Contract 185

ILLINOIS STATE WATER SURVEY

at the

University of Illinois
Urbana, Illinois

The Effect of Precipitation Scavenging of Airborne and Surface Pollutants on Surface and Groundwater Quality in Urban Areas

Principal Investigators:

Richard J. Schicht and Floyd A. Huff

FINAL REPORT-PART I
GROUNDWATER STUDIES

by
Richard J. Schicht

National Science Foundation
Engineering Division
NSF GK-38329
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ACKNOWLEDGMENTS

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INTRODUCTION

This project was undertaken to 1) study the general effect of precipitation scavenging of urban-industrial pollutants on groundwater quality, and 2) investigate the possibility that groundwater quality deteriorates more rapidly in regions where urban-induced precipitation enhances the natural rainfall.

The study was carried out in the East St. Louis area in order to take advantage of meteorological and atmospheric chemical data being collected and analyzed in conjunction with METROMEX, a comprehensive 6-year field and analysis program devoted to research on urban effects on precipitation (Changnon et al., 1971).

The field program portion of this 2-year study extended from June 1973 through September 1974. The program consisted basically of collecting weekly groundwater samples at six sites and groundwater samples from a large number of wells during June and September of 1973 and 1974. Groundwater levels were measured during these periods for preparation of piezometric surface maps. Continuous and monthly groundwater level data were available at several sites as part of the Illinois State Water Survey's groundwater monitoring program. Samples of the total weekly wet and dry deposition (rainout plus dry fallout) were collected at several locations.

The groundwater and rainwater samples were analyzed for a number of chemical constituents. These included calcium, magnesium, sodium, potassium, zinc, total dissolved minerals, nitrates, chlorides, sulfates, alkalinity, and hardness.

It was planned to use the groundwater level data collected during the study to prepare piezometric surface maps for flow net analysis to estimate groundwater recharge. The number of observation wells available for water level measurements was not sufficient to prepare detailed piezometric surface maps for analysis, and field personnel were not available to inventory additional wells. The groundwater levels collected during the study were invaluable, however, in determining the effects of the 1973 Mississippi River flood on groundwater levels in the area. Two reports were prepared summarizing the high groundwater level situation. They are included in this report as Appendixes A and B.

The chemical quality of the groundwater in the area was first investigated by Bowman and Reeds (1907). Bruin and Smith (1953) noted an appreciably high sulfate content in areas of high groundwater withdrawals which also coincided with highly urbanized and industrialized areas. Bruin and Smith also reported that the chemical quality of the groundwater is highly variable from place to place and at various depths.

There have been reports of an increase in the mineral content of the groundwater. For example, because of a gradual increase in the mineral content of groundwater, two municipalities in the area relocated their well fields that had been in an urban-industrial complex. One municipality located their new well field near the Mississippi River to take advantage of the infiltration of river water which is less mineralized than groundwater. The other municipality located their new well field in a rural area.

Changnon (1973) suggested that rainfall was instrumental in increases in mineral content. He plotted chloride and sulfate contents for water samples collected from 1948 through 1965 from a well in the area. According to Changnon the correspondence between the 1955-1956 rain and the chloride and sulfate contents suggests that the rainfall was instrumental in the sizeable increases in groundwater pollution.

The study area is in southwestern Illinois and includes parts of Madison, St. Clair, and Monroe Counties. It extends along the valley lowlands of the Mississippi River from Alton south to Dupo (Fig. 1). The area covers about 175 square miles and is approximately 30 miles long and 11 miles wide at the widest point. It lies completely within the METROMEX network area.

The area has been one of the most favorable groundwater areas in Illinois. It is underlain at depths of 170 feet or less by sand and gravel aquifers that have been prolific sources of water for more than 70 years. The available resources have promoted industrial expansion of the area and also facilitated urban growth.

The study area is heavily industrialized. Industries in the Alton-East Alton area include manufacturers of paper products, glass, explosives, steel products, and aluminum products. There are three large oil refineries in the Wood River area. A large steel mill is located in Granite City along with several manufacturers of steel products and a corn products manufacturing company. National City is a meat packing center. A large number of industries are located in the vicinity of East St. Louis including fertilizer plants, chemical plants, and ore refineries.

Detailed geohydrologic data on aquifer extent, aquifer hydraulic conductivity, groundwater recharge, groundwater levels, and groundwater withdrawals are available for the East St. Louis area. Mineral analyses of a large number of groundwater samples have been made. The groundwater geology has been studied in detail by Bergstrom and Walker (1956). Schicht (1965) made a quantitative evaluation of the groundwater resources of the area.

DATA COLLECTION PROGRAM

Groundwater samples for the period June 1, 1973, through September 30, 1974, were collected weekly from wells at six sites. At three of these sites high capacity production wells with pumping rates exceeding 500 gpm, screened in the lower more permeable part of the sand and gravel formation, were sampled. Small diameter (1¼-inch) piezometers with 3-foot well points constructed for groundwater level observation were sampled at the other three sites. The locations of the sites are shown in Fig. 2.

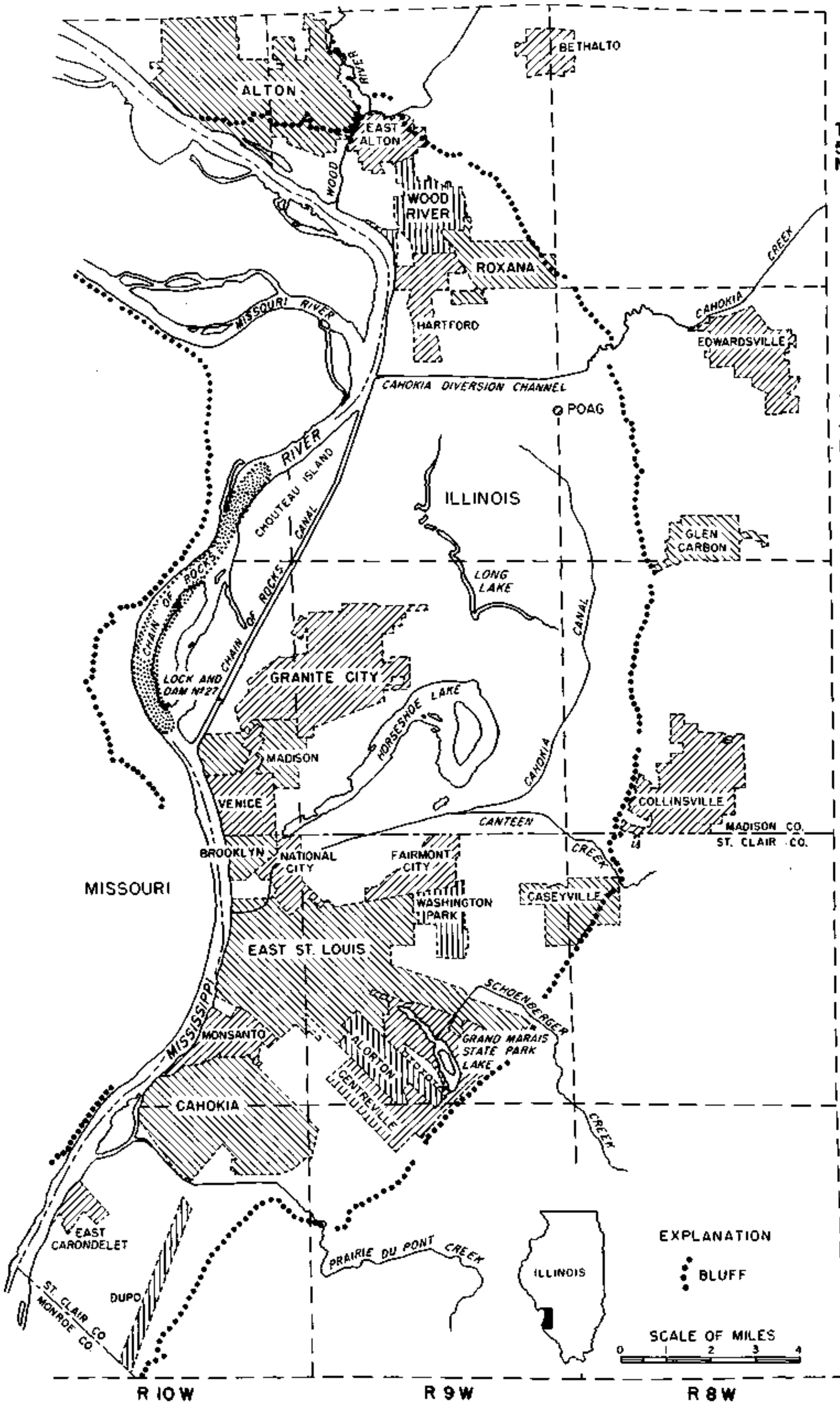


Figure 1. Location of the East St. Louis area.

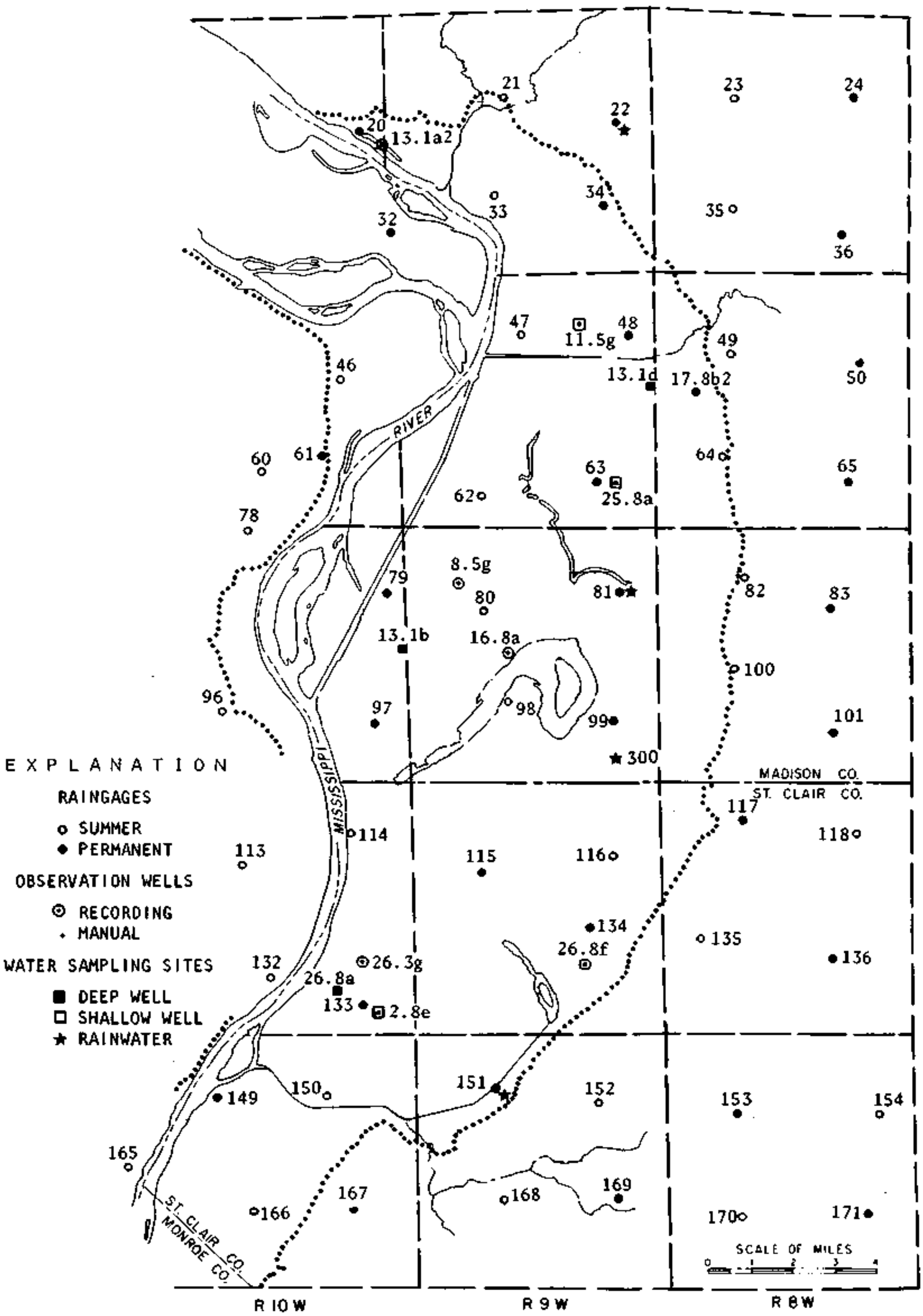


Figure 2. Hydrologic network and water sampling sites.

