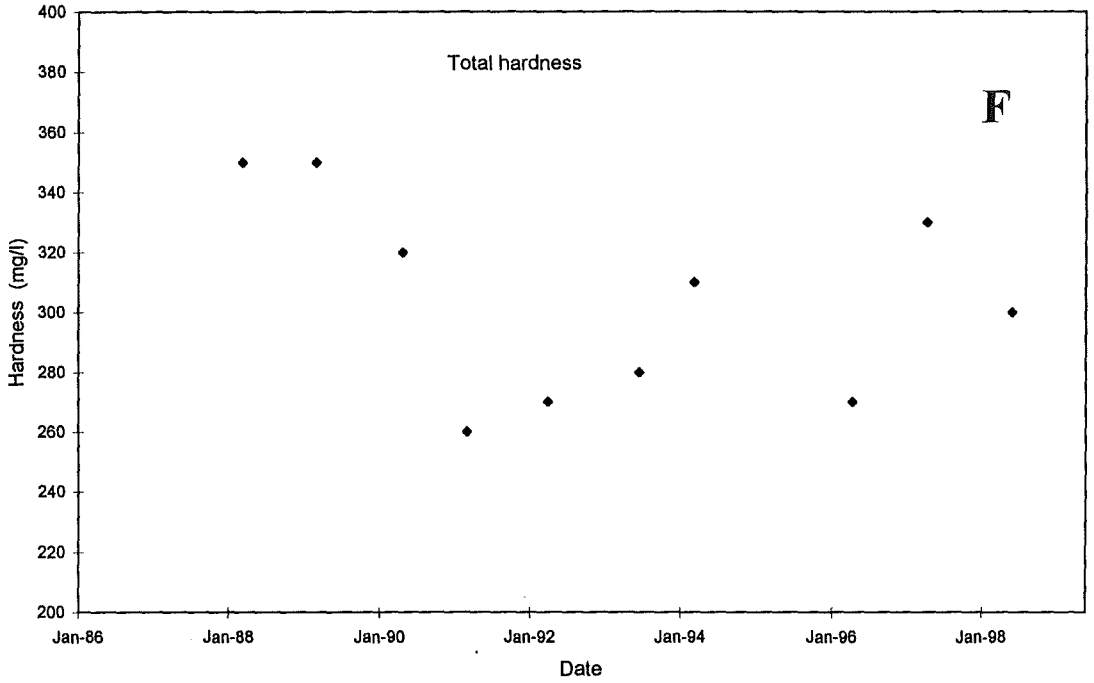
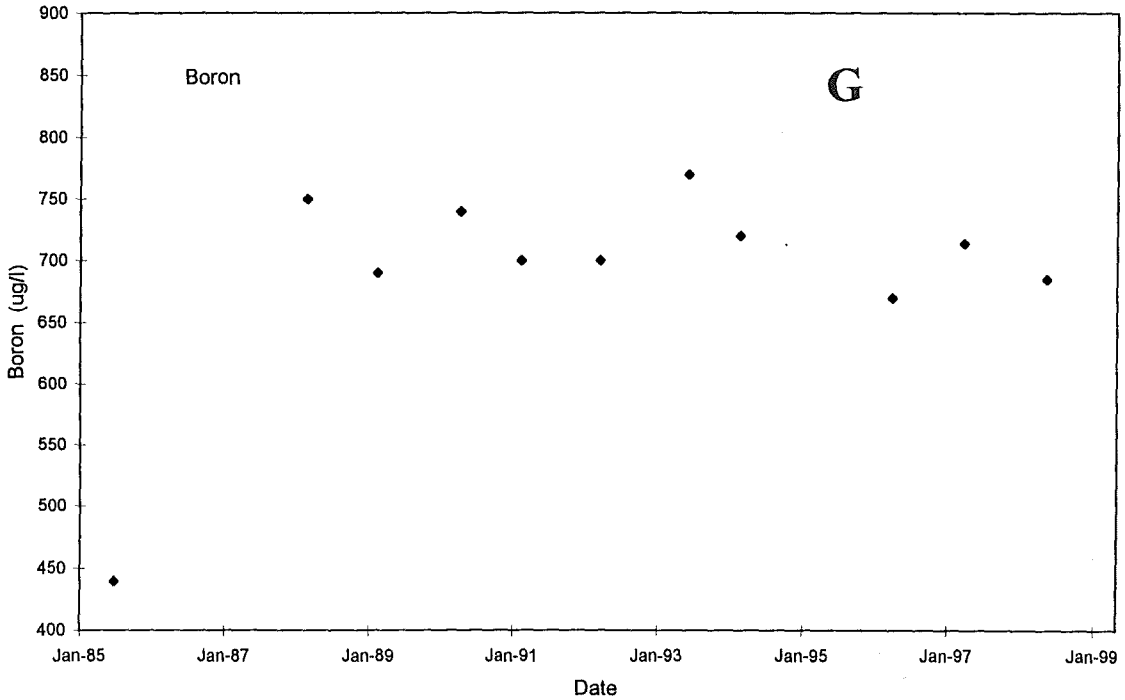


Figure 7. Water quality in well D(7-26)15bcc, continued.



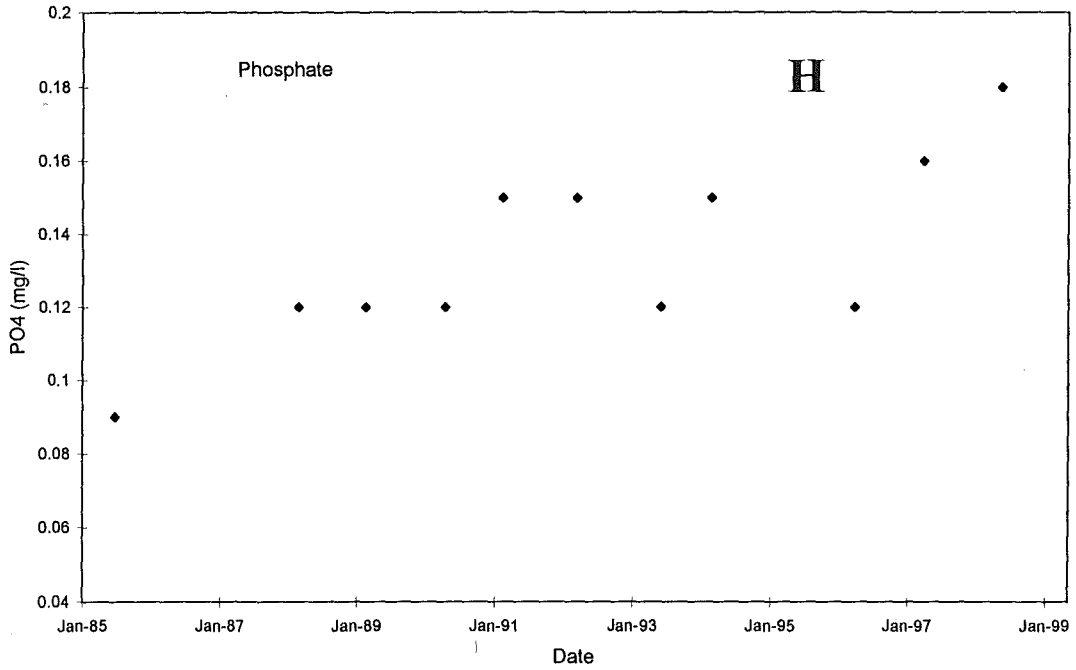
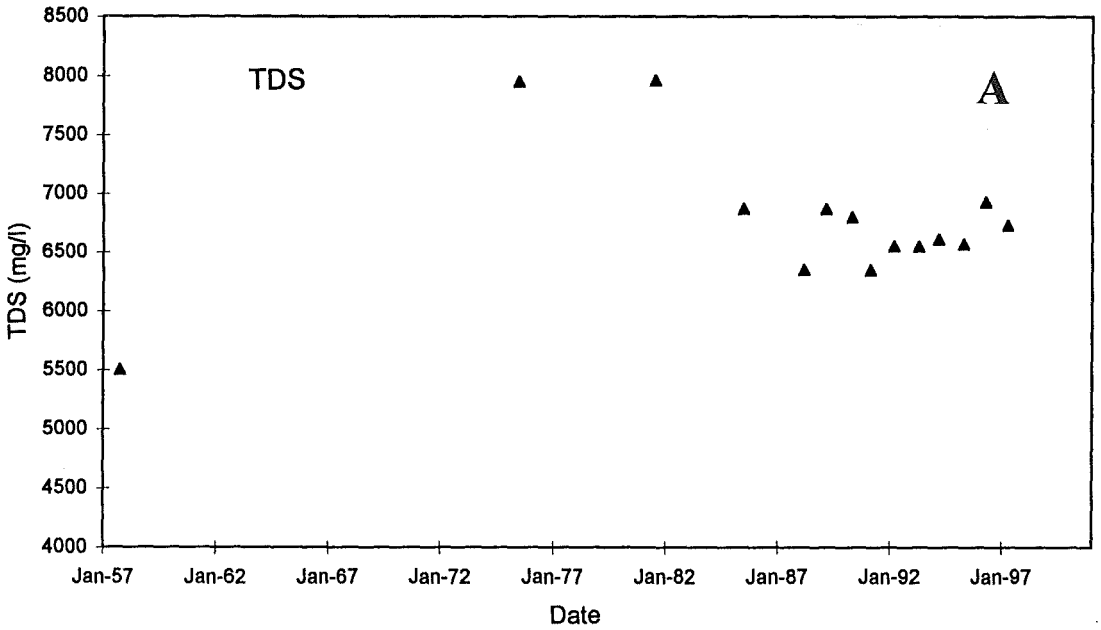


Table 8. Water quality data for well D(6-25)36cbb.

	T (C)	SPEC COND us/cm 90095	TDS mg/l 70301	pH (field) 00400	ALKAL-CACO3 mg/l 00410	ALKAL-CACO3 mg/l 90410	NO2+NO3 mg/l 00631	TOTAL HARD. CACO3 mg/l 00900	Ca mg/l 00915	Mg mg/l 00925	Na mg/l 00930	K mg/l 00925	Cl mg/l 00940	SO4 mg/l 00945	F mg/l 00950	SiO2 mg/l 00955	B ugL 01020	Fe ug/l 01046	Mn ug/l 01056
USGS Database:																			
10/15/57	46.0	8870	5500	9.4	134			370	130	12	1900		2500	730	7	121			
5/27/58	46.0	8620		8.8	107			330					2500						
6/18/63	46.5	8410			61			280					2400		8.8				
7/8/75			7950				0.03	340	120	8.7	2900	12	4100	710	6.8	53	1500	80	100
7/24/81		12100	7960	7.8			0.13	340	120	8.2	3000	10	4000	720	6.7	58	1500	140	110
7/16/85	46.5	11900	6870	7.4		59	<0.1	330	120	7.1	2500	10	3400	730	6.9	55	890	81	110
7/7/86	46.5	11000		7.9	62	64	<0.1					9.6	3500	700	8		1600		
3/15/88	46.5	11800	6350	7.9	63	64	<0.1		100	6.6	2200	9.6	3200	740	0.2	50	1300	100	100
3/8/89	45.5	11400	6870	7.9	64	64	<0.1	300	110	6.5	2400	9.2	3500	730	14	59	1400	50	110
4/30/90	46.0	11200	6800	7.8	65	64	<0.1	280	100	6.6	2300	9	3700	590	0.1	56	1600	50	100
3/4/91	45.0	11600	6350	7.7	65	63	<0.05	280	99	6.9	2400	10	3000	730	7.8	54	1600	30	110
3/17/92	47.0	11800	6550	7.9	65	65	<0.05	300	110	7	2300	6.9	3300	730	6.9	50	1600	20	100
4/28/93	46.4	11400	6550	7.8	64	64	<0.05	330	120	6.8	2400	9.1	3200	710	7.1	57	1500	80	110
3/15/94	46.0	11500	6610	7.7	64	65	<0.05	300	110	6.7	2300	9.9	3400	680	6.9	61	1500	40	90
4/26/95	46.0	11400	6570	7.8	62	66	<0.05	300	110	6.3	2400	11	3300	640	7.9	57	1500	50	100
4/17/96	46.5	11300	6930	7.9	63	66	<0.05	300	110	6.7	2500	10	3500	700	7.1	58	1700	66	100
4/15/97	47.0	11300	6730	7.7	66	65	<0.05	320	110	7.3	2380	8.8	3400	700	6.6	58	1580	<30	106
Swanberg et al, 1977:						HCO3													
	43.5		8292	7.85		80.5			135	7.9	3027	10.9	4517	787	7.2	65.8	1.65	0.24	
Mariner et al, 1977																			
	42		7436	7.58		103			110	10	2600	11	3800	680	6.4		1.4	<0.02	0.09
Stone and Witcher, 1982																			
	46		6286	6.8		64			64	7.6	1390	13.1	4011	672	6.7	55	0.6		

Depth 2161 feet; Plugged and abandoned, 1997 Lat 32-52'00" Lon 109-44'56"

Figure 8. Water quality in well D(6-25)36cbb.