Water samples at site 13.1d were collected from wells in a municipal well field located in a rural area. Sampling sites 13.1b and 26.8a are industrial well fields located within urban-industrial complexes in Granite City and near East St. Louis. Samples were collected from one of four wells at site 13.1d, from one of two wells at site 13.1b, and from one of three wells at site 26.8a, depending upon which wells were in operation at the time of sampling. Samples were collected at convenient taps in the discharge lines as close to the well as possible Sampling was interrupted for several weeks at sites 13.1b and 26.8a because of vacation and strike shutdowns.

Sites 11.5g and 25.8a are located in rural areas, Site 2.8e is located about 1 mile southeast of the urban-industrial complex near East St. Louis. Difficulty was encountered in sampling the small diameter wells at these sites because water was not flowing freely into the well through the well point and because problems with a portable sampling pump occurred. Chemical data from samples collected in these wells are not included in this report.

Water samples were collected from a large number of wells during four 2-week periods in June and September of 1973 and 1974. Samples collected during each period totaled 45 in June 1973; 47 in September 1973,62 in June 1974; and 47 in September 1974.

In was planned to collect samples from the same wells for each collection period so a direct comparison of chemical constituents could be made. This was not possible since many of the wells in operation during one collection period were not operating in the next period. The number of chemical analyses available for direct comparison of chemical constituents for each change period are given below.

Change period	*Chemical analyses available for direct comparison*
June 1973 - September 1973	29
June 1973-June 1974	32
June 1973 - September 1974	31
September 1973 - June 1974	33
September 1973 -September 1974	31
June 1974 - September 1974	39

Water samples collected during each 2-week period were primarily from high capacity industrial wells screened in the lower more permeable part of the aquifer. All groundwater samples were collected in 4-liter plastic containers. Storage of samples before analysis ranged from a few days to a month.

During the water sample collection periods, water levels were measured in a large number of wells to obtain data for the construction of water level contour maps. Water level measurements for each collection period numbered 158 in June 1973; 158 in September 1973; 109 in June 1974; and 54 in September 1974.

Weekly samples of wet-dry deposition were obtained for each week during the entire sampling period (June 1973 through September 1974) at three stations (22,81, and 151 in Fig. 2), and intermittently at a fourth station (300 in Fig. 2). These samples contained both deposition from rainstorms and dry deposition during the remainder of the week. The samples were collected in polyethylene baskets lined with a disposable polyethylene bag to eliminate collector cleansing and to provide a clean surface for the atmospheric deposition (Stout, 1969). The baskets and liners were furnished by the METROMEX project.

A limited number of weekly atmospheric deposition samples were obtained from the METROMEX project from a special sampler used to separate the wet and dry portions of the weekly deposition. This device was equipped with a motor-driven cover that exposes one collector during dry weather and another one during wet weather (Adam et al., 1973). These data were used to establish average ratios of wet to dry deposition for various chemical constituents. The ratios were then used in conjunction with our weekly samples for the 15-month sampling period to obtain first approximations of the separate contributions of wet and dry fallout to the total surface deposition. Unfortunately, the METROMEX sampling and analysis was restricted to atmospheric trace metals (Li, Ca, Na, K, Mg, and Zn), so their data could not be used to estimate wet-dry contributions of sulfates, nitrates, chlorides, and total dissolved minerals.

Rainfall data used in the study were obtained from the METROMEX network of recording raingages spaced approximately 3 miles apart *{see* Fig. 2).

CHEMICAL ANALYSES

Most of the groundwater samples were delivered to the Water Survey Chemistry Laboratory in 4-liter plastic containers which had been cleaned with hydrochloric acid and thoroughly rinsed with demineralized water. Rainwater samples were delivered in plastic bags which were immediately transferred to 4-liter containers.

Analyses of the samples were started immediately upon receipt of the samples. A 1000-milliliter (ml) aliquot of the supernatant water was pipetted from the sample for the sulfate determination. The aliquot was acidified with HC1 and the volume reduced to 200 ml by boiling gently. The sulfate was then precipitated as $BaS0_4$ which was filtered in tared sintered glass crucibles, after which the crucible and precipitate were dried and then weighed.

Chloride was determined by the mercuric nitrate-diphenylcarbazone colorimetric procedure reported by Clark (1950). Nitrate was determined by slightly modifying the colorimetric procedure of West and Ramachandran (1966). The modification included a change in aliquot size and measuring the absorbance with a Beckman Model DU spectrophotometer with a 10-centimeter (cm) cell. The total dissolved mineral content of the sample was estimated by conductivity. Calcium, magnesium, sodium, potassium, lithium, lead, and zinc were determined by atomic absorption spectroscopy.

GROUNDWATER QUALITY DATA

June and September Analyses

Chemical analyses of groundwater samples collected during June and September of 1973 and 1974 are summarized in Tables 1, 2, 3, and 4. The range in concentrations, the concentrations exceeded by 90% and 10% of the samples, and the median concentrations are given for each chemical constituent.

Most of the analyses were made from samples collected in two areas: the Wood River-East Alton area in Madison County and the area near East St. Louis in St. Clair County. Chemical concentrations were lower in the Wood River-East Alton area than in the vicinity of East St. Louis.

Infiltration of water from the Mississippi River could be part of the reason for the differing concentrations between the two areas. Conditions for infiltration have been more favorable in recent years in the Wood River-East Alton area than in the East St. Louis area. Conditions were particularly favorable during 1972 and 1973 when the Mississippi River was at flood stage for a prolonged period.

Table 1. Summary of chemical analyses for groundwater samples collected during June 1973.

(Chemical constituents in mg/l)

	Range	Concentrations exceeded by 90% of samples	Concentrations exceeded by 10% of samples	Median concentration
Madison County, 25 samples				
Ca	36-145	56	134	98
Mg	10-56	16	44	28
Na	2-102	56	59	15
K	1-10.8	1.5	4.7	2.9
Zn	0.0-1.9	0.0	0.17	0.0
NO_3	0.9-23.7	1.2	9.4	2.8
Cl	3-248	7	81	22
SO_4	25.1-263.1	42	198	94
TDM	214-858	278	678	506
St. Clair County, 20 samples				
Ca	72-378	100	266	172
Mg	21-99	33	73	42
Na	12-870	14	202	50
K	2.0-69	4.0	12.0	6.9
Zn	0.0-174	0.0	0.25	0.01
NO_3	0.3-70.2	0.7	6	1.90
Cl	4-935	11	223	50
SO_4	79-1947	129	1043	250
TDM	432-3562	514	2298	811

Table 2. Summary of chemical analyses for groundwater samples collected during September 1973.

(Chemical constituents in mg/l)

	Range	Concentrations exceeded by 90% of samples	Concentrations exceeded by 10% of samples	Median concentration
Madison County, 29 samples				
Ca	46.8-162	54.3	138.1	96
Mg	13-55	19	42	26
Na	8-112	10	59	14
K	0.9-11.3	0.9	5.6	3.4
Zn	0.0-3.8	0.0	0.13	0.01
NO_3	1.3-24.9	1.4	9.5	3.1
Cl	2-216	9	88	19
SO_4	15.6-265.8	37.8	214	88
TDM	239-950	289	682	483
St. Clair County, 18 samples				
Ca	96-332	97.9	237.2	166
Mg	30-101	30	71	46
Na	11-838	12	230	46
K	2.0-88	3.6	18.2	6.0
Zn	0.0-108	0.0	1.0	0.03
NO_3	1.4-200	1.4	8.0	3.2
Cl	11-415	14	190	65
SO_4	88-1900	102	1219	227
TDM	492-3497	511	2093	838

Table 3. Summary of chemical analyses for groundwater samples collected during June 1974.

(Chemical constituents in mg/l)

	Range	Concentrations exceeded by 90% of samples	Concentrations exceeded by 10% of samples	Median concentration
Madison County, 37 samples				
Ca	29.2-205	57.6	144.6	104
Mg	10-55	18	49	28
Na	8-79	11	50	17
K	0.9-7.3	1.0	5.0	2.9
Zn	0.0-3.6	0.0	0.77	0.05
NO_3	0-19.0	0.6	5.8	1.8
Cl	4-188	9	55	21
SO_4	23.4-309.2	37.6	224.9	109.2
TDM	186-1026	279	730	522
St. Clair County, 25 samples				
Ca	85.1-472	115	227	162
Mg	26-171	32	58	45
Na	14-775	18	236	58
K	2.4-120	3.7	11.1	6.7
Zn	0.0-74	0.0	1.41	0.07
NO_3	0.23-275	0.9	7.4	2.7
Cl	17-305	18	228	68
SO_4	18-1824	93	1047	250
TDM	527-3365	601	2023	910

Table 4. Summary of chemical analyses for groundwater samples collected during September 1974.

(Chemical constituents in mg/l)

	Range	Concentrations exceeded by 90% of samples	Concentrations exceeded by 10% of samples	Median concentration
Madison County, 31 samples				
Ca	42.8-180	56.9	149.6	101.5
Mg	12-66	19	47	27
Na	8-72	11	63	17
K	1.2-80	1.4	6.6	3.15
Zn	0.0-4.3	0.0	1.4	0.0
NO_3	0.07-46.4	0.5	12.1	1.5
Cl	6-240	7.1	107.2	25
SO_4	16.3-323.6	46.3	254.2	108.7
TDM	227-996	288	814	501
St. Clair County, 16 samples				
Ca	73.6-96	90	340	152.5
Mg	25-193	28	112	42
Na	10-110	15	539	50
K	2.2-134	3.8	63.8	6.4
Zn	0.0-33	0.0	15.2	0.01
NO_3	0.1-195	0.34	94.3	3.0
Cl	13-190	16	178	77
SO_4	13-2332	58	2044	267
TDM	366-4256	526	3566	856

Table 5. Summary of chemical analyses for the Mississippi River at East St. Louis from 20 samples collected from November 30, 1972, through September 27, 1974.