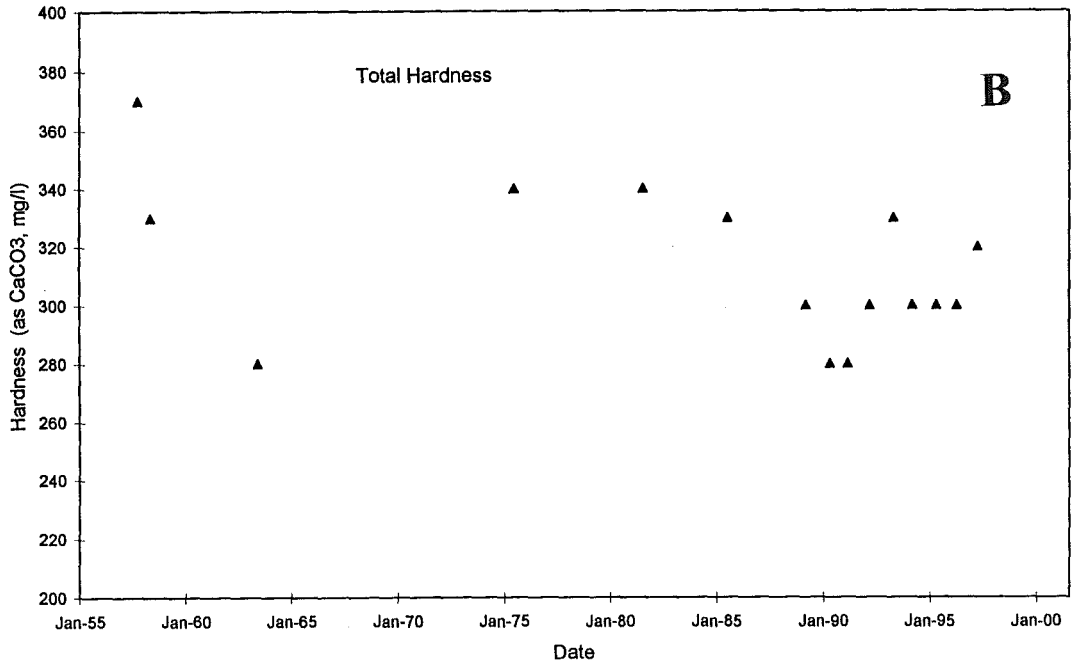
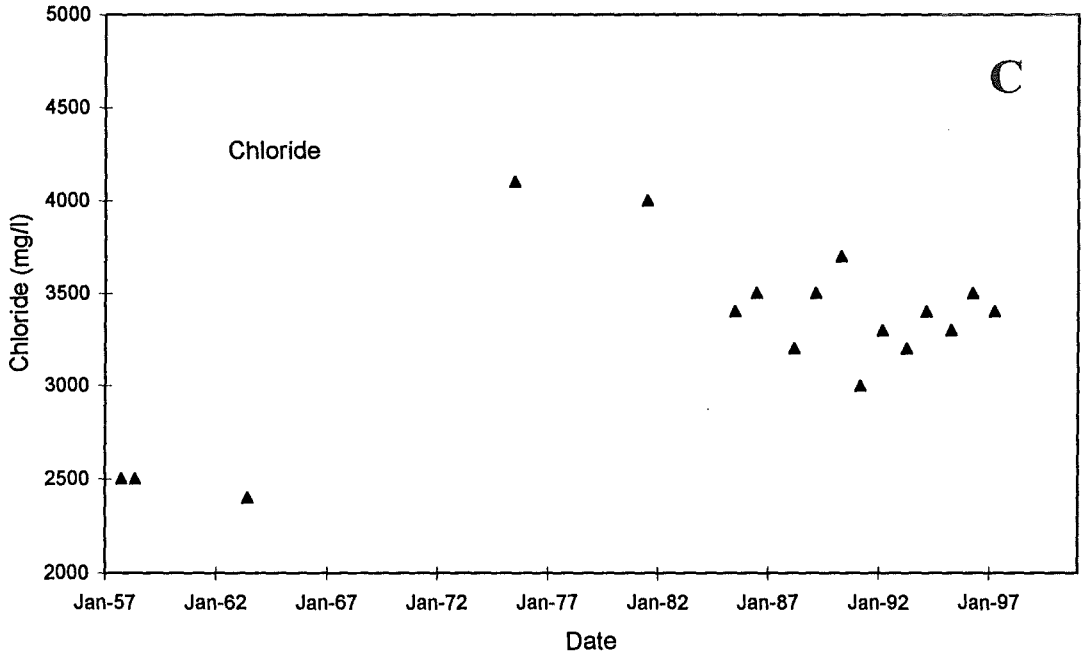


Figure 8. Water quality in well D(6-25)36cbb, continued.



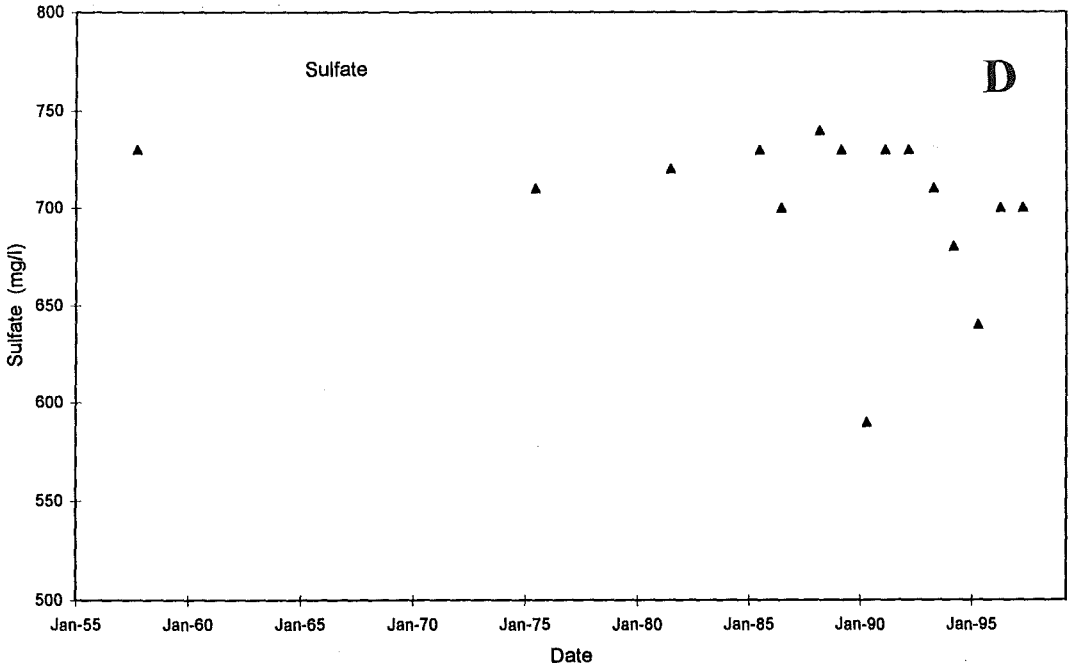
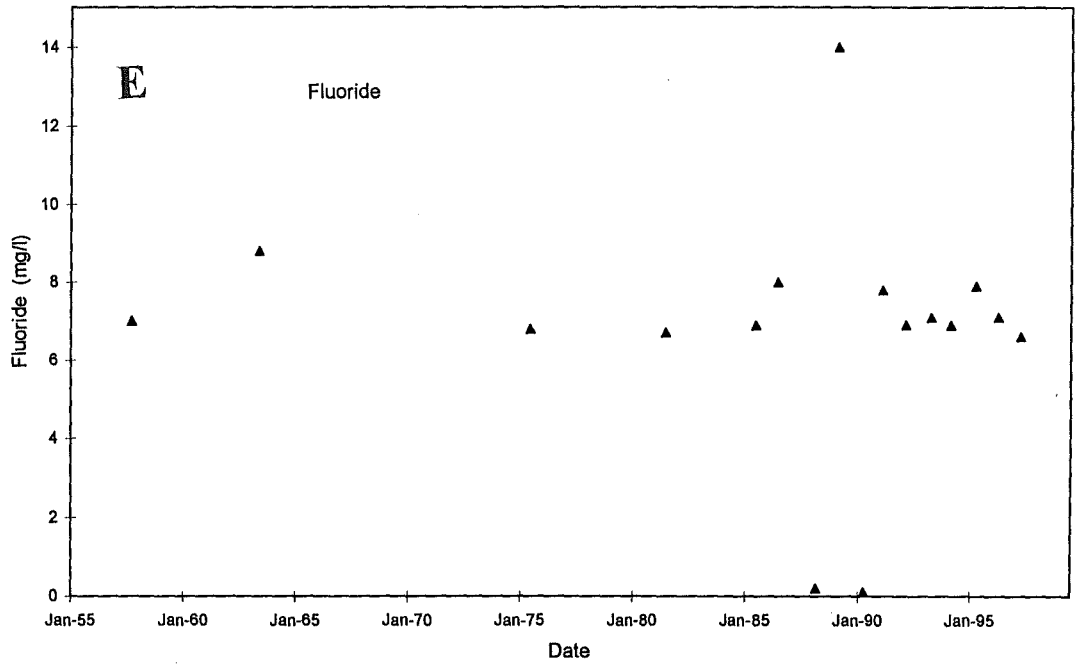


Figure 8. Water quality in well D(6-25)36cbb, continued.



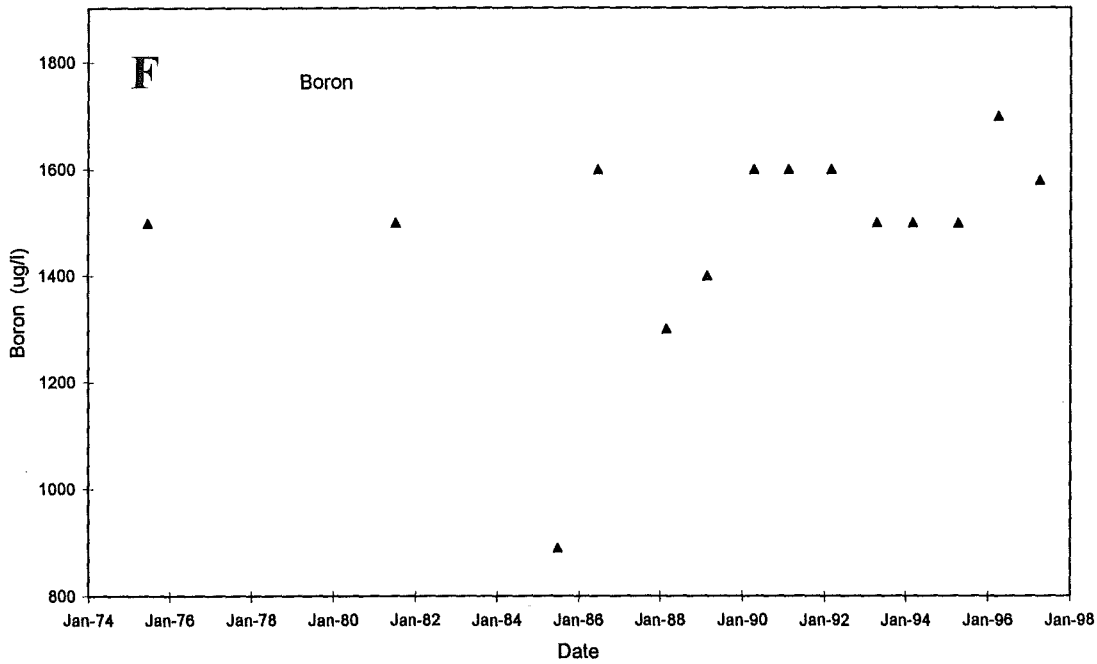
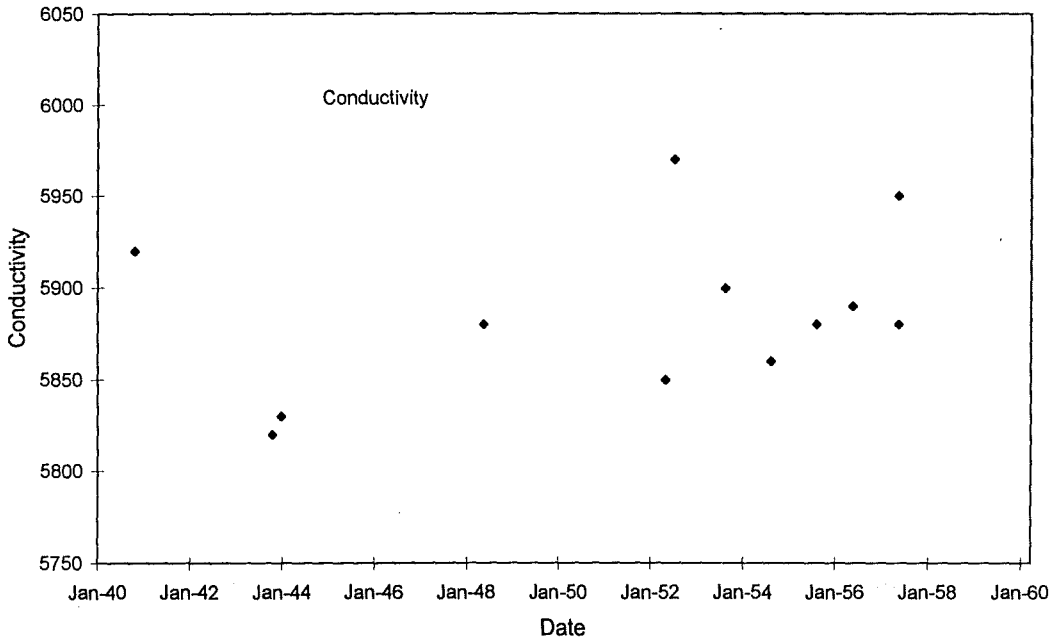


Table 9. Water quality data for well D(6-25)13cbb.

Date	T (C)	Flow gal/min	Spec Cond	TDS	pH	ANC CaCO3	HCO3	Total Hard	Non Carb Hard	Ca	Mg	Na	Na+K	Cl	SO4	F	SiO2	B	tot N NO3
(USGS database)																			
5/20/48	58	1300	5880		7.8	82	100							1700			54	<10	
5/8/52	59	1550	5850	3420	7.7	83	100	210	120	71	7		1200	1600	410	5.2	47		1.9
7/14/52	59	1500	5970			83	100							1600					
8/20/53	58		5900			94	120							1600					
8/17/54	58	1000	5860			81	99							1600					
8/15/55	58	1500	5880		8.2	92	110							1700					
5/29/56	58	1150	5890		8.1	82	100							1600					
5/21/57	58	1000	5880		7.5	89	110	250	160										
5/21/57	58	1000	5950		9.4	170	49	210	38			953		1600					
(Hem, 1950)																			
10/30/40	59	1550	5920	3530			101	220		74	8.7		1220	1660	416	6		1.3	
10/27/43			5820	3400			98	218		72	9.2		1210	1640	416	5.8		0.1	
1/5/44			5830											1650					
6/21/44			5480											1630					
(Stone and Witcher, 1982)																			
	58.9			3530						74	8.7		1220	1660	416	6		7	

Depth 3767 feet Lat 32-54'53" Lon 109-50'23"

Figure 9. Water quality in well D(6-24)13abd.



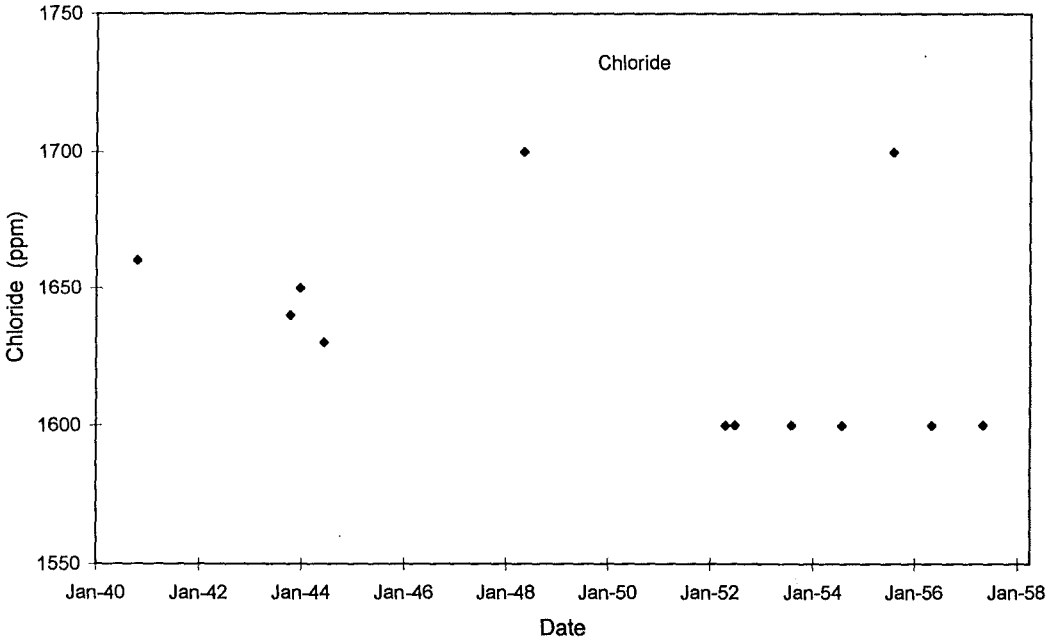
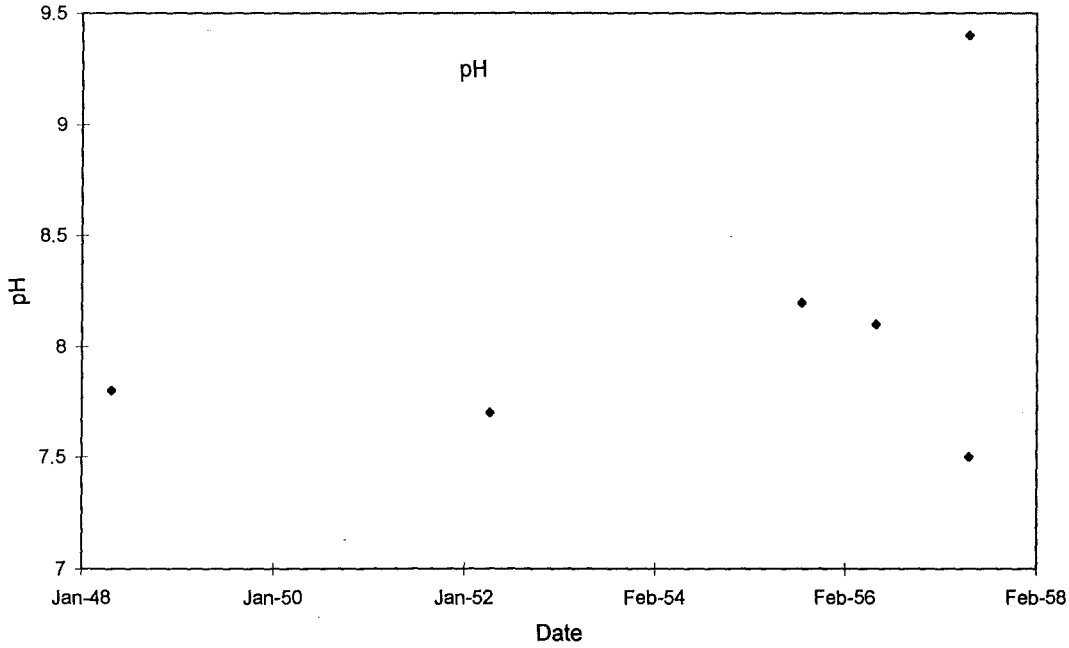


Figure 9. Water quality in well D(6-24)13abd, continued.