(Chemical constituents in mg/l)

	Range	*Concentrations exceeded by 90% of samples*	*Concentrations exceeded by 10% of samples*	*Median concentration*
Ca	40.0-67.4	46.4	64.0	56.0
Mg	12.2-24.9	15.2	23.5	20.1
Na	6.4-42.8	6.5	28.1	14.4
K	2.4-4.6	2.5	4.2	2.9
Zn	0.0-0.06	0	0.03	0
NO_3	2.8-20.1	3.9	18.8	15.1
Cl	9-25	13	23	19
SO_4	33.7-111 7	41.3	77.8	56.0
TDM	235-394	252	362	306.0

Chemical analyses for the Mississippi River at East St. Louis are summarized in Table 5. The analyses were made from samples collected at approximately monthly intervals. Concentrations of calcium, magnesium, sodium, chloride, sulfate, and total dissolved minerals in the Mississippi River were lower than those in groundwater. Concentrations of zinc and potassium in the river and groundwater appeared to be comparable, while concentrations of nitrates were significantly higher in the river than in groundwater.

Weekly Groundwater Samples

The weekly groundwater samples collected at three sites were analyzed for various chemical constituents. It was planned to use these analyses in studying the effects of infiltration from individual storms on groundwater quality.

Concentrations for each chemical constituent are shown in Figs. 3 through 11. Except for zinc and nitrate, lowest concentrations of chemical constituents were measured in samples from site 13.1d. The greatest variability in chemical concentrations was at site 26.8a, less than a mile from the Mississippi River. Part of the variability can be attributed to the relationship between the Mississippi River and groundwater stages. According to Schicht (1965) large groundwater development in the vicinity of site 26.8a had lowered groundwater levels below Mississippi River stages. Groundwater withdrawals were great enough to maintain this head differential. In recent years, however, according to data in Water Survey files, groundwater withdrawals in this area have declined appreciably. As a result, the relationship between the river and groundwater is similar to that which would occur under more natural conditions. That is, during periods of high river stages groundwater levels are lower than the river, and during periods of low river stages, groundwater levels are higher than the river. The chemical quality of water from wells at site 26.8a would therefore be affected by infiltration of water from the Mississippi River during periods of high river stage, and would not be affected by the river during periods of low river stage.

All other factors being equal, the closer the well is to the river the greater will be the effects of infiltration. Schicht (1965) noted a lag from 1 to 2 months in changes in quality in a well a few hundred feet from the river.

The relationship between Mississippi River stages and sulfate content at site 26.8a during the first 9 months of 1974 are shown in Fig. 12. The sulfate content in the well declined appreciably late in March as groundwater stages remained below river stages during most of January, February,

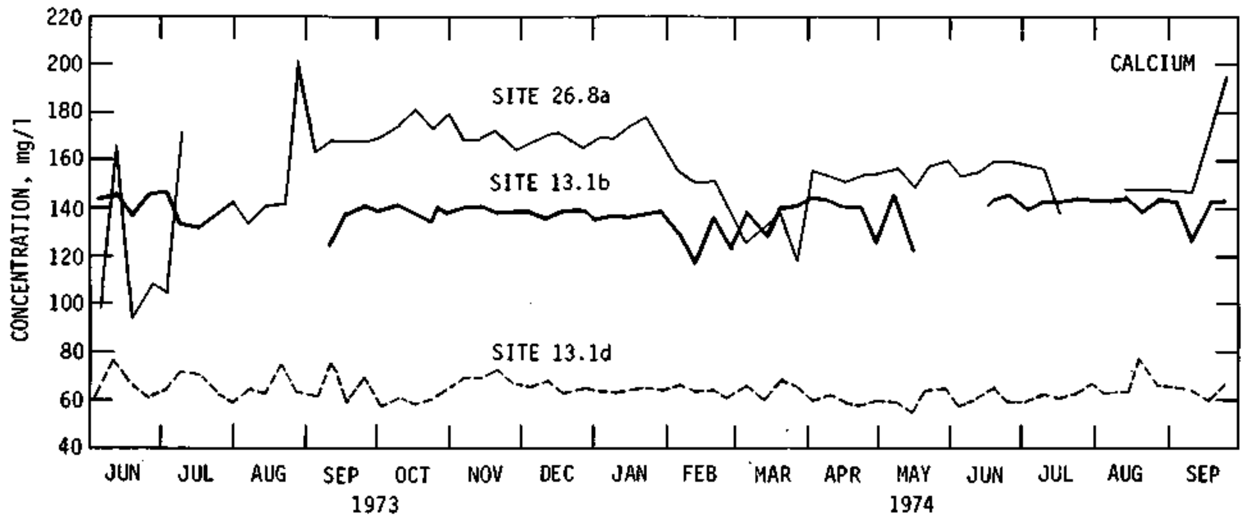


Figure 3. Weekly measurements of calcium in groundwater at three sites.

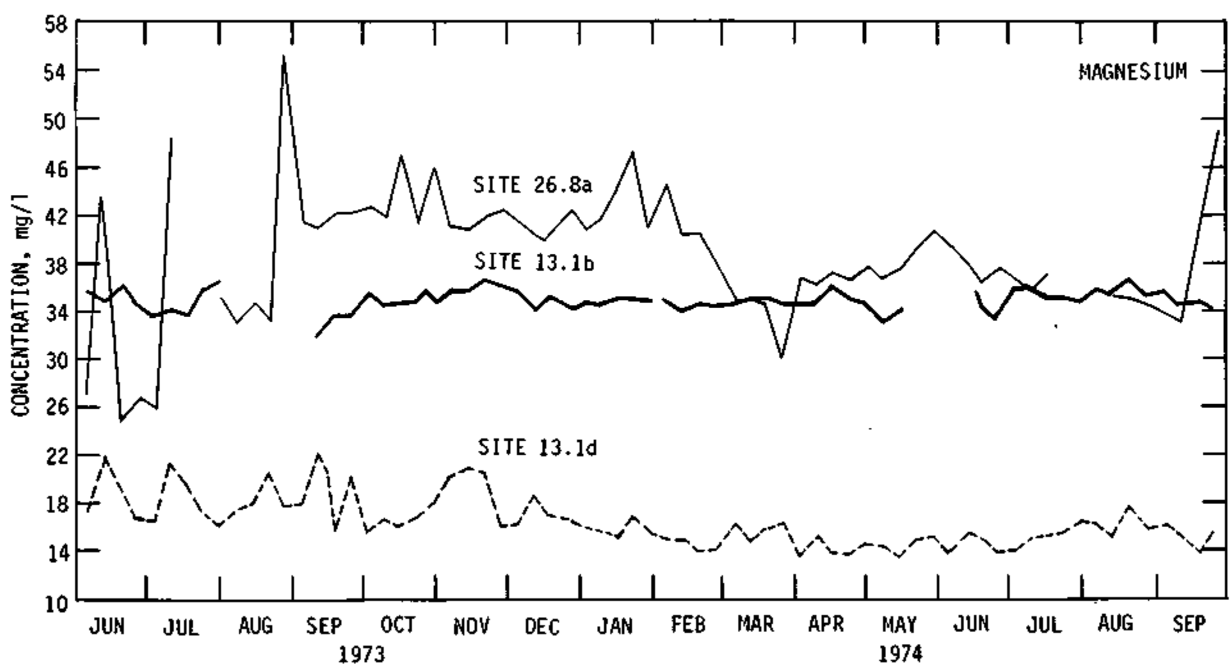


Figure 4. Weekly measurements of magnesium in groundwater at three sites.

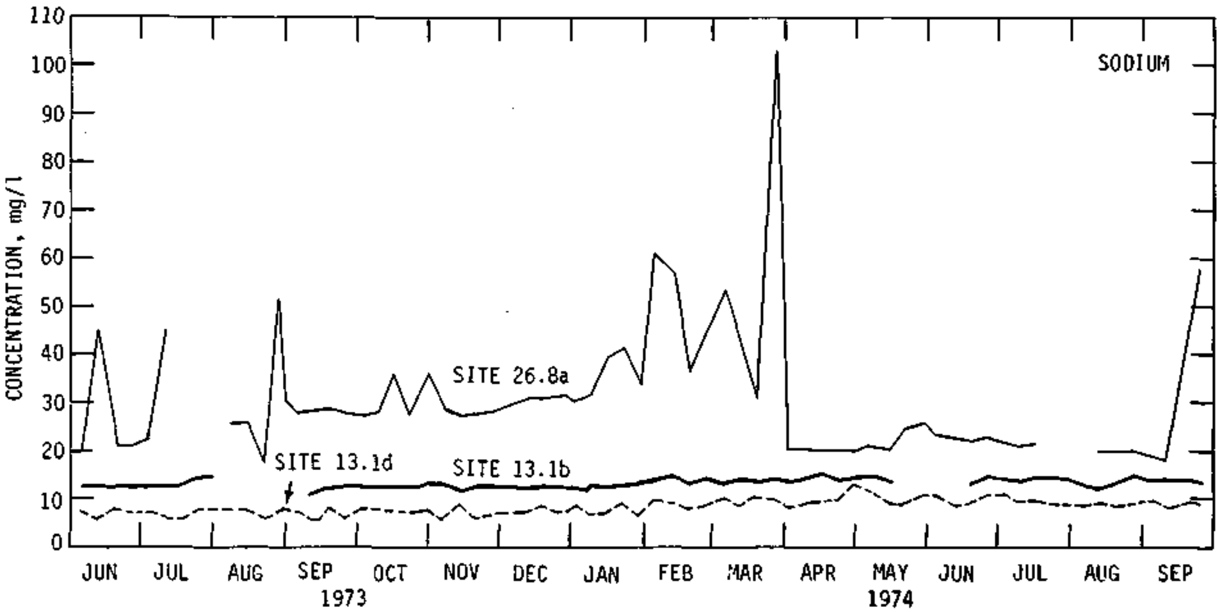


Figure 5. Weekly measurements of sodium in groundwater at three sites.