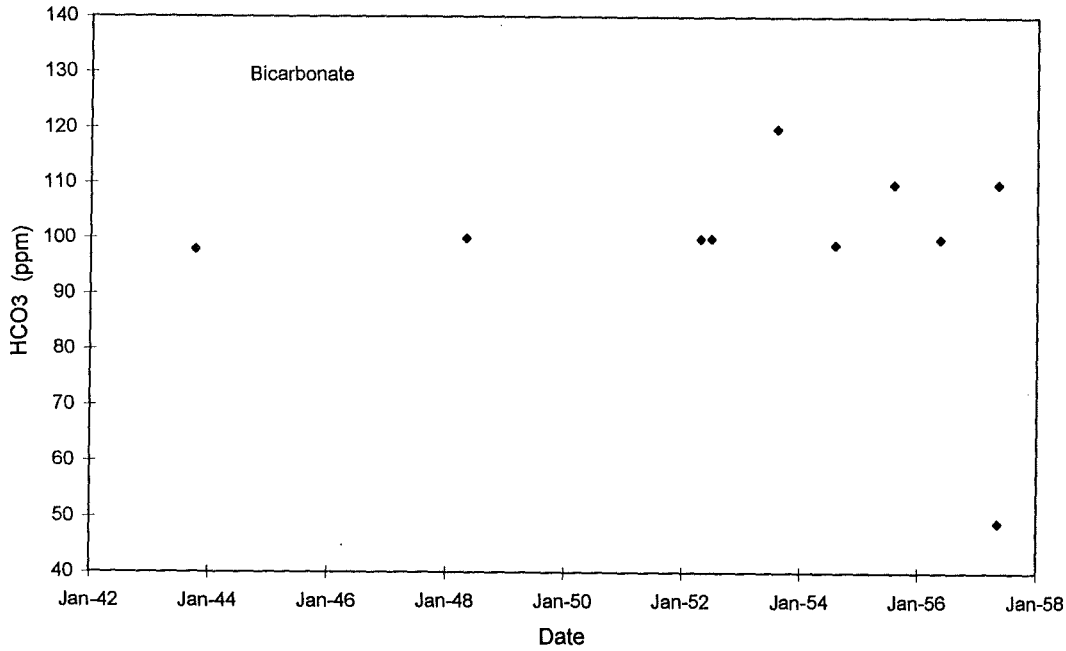
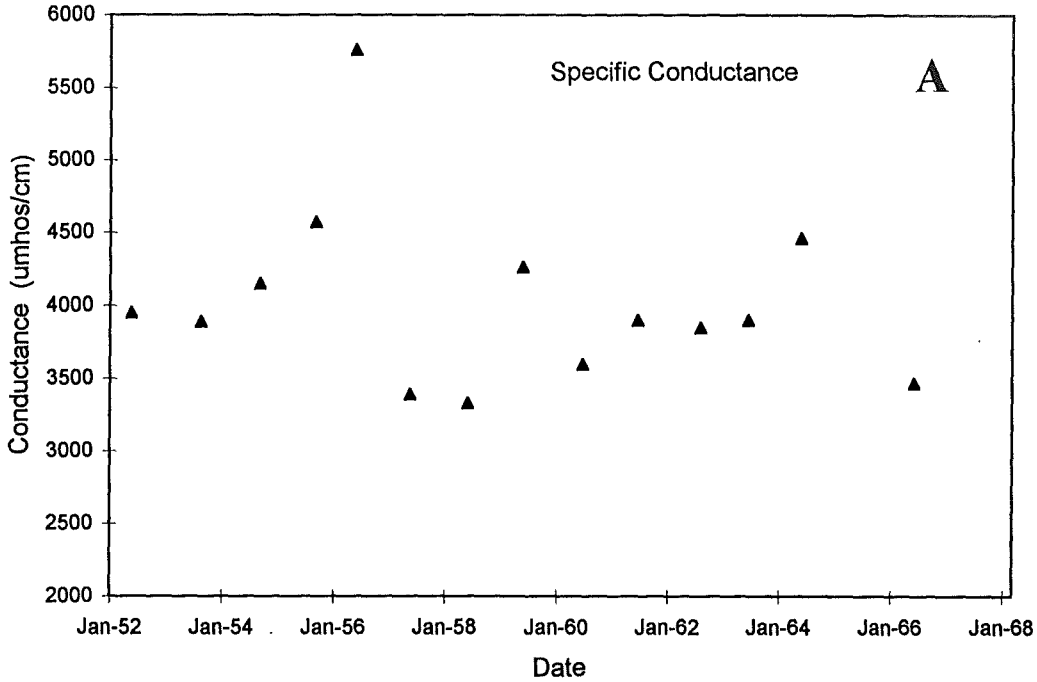


Table 10. Water quality data for well D(5-24)31aaa1.

Date	T (C)	Spec Cond	TDS	pH	ANC CaCO3	HCO3	Total Hard	Non Carb Hard	Ca	Mg	Na+K	Na %	Cl	SO4	F	SiO2	tot N NO3
5/26/52		3950	2460		330	400	910	580	260	65	530	56	850	500	1.4	45	22
8/20/53	18	3890			342	420							850				
9/14/54	18.5	4150			356	430							910				
9/13/55	19	4570	2880	6.9	358	440	1000	670	260	94	650	58	1100	550	1.4	49	
5/29/56	19	5760	3600	7.1	385	470	1300	920	360	100	800	57	1400	630	1.6	45	20
5/21/57	18.5	3390	2100	7.7	305	370	450	300	110	43	530	66	770	380	2	65	9.4
6/3/58		3330		7.3	299	360	650	350						700			
5/26/59	18.9	4260		7.2		460	860	480					940				
6/21/60	16.7	3600		7.2		410	540	200					760				
6/20/61		3900		7.9	356	430	750	390					840				
8/7/62	15.5	3850			366	450	840	470					820	480	1.2		
6/18/63	18	3900					770	390					840		2		
5/26/64	18	4460			399	490	740	340	270	18			980	500	2.5		
7/20/65	18				390	480	860	470	240	63			990	540	2		
6/7/66	17	3470		8.2	330	400	580	250	150	50	95		720	340	1.8	36	

Depth 58 feet Lat 32-57'39" Lon 109-54'54" Data from U.S. Geological Survey

Figure 10. Water quality in well D(5-24)31aaa.



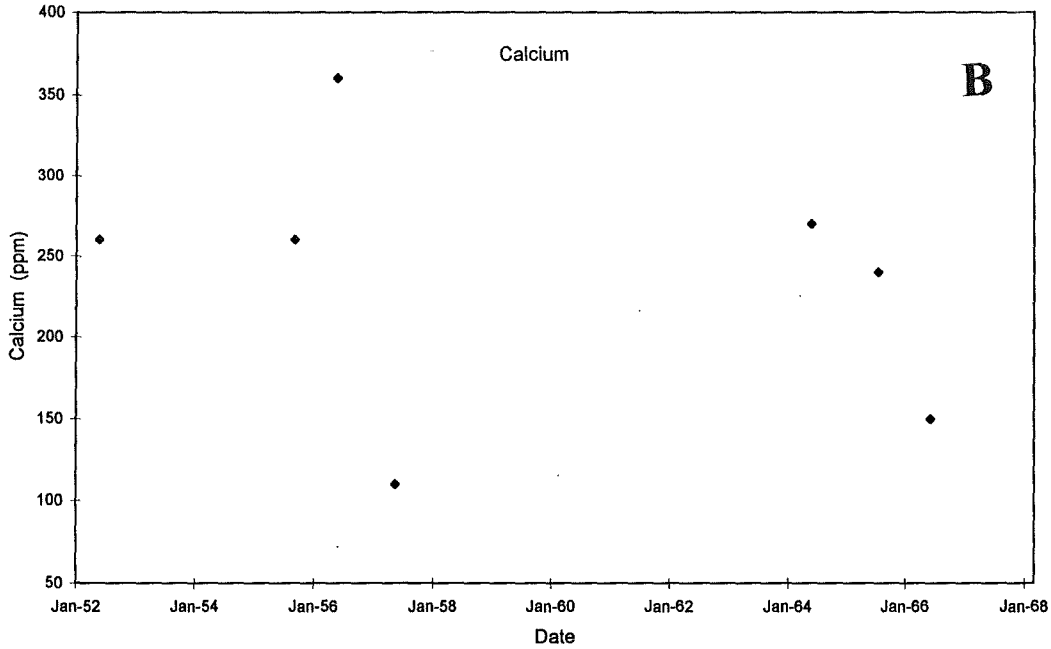
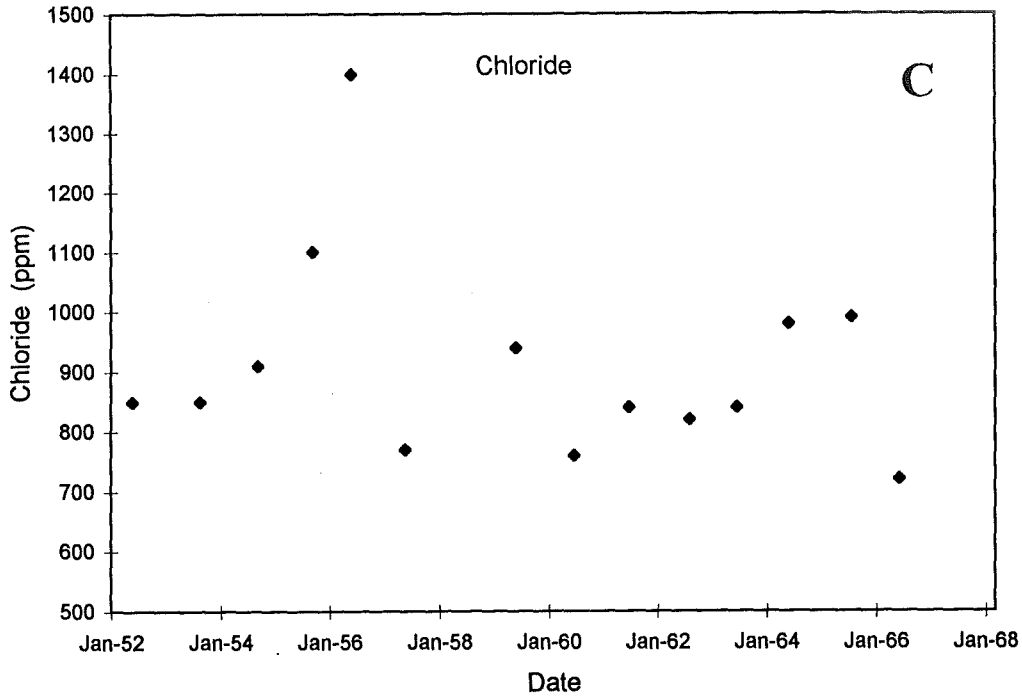


Figure 10. Water quality in well D(5-24)31aaa, continued.



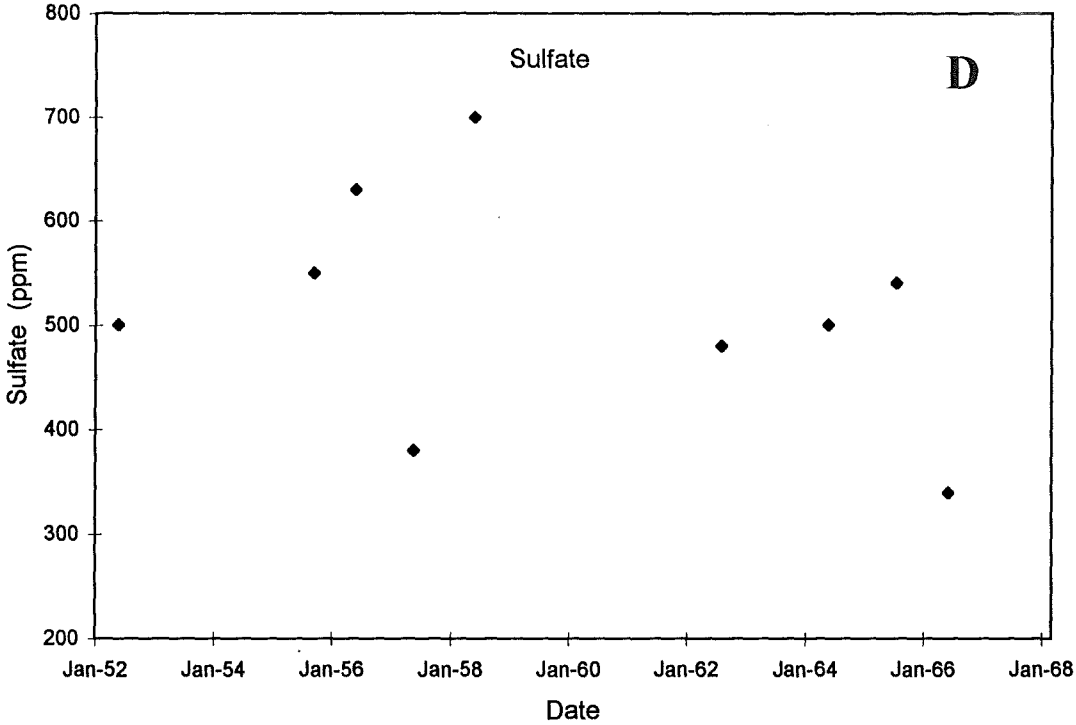
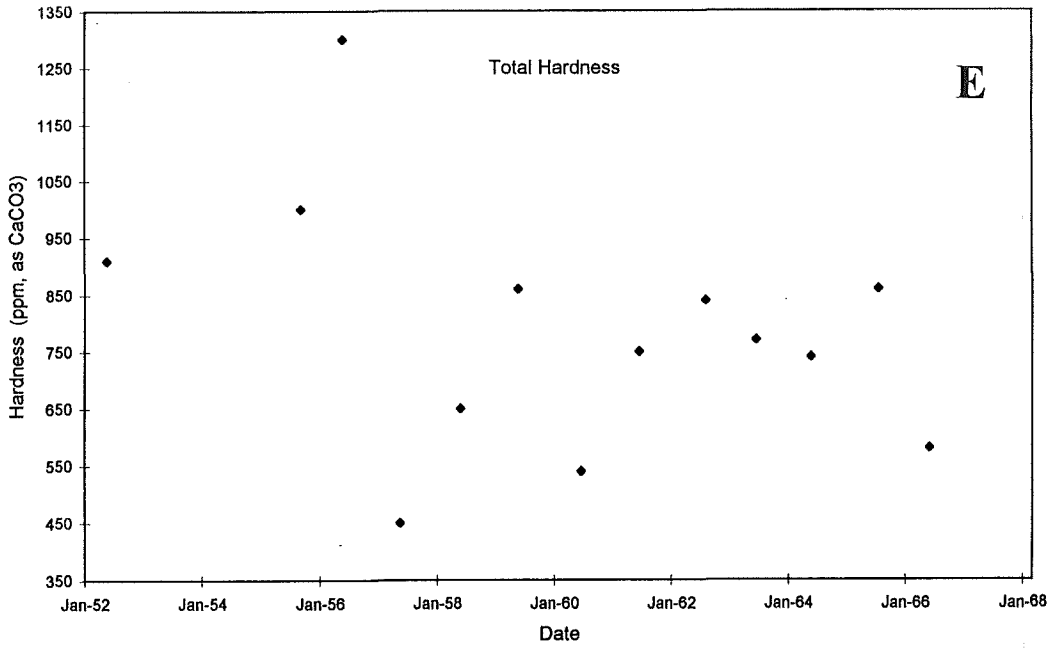


Figure 10. Water quality in well D(5-24)31aaa, continued.



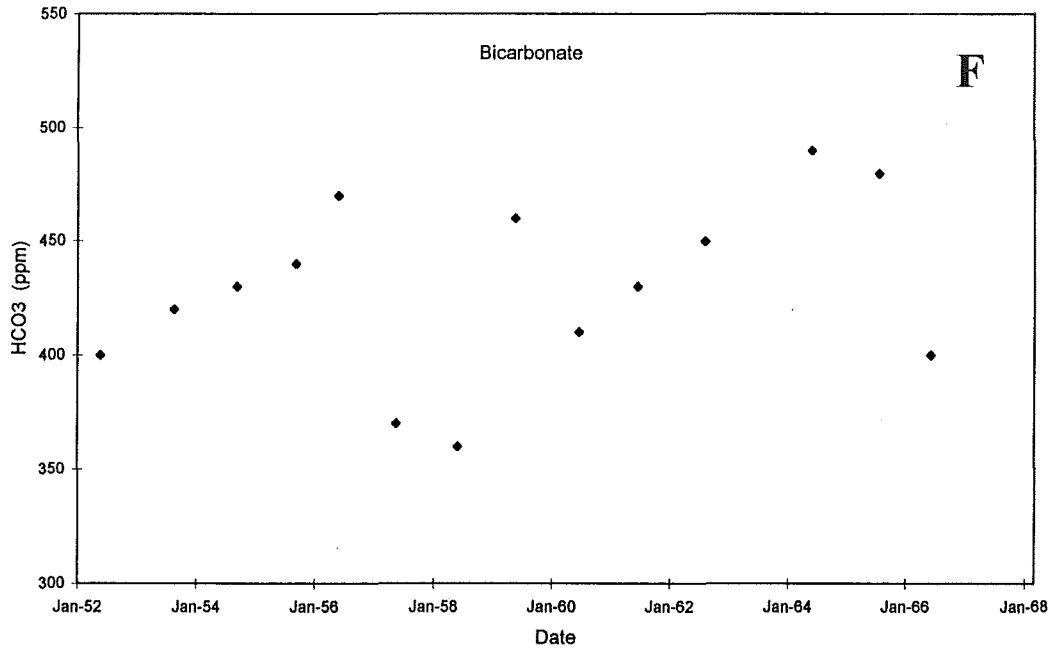


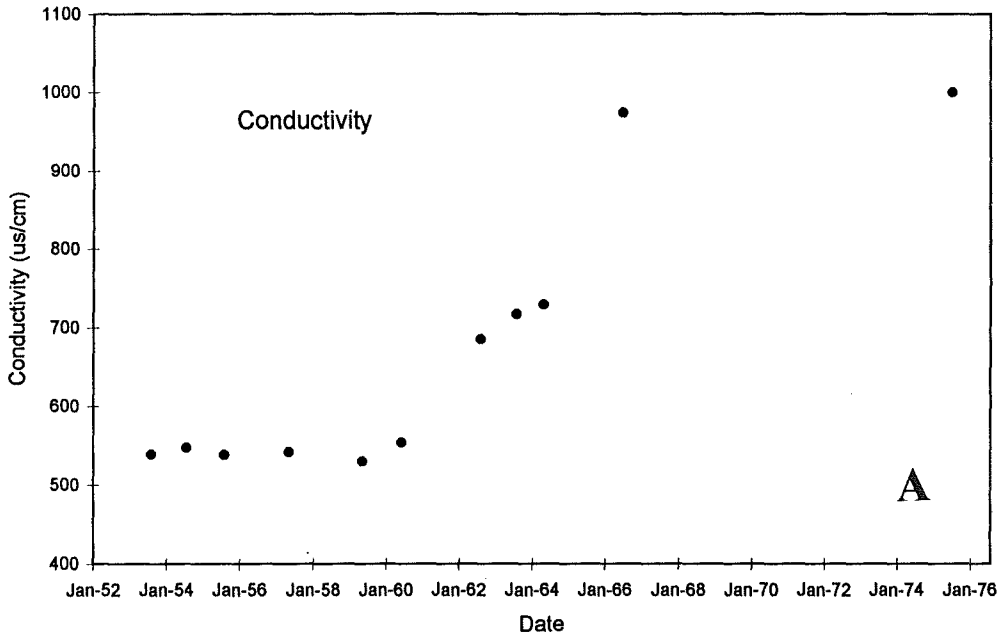
Table 11. Water quality data for well D(4-23)35ada.

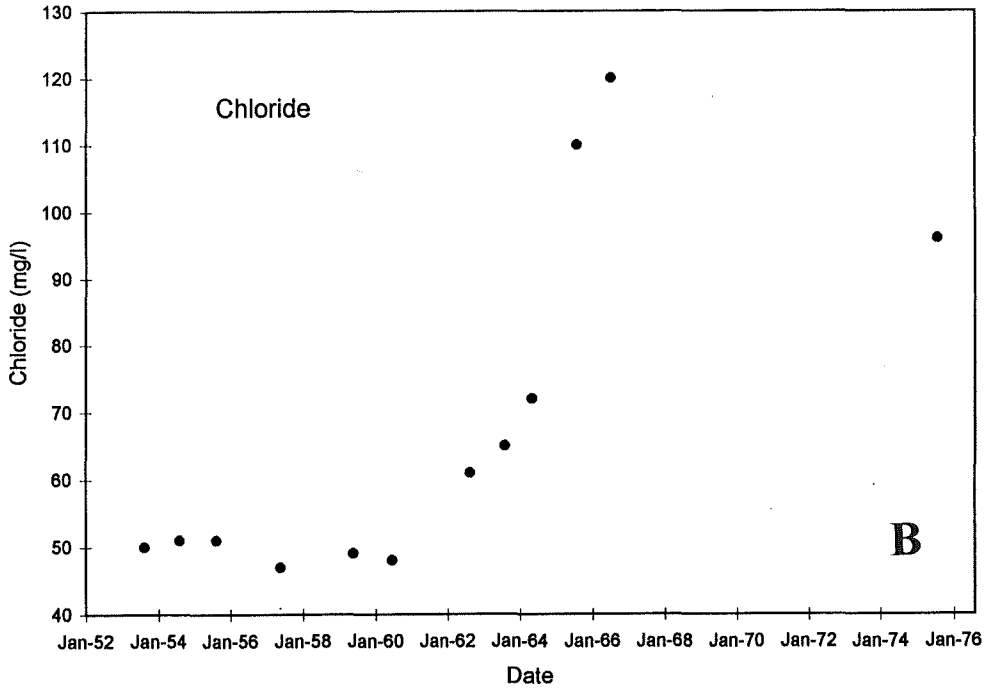
Date	T (C)	Cond	pH	Alkal CaCO3	HCO3	CO3	Hard (CaCO3)	Ca	Mg	Na+K	Cl	SO4	F
8/20/53	23	539		159	190	0					50		
8/5/54	22	547		161	200	0					51		
8/16/55	21.5	538	7.2	158	190	0					51		
5/21/57	23	542	7.2	164	200	0	110				47		
5/26/59	22	530	7	164	200		72				49		
6/21/60	23.5	554	7.2	173	210		68				48		
8/21/62	22	685	7.4	214	260	0	180				61	55	1.5
8/6/63	21.5	716	7.5	222	270	0	210				65	55	1.1
5/5/64	21.5	729	7.1	216	260	0	220	73	10		72	52	1.5
8/3/65	21.5		7.3	238	290	0	270	86	13		110	60	1.1
7/5/66	21.5	974	7	246	300	0	290	89	16	86	120	61	1
7/15/75		1000		236	290		300	98	14	101	96	140	1.3

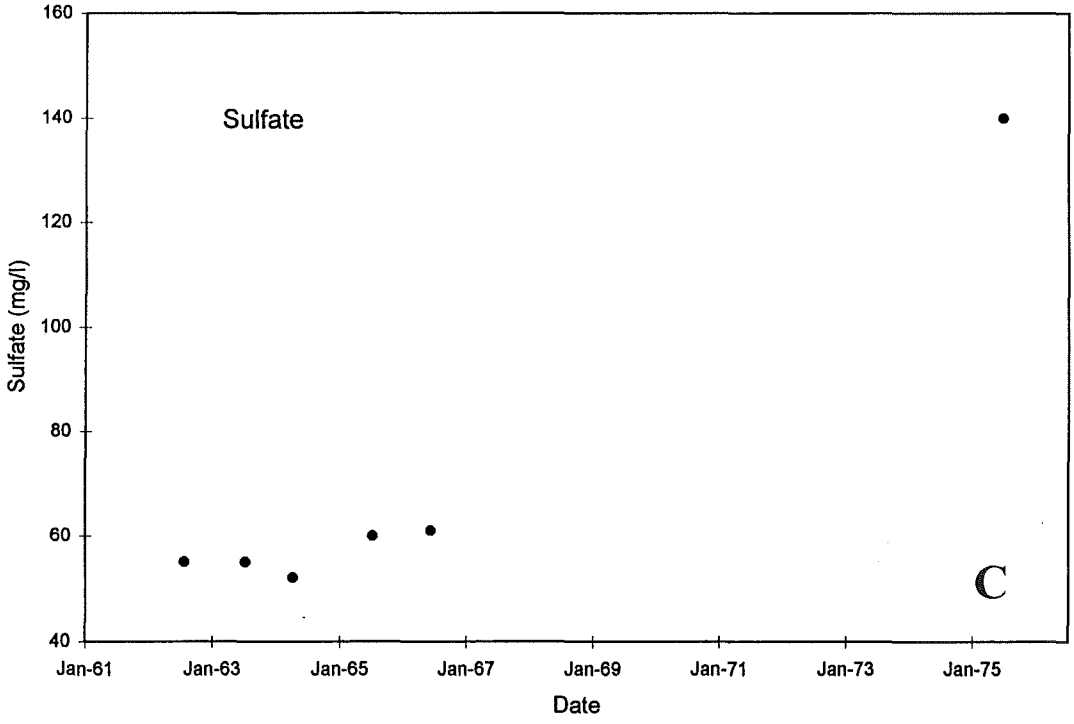
Depth 75 feet; Lat 33-02'40" Lon 110-03'11"