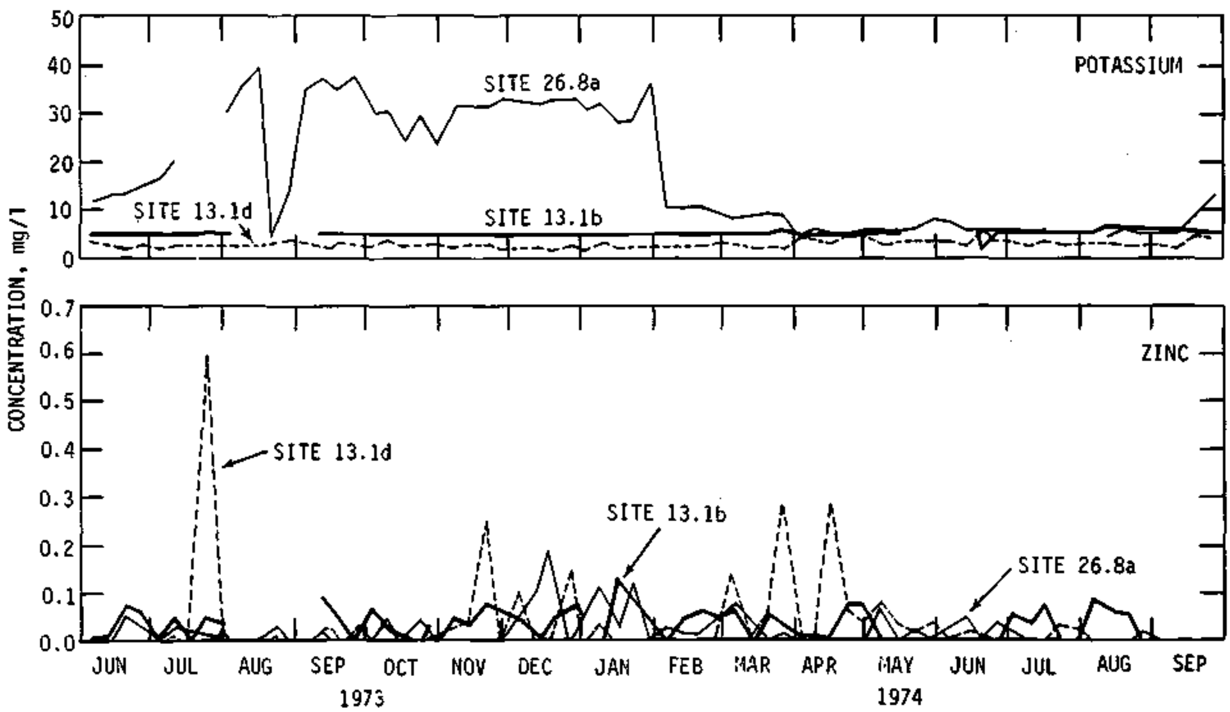


Figure 6. Weekly measurements of potassium and zinc in groundwater at three sites.

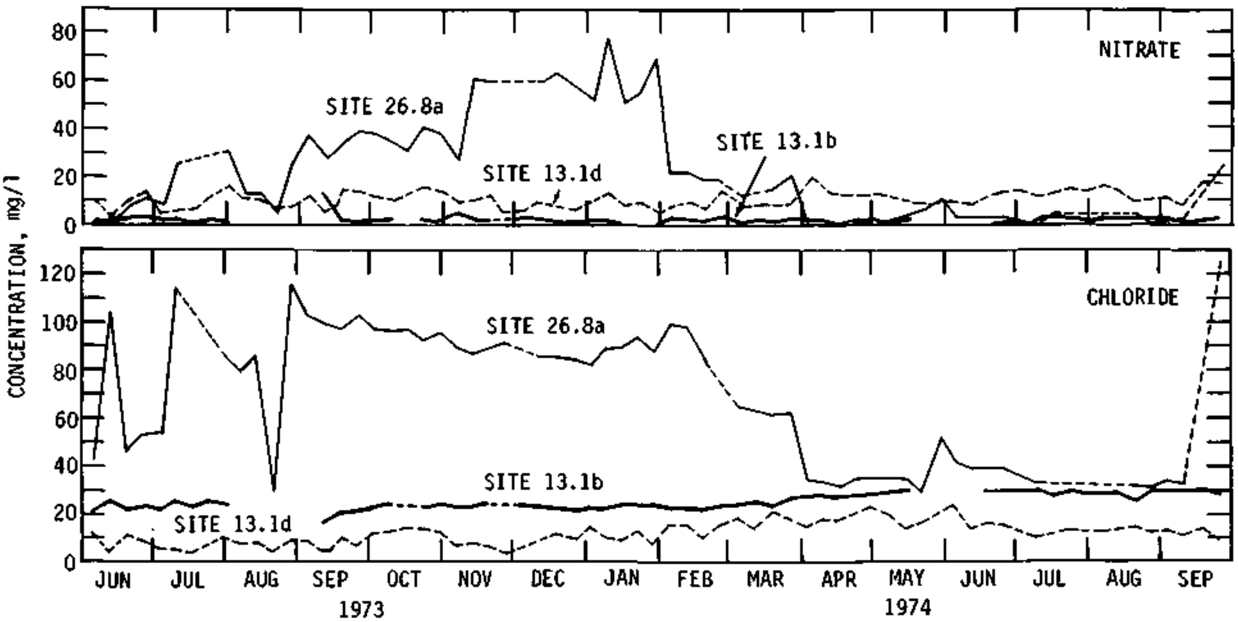


Figure 7. Weekly measurements of nitrate and chloride in groundwater at three sites.

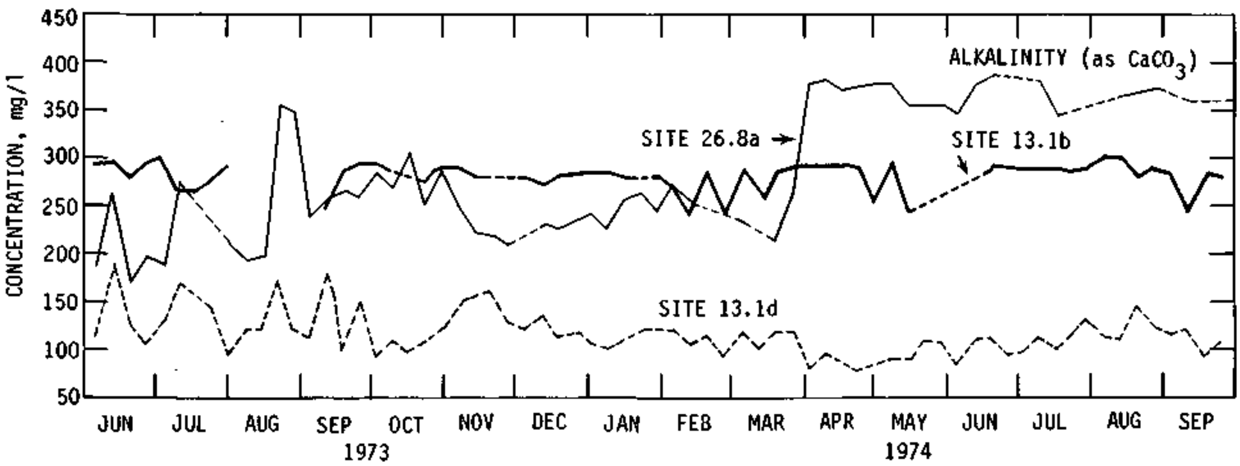


Figure 8. Weekly measurements of alkalinity (as $CaCO_3$) in groundwater at three sites.

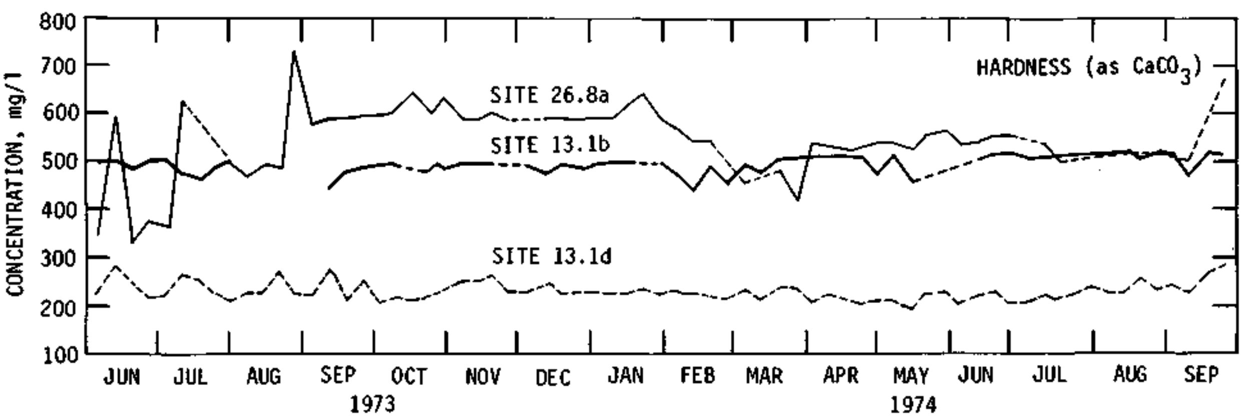


Figure 9. Weekly measurements of hardness (as $CaCO_3$) in groundwater at three sites.

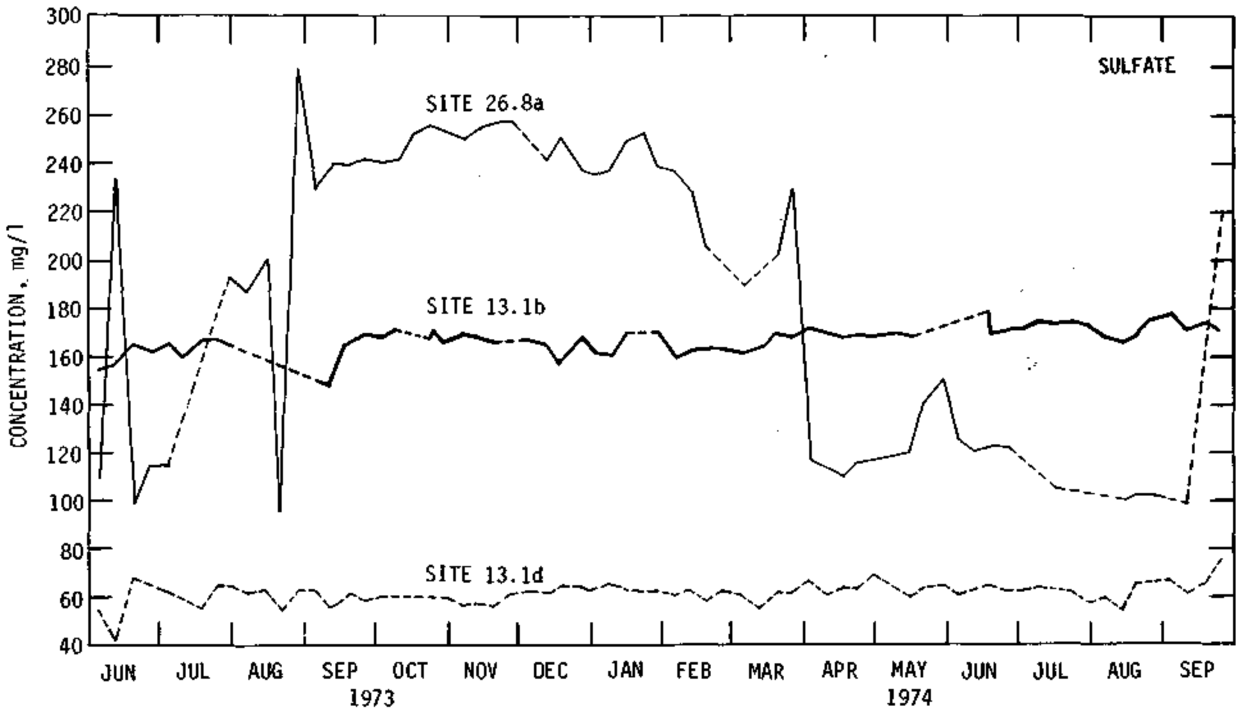


Figure 10. Weekly measurements of sulfate in groundwater at three sites.