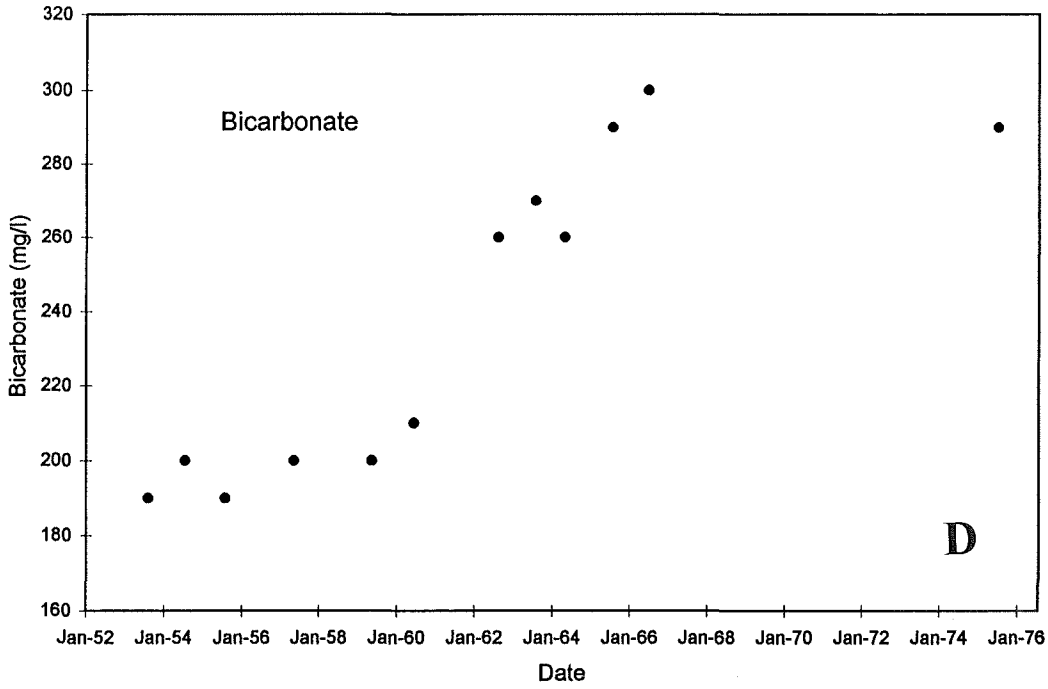
Data from U.S. Geological Survey

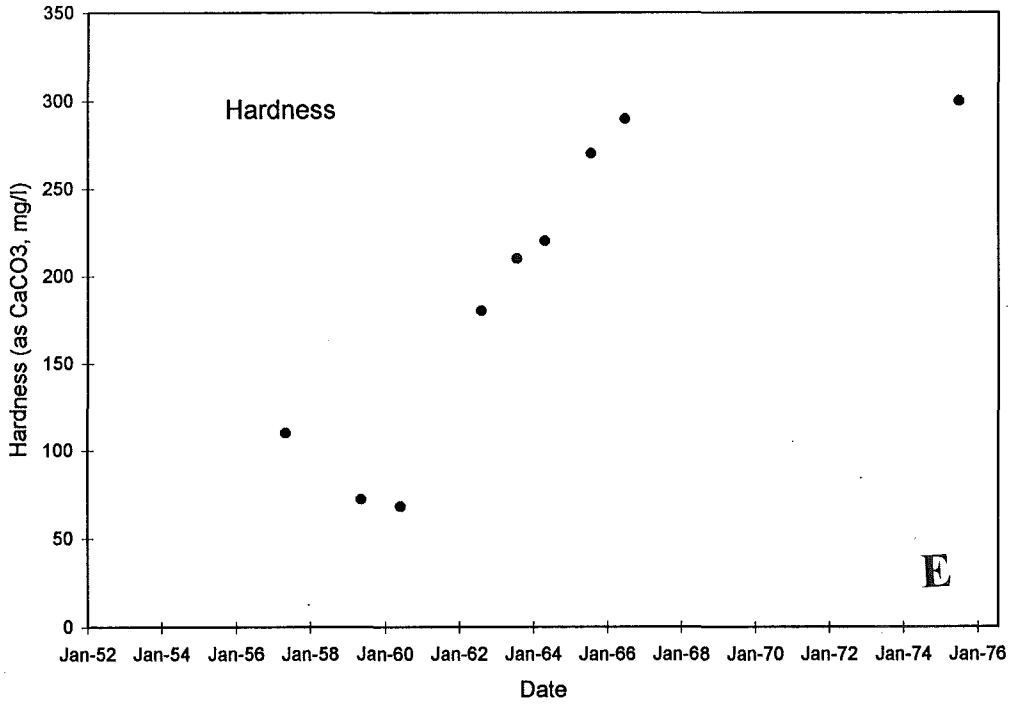
Figure 11. Water quality in well D(4-23)35ada.




Chloride
B
Chloride (mg/l)
130
120
110
100
90
80
70
60
50
40
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Date


Sulfate
C
Sulfate (mg/l)
160
140
120
100
80
60
40
Jan-61
Jan-63
Jan-65
Jan-67
Jan-69
Jan-71
Jan-73
Jan-75
Date


Bicarbonate
D
Bicarbonate (mg/l)
320
300
280
260
240
220
200
180
160
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Date


Hardness
E
Hardness (as CaCO3, mg/l)
350
300
250
200
150
100
50
0
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Date

Study of Muller and others (1973) and Muller (1973)

Groundwater quality trends

A major study of groundwater quality in the Safford Valley was attempted in the early 1970s. Although the work is largely that of students in hydrology summer field camps, the resulting reports seem to carry much weight because the study represented the only attempted study of long-term trends of groundwater quality in the Safford Valley up to that time. The study includes an analysis of the economics of agriculture, and ties the future of farming in Safford to the quality of groundwater.

The results were presented in a report titled '*An analysis of water quality problems in the Safford Valley, Arizona*', informally published as Hydrology Department Technical Report 15. (Muller and others, 1973), which was a compilation of the work of several University of Arizona Hydrology Department summer field camps. That report was summarized and semi-formally published in a hydrology symposia Proceedings, titled '*Salinity problems of the Safford Valley: an interdisciplinary analysis*' (Muller, 1973). Unless otherwise specified, the following discussion will pertain to the former report.

The opening sentence of the abstract of Muller and others (1973) states "A marked change in ground water quality in the Safford Valley of Graham County, Arizona, averaging approximately $+0.129 \times 10^3$ mhos electrical conductivity per year and +35 parts per million chloride per year, has been documented between 1940 and 1972 with data from ten long-term sample wells". Muller (1973) asserts "A change in groundwater quality, averaging approximately +0.13 millimhos electrical conductivity and +35 ppm chloride per year, has been documented in ten long-term sample wells".

The claim that the average salinity of groundwater in the Gila Valley is increasing by the amounts reported is a bold statement. For perspective, an increase of 0.129×10^3 or 0.13 millimhos equals 129 and 130 micromhos or μS/cm, respectively. At that rate, water in any particular well would be expected to increase 1300 μS/cm every decade. A well starting in 1972 at 1000 μS/cm would, in 1999, have a conductivity of 3640 (approximately 2200 mg/l TDS). After forty years, a well starting at 1000 μS/cm would have a conductivity of 6200 μS/cm (3720 mg/l TDS).

A reader may left with the impression that water quality problems not only will affect the future of agriculture in the Gila Valley, but are also largely the *result* of agriculture. It is for those reasons that the Muller reports are critically evaluated here.

The three figures from the Muller report of interest here are "Long-term sample well location map", the "1944-1972 Electrical Conductivity Change" map and the "1944-1972 Chloride change" map. The last two maps are reproduced in reduced size here as Figures 12 and 13, with the 10 long-term sample well locations added. Of paramount importance to their modeling of groundwater quality changes, and to the economic analyses and forecasts are the data for these wells (Muller and others, 1973, Table 5, page 48), reproduced here as Table 12.

The major limitation of doing water-quality-change studies, as admitted in that report, is the lack of wells with a long history of chemical analyses. In a valley with literally thousands of wells, only ten were identified by Muller's group as having more than twenty years of monitoring data. In two of these cases, only two analyses were used to establish 'trends' in a system that has been shown to be highly variable over short period of time and over short distances (e.g., Hem, 1950). Six of the ten wells had only three analyses.

With only ten wells to serve as 'control points' in a study area of more than 180 square miles, the establishment of detailed contours of conductivity and chloride change is over-interpretation. Curiously, the patterns of contour lines for long-term changes in electrical

conductivity (EC) (Figure 12) and chloride (Figure 13) do not match, even though they rely on the same wells as control points. Furthermore, conductivity is mostly the result of the levels of chloride and sodium, the two most important measures of water quality in the Safford Valley, and conductivity should mirror changes in those constituents. Yet, where the largest magnitudes of conductivity changes are plotted, there are no similar bullseyes for chloride. That a change in conductivity of this magnitude is not matched by a similar change in chloride is astonishing.

Discussion of well data

The following discussion details errors made in the data presented in Muller and others (1973), Table 12 of this report. (That table is not presented in the Muller, 1973 publication). References in Muller's Table 12 are as follows: [9] = Calvin, 1946; [17] = Dutt and McCeary, 1970; [38] = Hem, 1950; [58] = Smith and others, 1963; [59] = Smith and others, 1964; [80] = "Wright, 1972", which is the data from the 1972 hydrology summer field camp, presented as an appendix of Muller and others(1973).

WELL 'A' "D(5-23)13ad"

- This well is actually D(5-23)12ad. There is no well listed in references [38], [58], or [59] in section 13 with that owner or chemical data.
- The well should not be plotted because section 12 is off their map.
- The sample date in [38] is 4/43, not 4/44.
- Wells listed in [59] generally do not have quarter designations, and this well does not. Therefore, whether the well listed in [59] is in 12ad, or is another well in section 12 cannot be determined from the information reported in that reference.
- The USGS Ft. Thomas quadrangle shows at least three wells in the SE ¼ of section 12. Without proper ¼-¼ designations, these wells (and any others in section 12) cannot be distinguished from a list such as in [59].
- Reference [80], which is an appendix of the Muller report itself, does not list this well in its tabulation of water quality measurements taken in 7/72. The source of this data could not be found.
- The well listed in [38] as section 12ad is 30 feet deep. The well in [59] is 50 feet deep. Therefore, the reason for the difference in EC and Cl between 1944 and 1972 is because the samples are from two different wells.