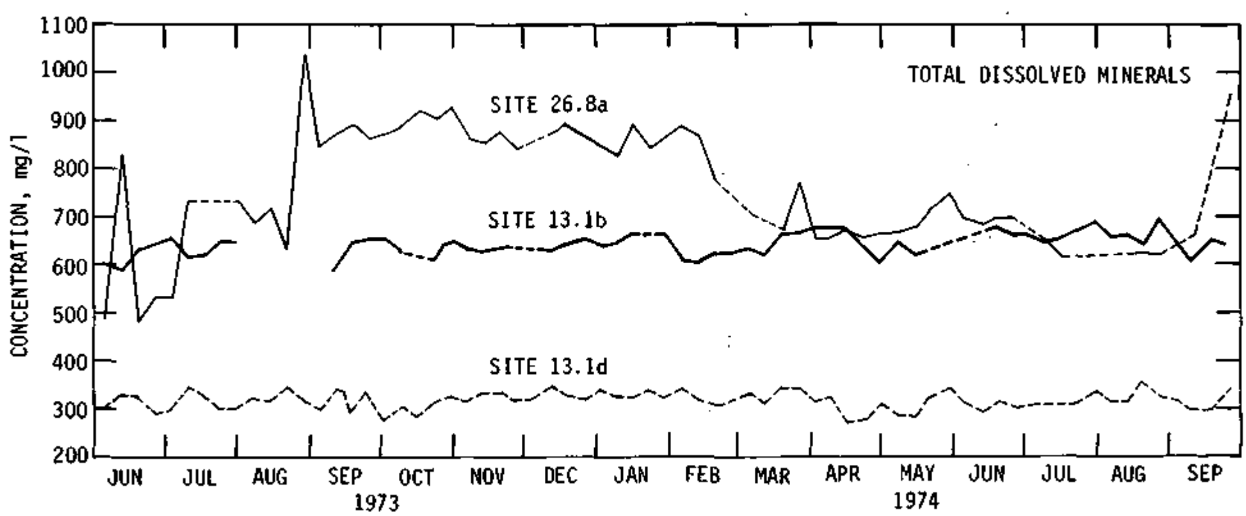


Figure 11. Weekly measurements of total dissolved minerals in groundwater at three sites.

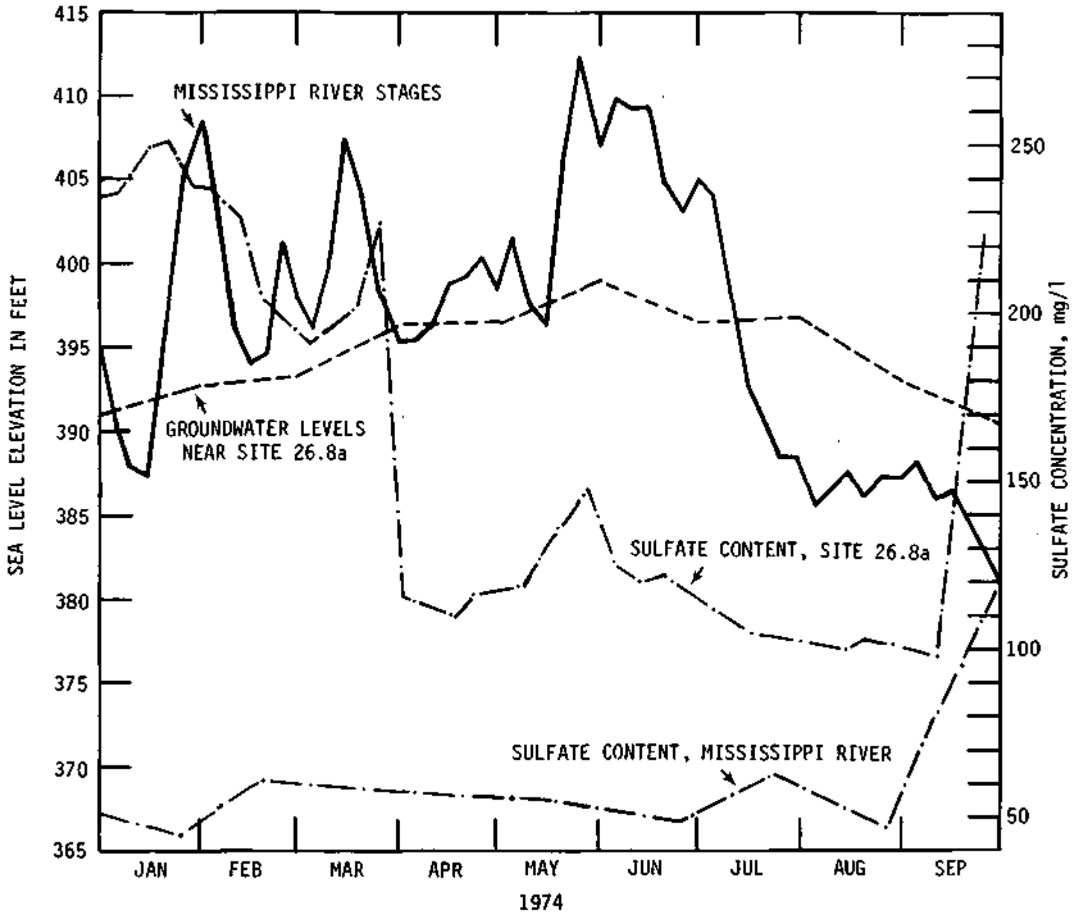


Figure 12. Relationship between sulfate content in Mississippi River and in a well at site 26.8a.

and March. The river stage declined below the groundwater stage during July. Sulfate content increased appreciably about 2 months later.

There are other factors affecting the groundwater quality at site 26.8a. It is close to a fertilizer plant, a large chemical plant, a zinc plant, and a landfill. Change in groundwater flow patterns because of nearby reductions or increases in groundwater pumpage could affect groundwater quality at the site.

With the exception of zinc, only slight week-to-week variations in chemical concentrations were recorded at sites 13.1b and 13.1d. Some of the variation may be attributed to sampling procedures. For example, the quality of groundwater is often influenced by the rate of pumping as well as the idle period and time of pumping prior to collection of the sample.

Considerable variations were recorded in zinc content. This could be attributed to the use of zinc in alloys used in well construction.

Although groundwater chemical quality in the area is highly variable, as illustrated by maps showing chloride and sulfate concentrations (Figs. 13 through 20), areas of high concentration can be delineated. For example, areas where chloride content exceeds 50 mg/l are shown in Figs. 13 through 16. The areas of high chloride content correspond to urban-industrial areas, and along the Madison-St. Clair County line, extend east of an industrial center at Fairmont City.

Sulfate concentrations are given in Figs. 17 through 20. Sulfate concentrations of greater than 200 mg/1 were delineated in the southern part of the area. Decreasing concentrations of sulfates are shown near the Mississippi River in the northern part of the area illustrating the dilution effect of the river.

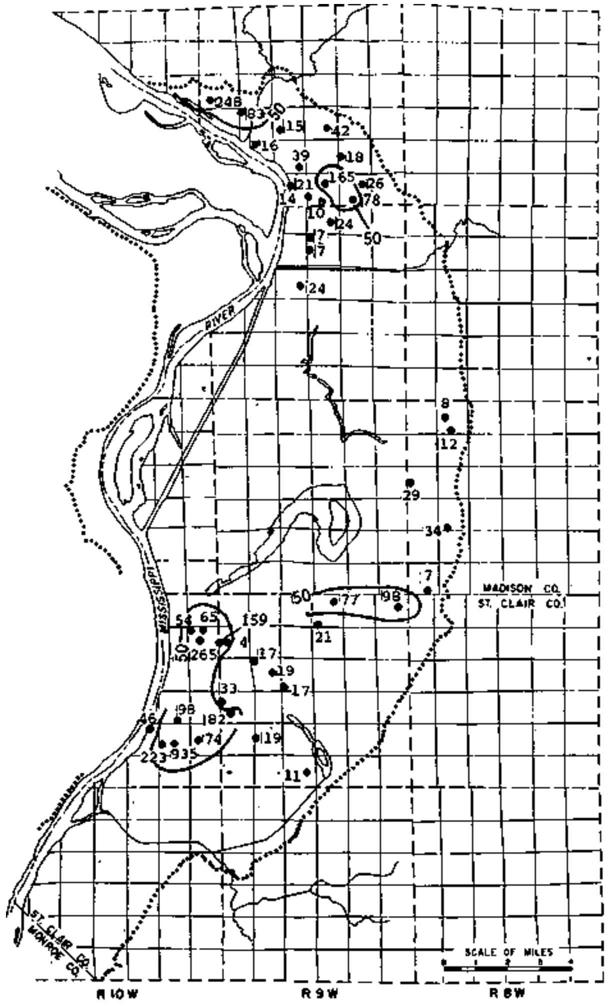


Figure 13. Chloride content (mg/l) during June 1973.

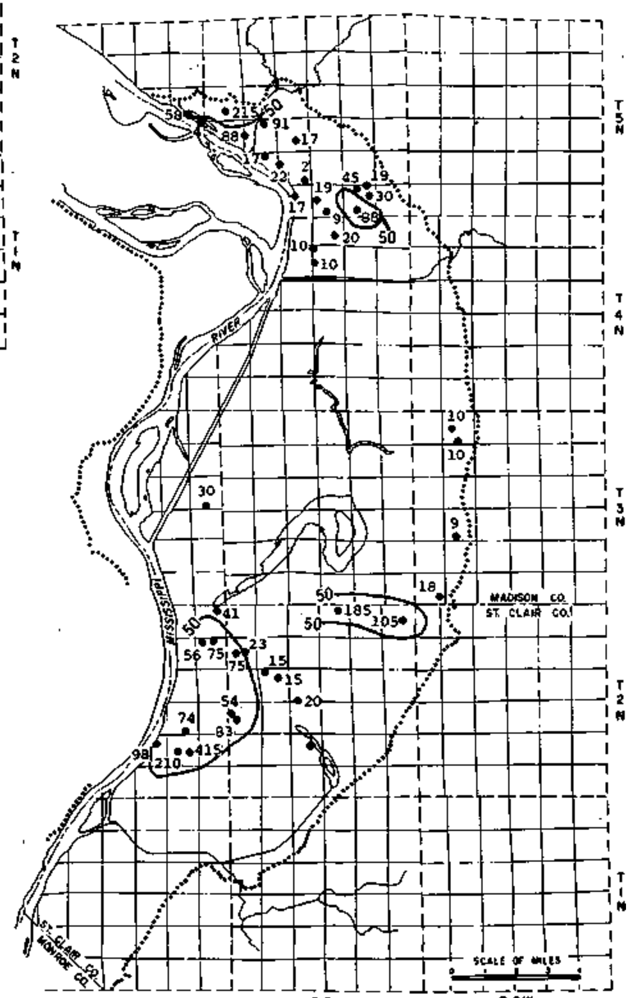


Figure 14. Chloride content (mg/l) during September 1973.

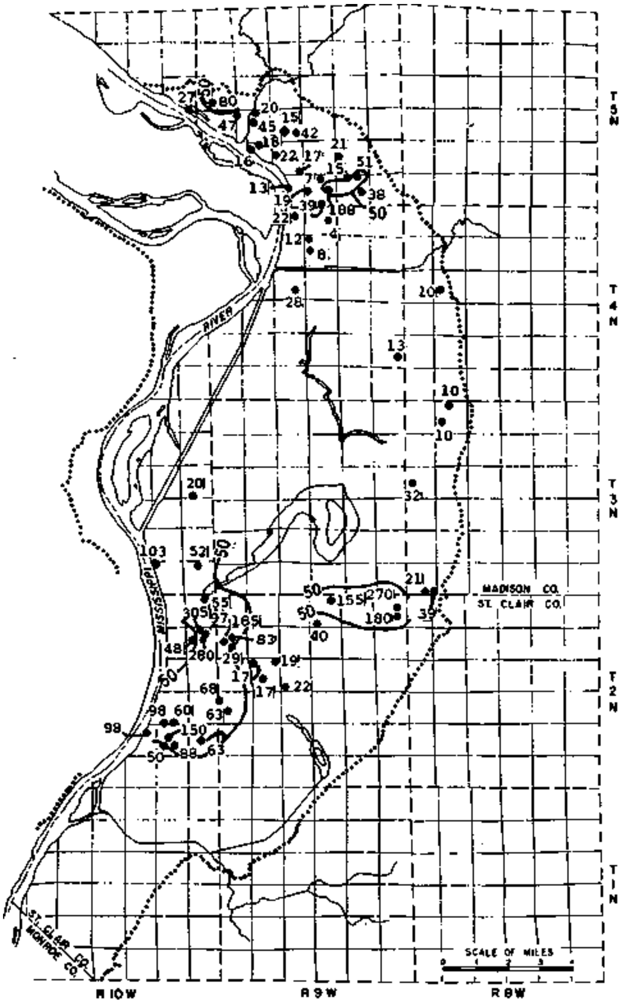


Figure 15. Chloride content (mg/l) during June 1974.

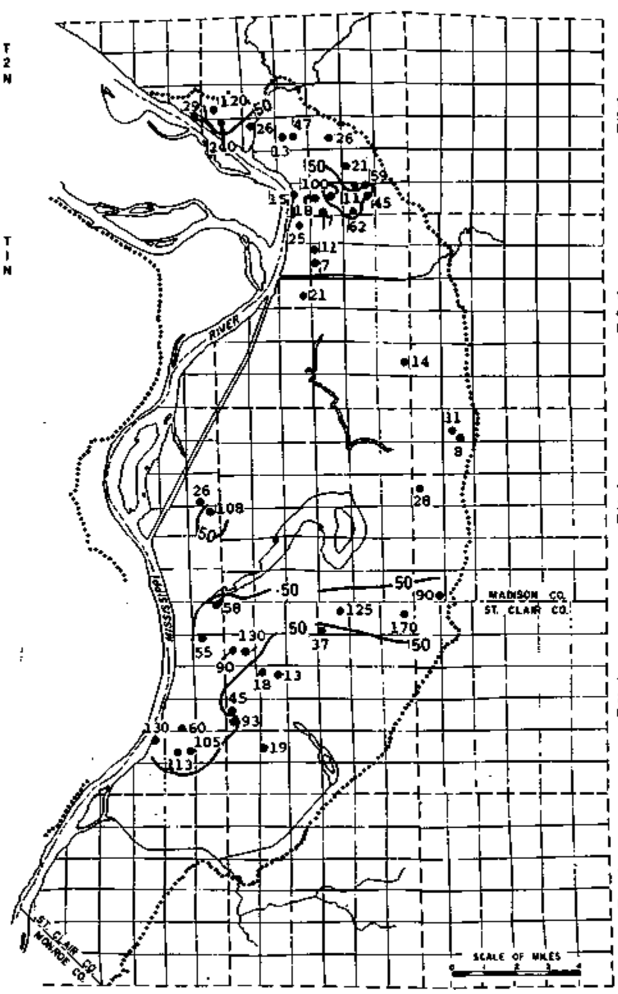
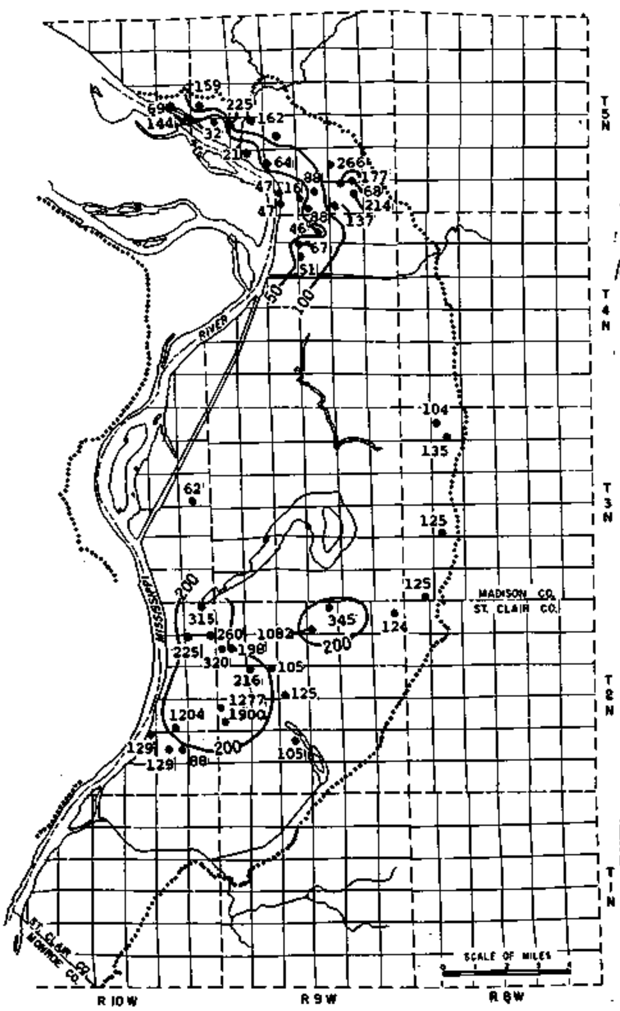


Figure 16. Chloride content (mg/l) during September 1974,

Figure 17. Sulfate content (mg/l) during June 1973.



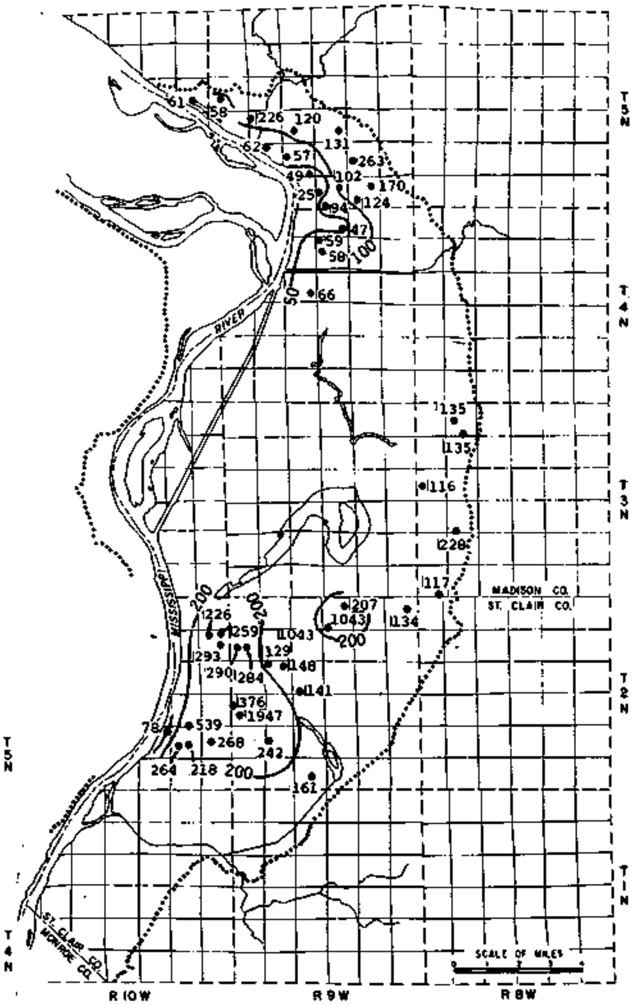


Figure 18. Sulfate content (mg/l) during September 1973.

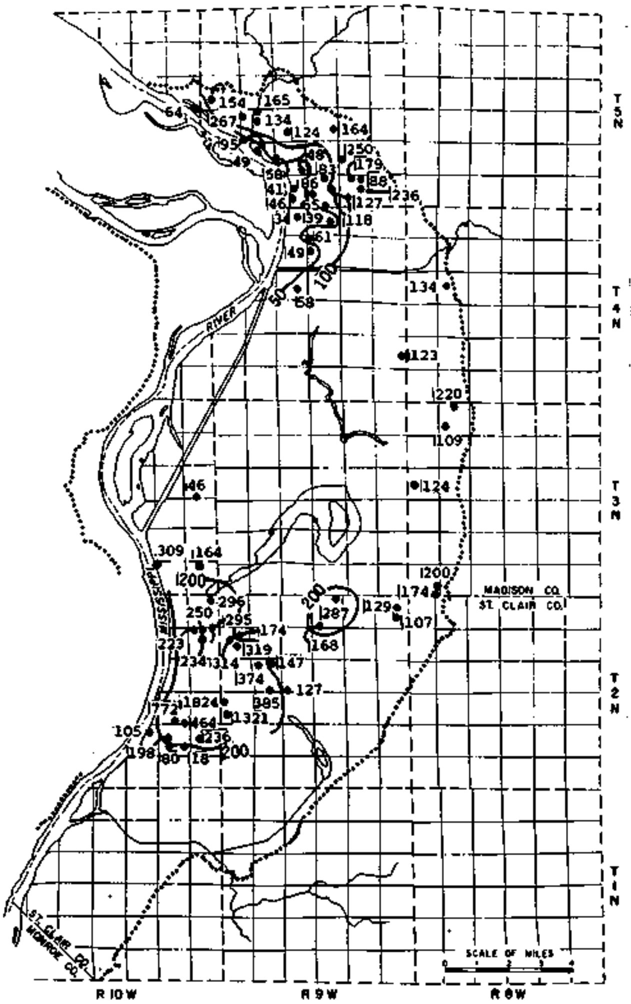


Figure 19. Sulfate content (mg/l) during June **1974.**

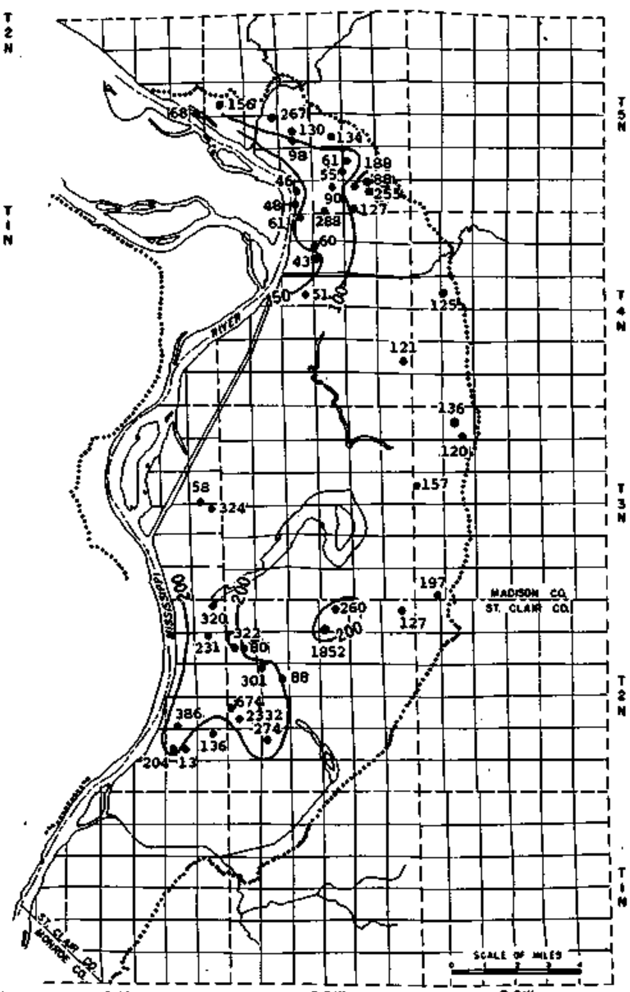


Figure 20. Sulfate content (mg/l) during September 1974.