WELL 'B' D(4-23)27dd

- This well, located in Township 4 South, should not be plotted, because their maps only extend to part-way up T5S and T4S is off the map.
- Well B is on their map anyway, but is plotted in D(5-24)16cc, in the wrong section of the wrong Township and Range.
- The "H. Uhli" well in [38] is in the SE ¼ *of the* NE ¼ (27ad, depth 65 feet). The "H. Uhli" well in [58] gives only the SE ¼ (27d, depth, 60 feet). Another reference, not used by the Muller group (Smith and others, 1949), lists a well under the name H.H. Uhli in section 27 (with no ¼ section) having a depth of 50 feet. With such conflicting information, it is possible that two different wells were sampled.
- Two analyses are available for the 27ad well in [38], but only one was presented in their table of data and used in subsequent interpretations. In the case of well E, by contrast, three analyses were available in [38] and all three were used. The reason for using all of the available data for one well, but only selected data for another is not given.

- The two analyses from [38] show that the chloride changed significantly from June, 1940 to April, 1943, and the change was a *decrease* from 1388 to 1140 ppm.
- Reference [80], which is an appendix of the Muller report itself, does not list this well in its tabulation of water quality measurements taken in 7/72. The source of this data could not be found.
- The EC of 7.6 (=7600 μmhos or μS/cm) is reported to be from [58] , but that reference does not list any EC values. The value for EC, therefore, had to be *calculated* from the TDS value listed in [58]. One of the criteria for choosing the ten wells for the long-term trend analysis was that they were all supposed to have EC *measurements*. Using the strict criteria imposed by the Muller group, this well should technically not have been included as a long-term monitoring well. If calculated EC values are acceptable, then there are probably many more wells than just ten available for evaluations of long-term trends. Because EC and TDS are linearly related, one can be calculated from the other fairly accurately, but in doing so the result should always be reported as a calculated value, not as a measurement.
- In the explanation section of the Muller group's Map 14, 'Long-term sample well location map', is the statement "Water quality data over a minimum period of twenty years was available only for these ten wells." Well B, however has only a 14 year sampling period, and therefore should not have been included as a long-term well if the minimum required sampling period was twenty years.

WELL 'C' "D(4-24)31dd"

- This well is D(5-24)31 but is incorrectly labeled as D(4-24)31dd in their table, (which would be off their map anyway)
- Reference [59] does not give a ¼-section designation for the 'E. Palmer' well in section 31. ADWR's GWSI database lists 20 wells in section 31, 9 of which are under the name E. Palmer.
- Table 5 lists the 1941 EC and Cl as 2.2 mmhos and 1520 ppm, while the 1960 values are 8.0 and 2240. The supposed change in conductivity (3.6X) is much greater in magnitude than the chloride increase (1.5X). The reason for the discrepancy can be traced to the source of the data for the 1941 analysis, (Hem, 1950; p. 158-159, analysis #2104), which reports a conductivity of 5.64 mmhos for the E. Palmer well, not the 2.2 in the table.
- On the Muller group's '1944-1972 Electrical Conductivity Change' map, well C is located on the +4000 μmho contour line, even though the data as presented in the table show a change of +5800 μmhos.
- The depth of the well in [38] is 76 feet; the depth listed in [59] is 80 feet. There is a possibility that two different wells were sampled.
- In the explanation section of the Muller group's Map 14, 'long-term sample well location map', is the statement "Water quality data over a minimum period of twenty years was available only for these ten wells". Well C, however has a sampling record of only 18½ years, and therefore should not have been included as a long-term well if the minimum sampling period required was twenty years.

WELL 'D' "D(6-24)2dd"

- The well sampled in [38] was in the SE ¼ of the NE ¼ (2ad), not 2dd
- The 5/51 analysis is from [59], not [58], and no ¼-section is given
- Well D data in Table 5 show a *decrease* of 1900 μmhos over time, but the well is located between contours showing *increases* in EC of 1000 to 2000 μmhos.

- Four wells are shown on the USGS Pima quadrangle map as being in 2dd. If the plotted location of the well on the Muller map is correct (2dd), and Hem's well location designation (2ad) is also correct, two different wells were sampled. ADWR's GWSI database lists 19 wells in section 2, 13 of which are under the name Hancock.

WELL 'E' "D(6-25)18ca"

- Well E is incorrectly plotted in 18bd.
- One of the large-magnitude bullseyes of conductivity change in the Muller report maps (Figure 12) is two miles north of Pima, centered just north well E. Using the data given in their Table 5, the change in EC should be +5800 μmhos, but the well is located on the +3000 μmho contour.
- The EC for the first entry is given as 1.2, but in [38], Hem reports 2.2.
- All three of the values in the table for chloride from [38] are actually the HCO_3 analyses for the well. The Cl measurements of Hem (1950, p. 128, analyses #1232-1234) are: 455, 260, and 395 ppm. These measurements illustrate the highly variable nature of the chemistry of a single well over short time periods.
- The analysis attributed to [58] is from [59].
- Reference[59] does not give a ¼-section for the well. ADWR's GWSI database lists at least 6 wells in section 18 under the name Dodge-Nevada Canal Company.
- The depth of the well measured in [38] is 66 feet. The depth of the well in [59] is 50 feet. Therefore, two different wells were sampled, and any declarations about changes in EC over time are meaningless.

WELL 'F' D(6-25)28dd

- Wells F and G are plotted (or labeled) reversed on Muller's well location map.
- Reference [38] shows two wells in 28dd under the name Smithville Canal Co (Hem, 1950, page 138, analyses 1554-56, and 1559). The depth is given only for the first listed (82 feet), but not for the well used in the table. The well listed in [59] has a depth of 60 feet (p.73).
- The reference for the second analysis of well F is from [59], not [58]. The reference does not give the quarter-section for this well.
- ADWR's GWSI database lists two wells in section 28 under the name Smithville Canal Co., and [38] lists two under the same name in 28dd. It is possible that the reason for the apparent increase in salinity is that two different wells were sampled.

WELL 'G' "D(6-25)28dc"

- Well G and F are plotted (or labeled) reversed on Muller's map 14.
- The date of sampling in [38] is 5/43, not 5/41.
- Two analyses are reported in [38] (p. 138) but only one is used. The second analysis is on 3/31/44; EC is given as 2.8 and Cl is 525 (analysis #1558). The reason for not using all of the available data for the trend analyses is not given in their report.
- Reference [59] (p. 73) gives an EC value of 5.5, not 5.4.
- Table 5 lists the owner as E. Hoopes. References [58] and [59] both list the same analysis for a well in section 28 under the name G. Hoopes, and [38] lists the owner as R. Hoopes.
- The G. Hoopes well in [58] is in the SW quarter, 28c, not 28d. Reference [59] does not give the quarter section. ADWR's GWSI database lists a well under the name R. Hoops in 28cd.
- The sampling date for the well in [58] and [59] is given as 5/61, not the 9/58 shown in Table 5. There is no sampling date of 9/58 for any Hoopes well in [58] or [59].

- Reference [80], which is an appendix of the Muller report itself, does not list this well in its tabulation of water quality measurements taken in 7/72. The source of this data could not be found.

WELL 'H' D(7-26)22cb

- The Cl value attributed to [38] is incorrect. The correct value is 340 ppm, not 918.
- The Cl value attributed to [59] is incorrect. The correct value is 918 ppm, not 400.
- Reference [80], which is an appendix of the Muller report itself, does not list this well in its tabulation of water quality measurements taken in 7/72.
- As presented in Muller's table, the data show the EC doubling at the same time the Cl level is decreasing by more than half, a situation that is highly unlikely.
- The well listed in [38] has a depth of 100 feet; the well in [59] is 85 feet deep. The most likely explanation for the supposed change in water quality in this well is that two different wells were sampled.

WELL 'I' D(7-27)17db

- Well I is incorrectly plotted in 17ad on the well location map.
- The third analysis has a sample date of July, 1966, but is attributed to reference [9], which was written in 1946. That book is a narrative of the early history of the Gila River region and contains no water quality analyses. The actual source of the data is [17].
- Reference [80], which is an appendix of the Muller report itself, does list a well with location 17dba in its tabulation of water quality measurements taken in 7/72, but the data do not match that presented in the table.
- Ref. [59] does not give the quarter-section for this well. Dutt and McCreary 1970) does not list owners for any wells and gives the location only as 17d. ADWR's GWSI database lists 11 wells in section 17. Only one entry gives an owner, and that is in 17cda, owned by S. Claridge.
- The well in [59] has a depth of 85 feet, whereas the well in Dutt and McCreary has a depth of 120 feet. (Ref. [38] does not list a depth for this well). Therefore, the reason for the "change" in water quality in well 'I' is that two different wells were sampled.

WELL 'J' "D(7-27)03cb"

- The source of the data attributed to [38] is unknown. No well with the listed owner and with the data in Table 5, in the township and range indicated could be found in [38]. Thus, this data cannot be evaluated.
- The source of the data attributed to [58] is unknown. No well with the listed owner and the data shown in the table, in the township and range indicated could be found in [38], [58], [59] or [17]. Thus, this data cannot be evaluated.
- As with well B, the EC (1.6 mmhos) is reported to be from [58], but that reference does not list any EC values, only TDS. The value for EC, therefore, had to be calculated from a TDS measurement. One of the criteria for choosing the ten wells for the long-term trend analysis was that they were all supposed to have EC measurements. Using the strict criteria imposed by Muller's students, this well, as with well B, technically should not have been included in the study.
- No wells are listed in the ADWR GWSI database in quarter cb of section 3.
- Reference [80], which is an appendix of the Muller report itself, does not list this well in its tabulation of water quality measurements taken in 7/72.

Long-Term Sample Well Chemical Comparison

Designation	Location	Owner	Sampling Date	Data Source	Electrical Conductivity ($EC \times 10^{-3}$)	Chloride (ppm)
A	5 23 13 ad	F. Moody	4/44	(38)	2.5	475
			6/54	(59)	6.9	2258
			7/72	(80)	7.6	2200
B	4 23 27 dd	H. Uhli	6/40	(38)	5.4	1388
			2/54	(58)	7.6	2680
C	4 24 31 dd	E. Palmer	8/41	(38)	2.2	1520
			3/60	(59)	8.0	2224
D	6 24 02 dd	L. Hancock	7/41	(38)	9.4	1800
			5/51	(58)	7.3	1544
			7/72	(80)	7.5	1580
E	6 25 18 ca	Dodge-Nevada Canal Co.	6/40	(38)	1.2	328
			4/43	(38)	1.6	388
			3/44	(38)	2.2	488
			11/59	(58)	4.9	1230
			7/72	(80)	7.0	1400
F	6 25 28 dd	Smithville Canal Co.	3/44	(38)	2.6	480
			11/59	(58)	5.3	1359
			7/72	(80)	5.8	1504
G	6 25 28 dc	E. Hoopes	5/41	(38)	2.6	485
			9/58	(59)	5.4	1346
			7/72	(80)	5.7	1515
H	7 26 22 cb	A. Montereth	5/41	(38)	2.0	918
			9/58	(59)	4.2	400
			7/72	(80)	2.2	350
I	7 27 17 db	S. Claridge	7/40	(38)	1.4	232
			3/61	(59)	2.2	334
			7/66	(9)	2.4	400
			7/72	(80)	2.8	440
J	7 27 03 cb	P. Allred	4/43	(38)	1.2	200
			6/59	(58)	1.6	290
			7/72	(80)	1.9	320

Table 12. Well data in Muller and others (1973) Table 5.