Table 6. Comparison of seasonal median concentrations of combined atmospheric rainout and dry fallout at three selected stations during weeks with rain (from Huff, 1975).

(Median concentrations in mg/l)

Station	*Ca*	*Mg*	*Na*	*K*	*Zn*	*NO_3*	*Cl*	*SO_4*	*TDM*	*Number of samples*
Summer, 1973										
22	0.77	0.08	0.02	0.07	0.03	1.24	0.22	4.12	15.4	5
81	1.93	0.23	0.09	0.13	0.02	1.77	0.29	4.19	13.6	7
151	4.54	0.61	0.10	0.38	0.01	1.23	0.31	4.45	19.8	8
Fall, 1973										
22	1.54	0.16	0.09	0.21	0.09	2.30	0.39	6.15	10.6	9
81	2.57	0.36	0.08	0.18	0.03	1.81	0.38	4.65	12.3	9
151	4.23	0.71	0.06	0.30	0.03	1.69	1.37	2.75	14.3	10
Winter, 1973-1974										
22	0.96	0.07	0.08	0.05	0.05	1.37	0.24	3.66	8.1	9
81	0.61	0.10	0.16	0.08	0.03	150	0.11	2.96	9.9	11
151	2.50	0.43	0.16	0.05	0.05	1.22	0.32	3.32	12.3	11
Spring, 1974										
22	1.97	0.20	0.12	0.13	0.12	3.21	0.48	7.20	17.5	6
81	2.14	0.23	0.24	0.12	0.03	1.77	0.49	4.81	16.8	11
151	4.13	0.61	0.37	0.24	0.05	1.69	0.63	4.32	17.3	11
Summer, 1974										
22	1.81	0.19	0.30	0.22	0.19	1.94	0.62	7.03	15.0	6
81	2.59	0.27	0.18	0.29	0.01	0.63	0.76	4.38	17.1	8
151	3.51	0.52	0.14	1.07	0.02	1.46	0.57	4.61	19.8	6

WEEKLY CONCENTRATIONS AND DEPOSITIONS OF ATMOSPHERIC RAINOUT AND FALLOUT

Weekly samples of rainwater and dry fallout were collected at three locations in large plastic bags *(see* Stout, 1969, for description). All three locations are outside of major urban-industrial complexes. Station 22 is frequently downwind of the Alton-Wood River industrial area, station 81 is frequently downwind of the Granite City industrial area, and station 151 is frequently downwind of the East St. Louis industrial area *(see* Fig. 2).

Median values of the weekly concentrations of rainwater and dry fallout combined, as reported by Huff (1975), were obtained from samples at the three stations and are given in Table 6. (For further discussion concerning atmospheric rainout and fallout deposition the reader is referred to Huff, 1975.)

EFFECTS OF PRECIPITATION SCAVENGING OF URBAN-INDUSTRIAL POLLUTANTS ON GROUNDWATER QUALITY

The vehicle for transporting atmospheric pollutants to the groundwater reservoir is that part of the rainfall or melted snow that infiltrates from the surface into soil and other rock materials directly below the surface, and then moves slowly downward through unsaturated materials to the water table where it enters the saturated zone and becomes groundwater. The

Table 7. Comparison of concentrations of chemical constituents in atmospheric rainout and dry fallout with groundwater.

(Chemical constituents in mg/l)

	Rainout and dry fallout		Groundwater		
	High median	High median increased five times	Low	Low 90%	Low median
Ca	4.54	22.70	29.2	54.3	96
Mg	0.71	3.55	10	16	26
Na	0.37	1.85	2	10	14
K	1.07	5.35	0.9	0.9	2.9
Zn	0.19	0.95	0.0	0.0	0.0
NO_3	3.21	16.05	0.0	0.34	1.5
Cl	0.76	3.80	2	7	19
SO_4	7.20	36.00	13	37.6	88
TDM	19.8	99.0	186	278	483

effect on changes in groundwater quality from atmospheric urban-industrial pollutants is partly dependent upon the percent of precipitation that reaches the water table (groundwater recharge), the percent of precipitation that evaporates and transpires, and to some extent the hydrogeology of the aquifer. Most of the precipitation that falls on the surface and seeps into the ground is returned to the atmosphere by evaporation and transpiration and is lost as far as groundwater recharge is concerned. As the water is evaporated and transpired, its chemical constituents are either concentrated in the downward percolating water, or precipitated, or adsorbed by the soil.

Other factors that influence the effect of atmospheric pollutants on groundwater quality are exchange and adsorption rates, biological activity of the soil material, and the uptake of nutrients by plants. Chloride, for example, is relatively free from effects of exchange, adsorption, biological activity, and plant uptake. Zinc is readily attenutated by soil material. Sulfate reduction will occur if sulfate-reducing bacteria are active in the soil. Nitrate is readily taken up by plants.

Increase in chemical concentration for constituents such as chloride will be largely dependent upon the ratio of groundwater recharge to evapotranspiration; the higher the groundwater recharge and the lower the evapotranspiration, the less of an increase in concentration will occur. According to Schicht (1965) groundwater recharge in the area from precipitation averages about 7.8 inches per year. According to Jones (1966) annual evapotranspiration in the study area is about 29 inches. Thus, the concentration of chloride in the recharge water may increase almost five times before reaching the water table. It should be noted that the five-fold increase in chloride concentration does not include chlorides that might be dissolved from overlying earth materials.

Concentrations of chemical constituents in atmospheric rainout were compared with concentrations of chemical constituents in groundwater. The highest median concentrations recorded in atmospheric rainout and dry fallout (Table 6) and the lowest concentrations recorded in ground water (Tables 1-4) are given in Table 7. Median concentrations of calcium, magnesium, sodium, chloride, sulfate, and total dissolved minerals in rainout and dry fallout are considerably less than their lowest concentrations recorded in groundwater. Even after a five-fold increase, concentrations for calcium, magnesium, sodium, and total dissolved minerals remain considerably less than their lowest concentrations in groundwater. After an increase of five times, the highest median concentrations for sulfate exceeds the lowest concentration in groundwater (Table 7). It is less, however, than the sulfate content exceeded in 90% of the groundwater samples.

The concentration in the median sample of groundwater for zinc is low, ranging from 0.0 mg/l to 0.07 mg/l. Median concentrations of zinc in atmospheric rainout and dry fallout range from 0.01 to 0.19 mg/l (Table 6). Zinc concentrations in groundwater in a few samples were extremely high (174 mg/l in one sample from a well at a zinc processing plant). Although the zinc concentrations in rainout and dry fallout are significant compared with the concentrations in most of the groundwater samples, zinc is readily attenuated by soil materials. Griffin et al. (1976) reported that zinc is strongly attenuated by even small amounts of clay.

The potassium content in rainout and dry fallout is significant compared with its content in groundwater. However, according to Griffin et al. (1976), potassium is moderately attenuated by soil materials. The nitrate content in rainout and dry fallout is also significant in comparison with normal nitrate content in groundwater. Plant uptake of nitrates is significant, however.

In summary, at the concentrations measured during this study, it is highly unlikely that precipitation scavenging of urban-industrial pollutants contributes significantly to the degradation of groundwater quality.

PIPER AND SCHOELLER DIAGRAMS

Graphical methods described here were used to detect trends in groundwater quality from analyses of weekly samples.

Ionic values of the major groundwater constituents Ca, Mg, Na, K, Cl, SO_4, and Alkalinity (as $CaCO_3$) were converted to equivalents per million (epm) and plotted graphically with the use of techniques described by Piper and Schoeller (Hem, 1959). The Piper method uses a trilinear diagram in which cation and anion equivalent proportions are plotted on their respective triangular fields, and their intersecting projected point is then located on a diamond-shaped field in the upper center of the graph. The Schoeller technique utilizes a semilogarithmic graph in which cation and anion equivalents are plotted on the logarithmic scale. Adjacent points are then connected by lines and the resultant pattern characterizes the water type. In order to avoid an indistinguishable mass of plots the data were reduced in number by plotting analyses from every three months instead of weekly. For historical comparison available analyses from earlier years were also plotted on the graphs.

Water from all three sites fell into the same general field in the Piper trilinear plots — that of a Ca-Mg-HCO_3-SO_4 type (Figs. 21 through 23). This type of water, plotted in a Schoeller diagram (Figs. 24 through 26) has a U shape and is typical of waters found in areas of direct groundwater recharge. One feature of a Schoeller plot is that it lends itself easily to using ratios of the various constituents. For instance, a noticeable consistency was seen among all samples in their Ca/Mg ratio. Values of this ratio at sites 13.1d, 26.8a, and 13.1b averaged 2.32, 2.39, and 2.46, respectively, with deviations generally less than 10%.

Other ratios for these three sites were determined during the calculations for using the Piper plots, and three of these proved of interest, Na/total cations, Cl/total anions, and SO_4/total anions. The Na/cations ratios of 0.09, 0.14, and 0.07 and the Cl/anions ratios of 0.08, 0.12, and 0.06 for the three sites were consistently low. These relatively low proportions were also observed in the historic data at all sites. The SO_4/anions ratio, on the other hand, indicated a greater proportion of this anion, 0.23, 0.29, and 0.32, respectively.