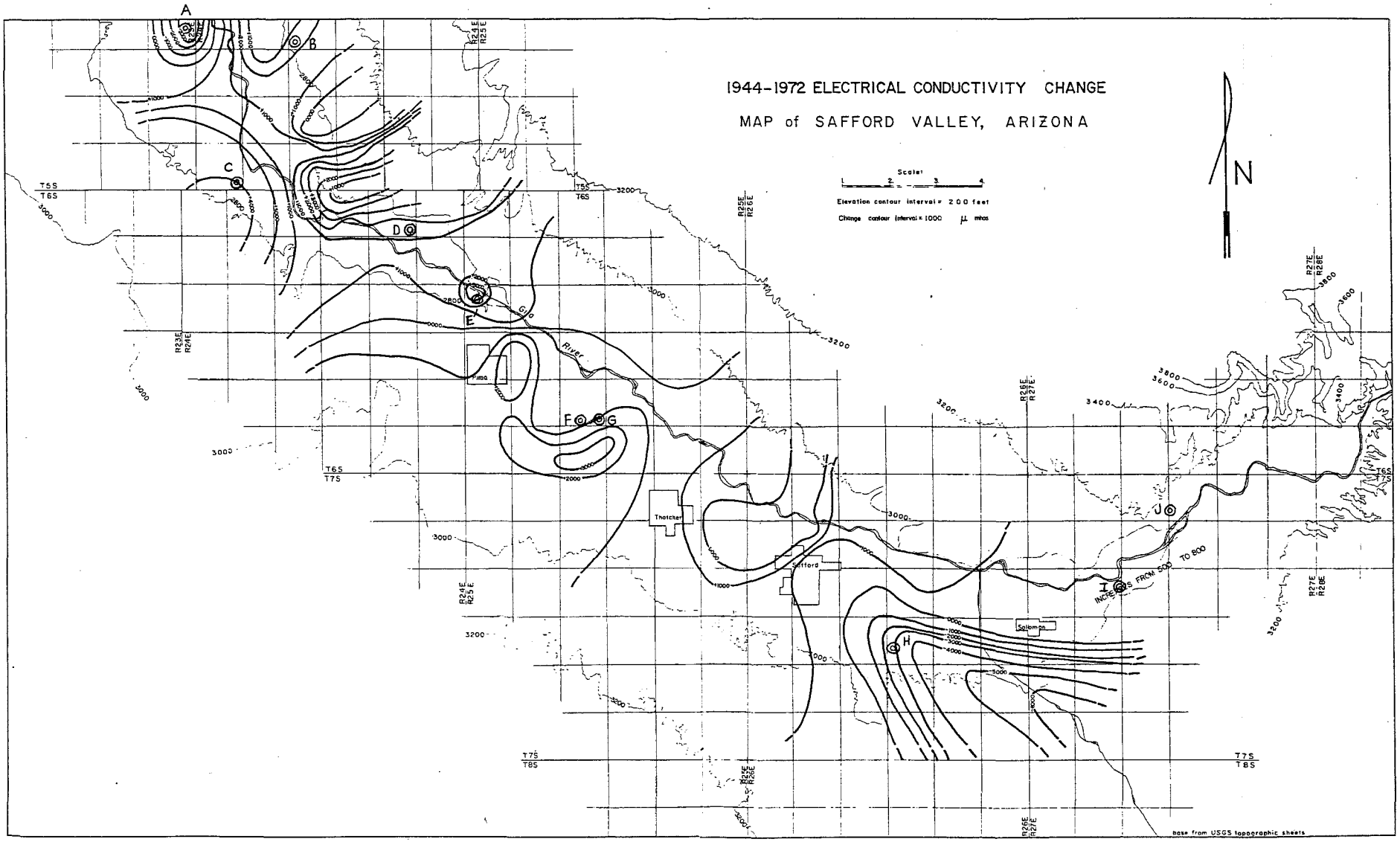


Figure 12. Muller and others (1973) map of conductivity change, 1944-1972.

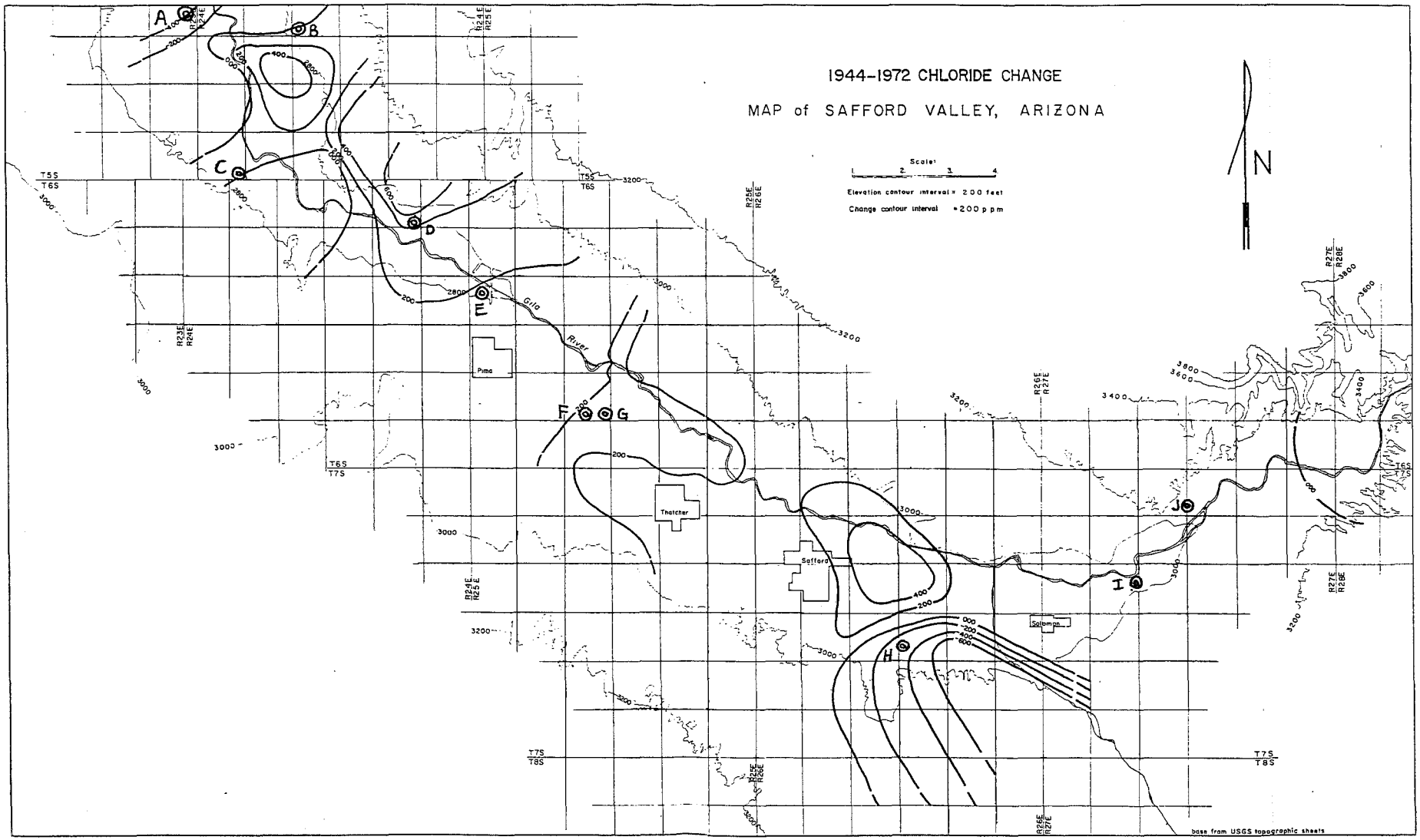


Figure 13. Muller and others (1973) map of chloride change, 1944-1972.

2000 μmhos 1941 to 4200 μmhos in 1958, the Cl level *decreased* by more than a factor of 2. That is a situation that is virtually impossible in a natural system.

As described in Muller and others (1973), the electrical conductivity measurements in their Safford project are only accurate to ±10 percent. Therefore, it should be kept in mind that that variability means that two measurements of, say, 7400 and 8000 μs/cm could represent the same value when the error is taken into account. That is, 7400 and 8000 are within 10 percent of each other, and could be the result from two measurements of the same sample. The concept of an error range is extremely important, and routine, in geochemical analyses, but seems to be under-appreciated in many water quality studies. If in the interpretation of water quality changes, two measurements are within 10 percent of each other, that means that there might not be any real difference between the two measurements, and any resulting 'trend' based on small differences may disappear when error ranges are considered.

Another clue that the interpretation of the water quality trends are not correct is the fact that none of the ten wells with long term trend data lie on the contour lines supposedly derived from them. For example, according to data in Muller Table 5 and the trend lines in their Figure 12, well C had an increase in EC of nearly 6000 μmhos, yet is shown with the 4000 μmho line going through it. Well E data supposedly indicate an increase of 5800 μmhos, but the well is shown on the 3000 μmhos contour. Wells F and G are plotted on the 1000 μmhos contour, but the data for the wells show supposed increases on the order of 3000 μmhos.

In summary, the data and results presented in Muller and others (1973) are so fraught with errors that the report should be considered completely meaningless.

Evaluation of Muller study

An evaluation of the data in the maps and Table 5 of Muller and others (1973) leads to the following observations:

- Most of the well locations and water-quality data are wrong, either because of typographical errors or transposition.
- Many of the well locations are plagued with uncertainty because the various references do not always give quarter sections and there is often more than one well in a given section having the same owner.
- Two wells (B, C) did not meet the stated minimum requirement of a sampling record of at least twenty years.
- Two of the wells (B, J) apparently had calculated values for conductivity although the stated requirement for long term wells was that they had measured values available.
- Attention was not paid to the depth of the well when determining whether a well in one reference was the same well as listed in other references. In at least five of the ten entries (A, B, E, H, I), it is certain that two or more different wells were sampled, rendering results based on these wells meaningless. Alleged changes in three other wells (C, D, and F) were probably due to two different wells being sampled, but owing to conflicting or insufficient data, this cannot be determined with certainty. Changes in well G are probably from this scenario also, but without more information, such as depth of the well, it cannot be proved. Thus, it is possible that in nine of the ten entries, two or more different wells were sampled, making the data in the Muller group's Table 5 worthless.
- None of the data for well J could be found in any of the attributed references.
- None of the data attributed to reference [80] could be found, even though other data from the 1972 sampling is reported in an appendix of the Muller reports.
- In two of the wells, only two analyses were used to establish 'trends' in a system that has been shown (even by the Muller group) to be highly variable over short period of time and over short distances.

The maps in the Muller reports are equally troubling as the data their Table 5 (Table 12 of this report). An area of more than 14 square miles of bottom land downstream from Pima is completely enclosed in the 10,000 μmho contour on the 1969 iso-conductivity map. On the corresponding 1972 iso-conductivity map, that same area straddles the 5000 μmho contour. That is a 5000 μmho decrease in four years, which is not only inconceivable, but is contrary to the supposed increases shown on the 1944-1972 conductivity change map (Figure 12 of this report) and discussed in the Muller reports.

Unfortunately, errors in the Muller reports are not limited to their water-quality data. Trend lines for electrical conductivity and chloride change are presented as Figures 12 and 13 of Muller and others (1973) and as Figures 4 and 5, without labels, in Muller (1973). Because the trend lines are based on the incorrect analytical data in their table, those trend lines are also incorrect, and therefore are completely meaningless. Unfortunately, the entire economic analysis and predictions of future salinity problems presented in the reports are based on the numbers generated from statistical analysis of the trend lines. Thus, the economic analysis and forecasts of salinity levels at future dates are invalid.

In several cases in their Table 5, there were clues that some of the numbers just had to be wrong because they simply did not make sense. For example, in well H, a clue that the chloride values are not right is that at the same time the EC is supposed to have more than doubled from

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