Water from site 13.1d had considerable variability in Cl, but Cl was usually several times greater than that observed in a 1940 sample. Samples at site 13.1b exhibited little variation in character (Figs. 23 and 26) both throughout the sampling period and in comparison with historic data. Samples at site 26.8a showed considerable variability in Na, Cl, and SO_4 during sampling

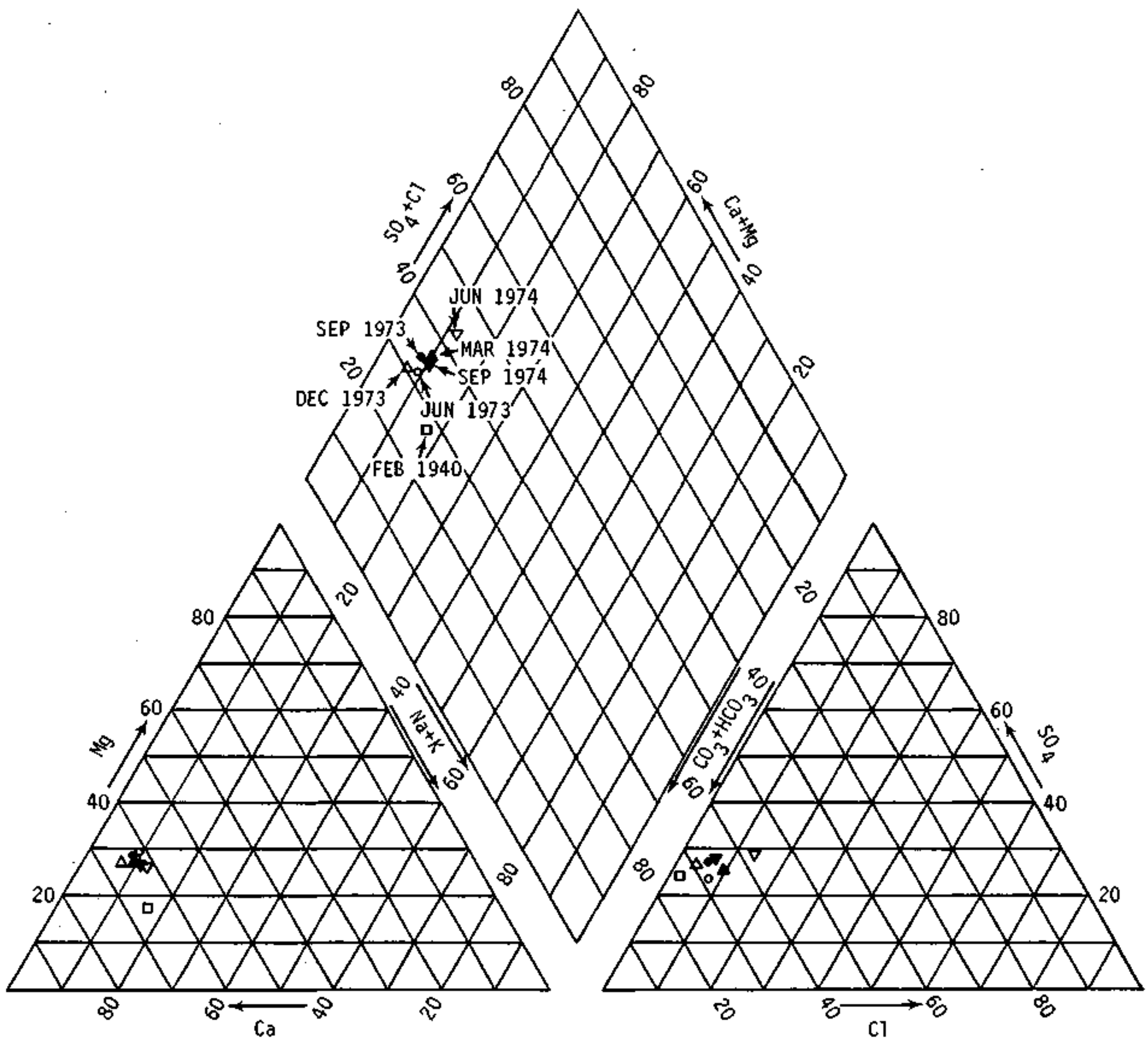


Figure 21. Piper trilinear diagram for site 13.1d.

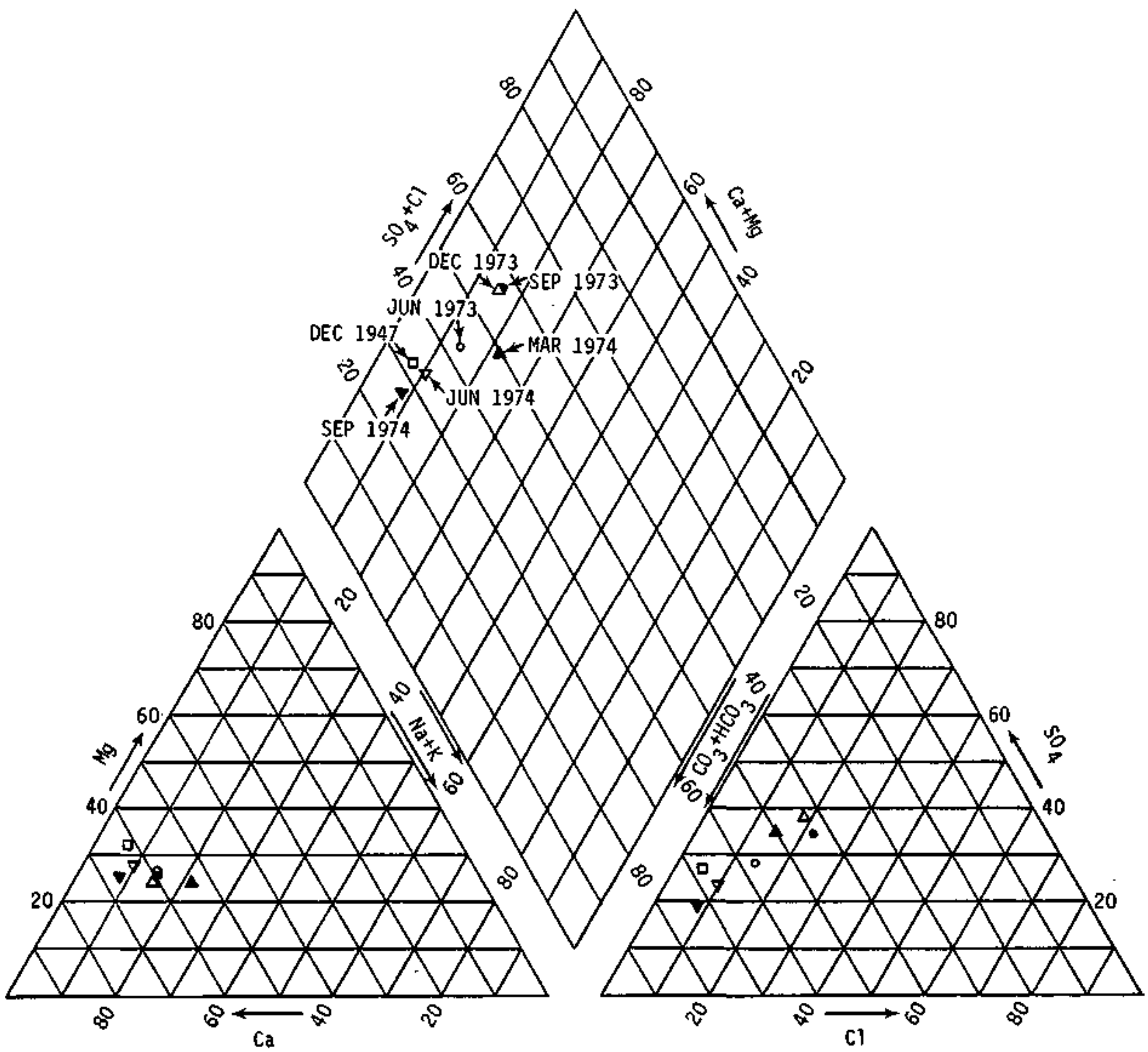


Figure 22. Piper trilinear diagram for site 26.8a.

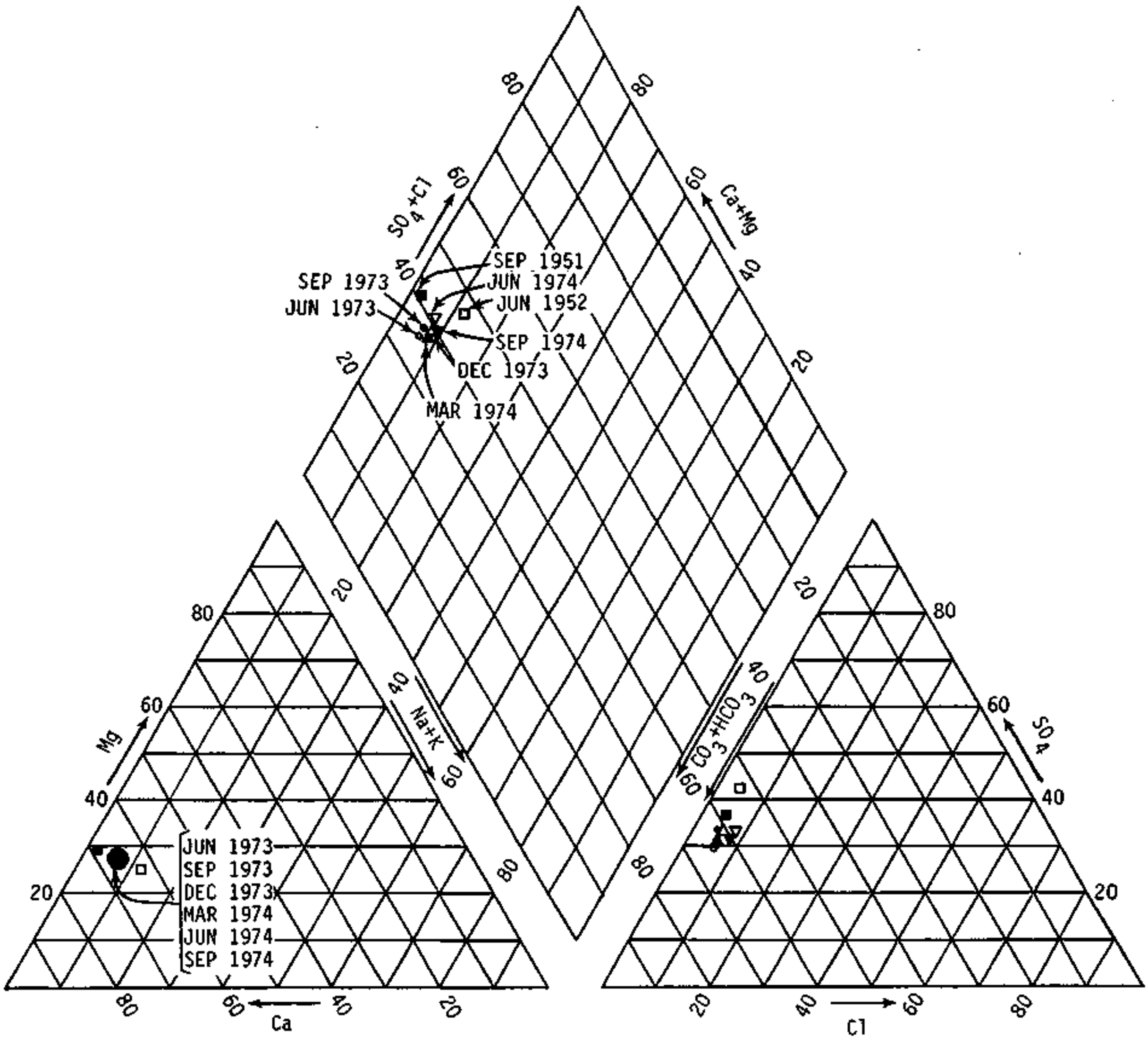


Figure 23. Piper trilinear diagram for site 13.1b.

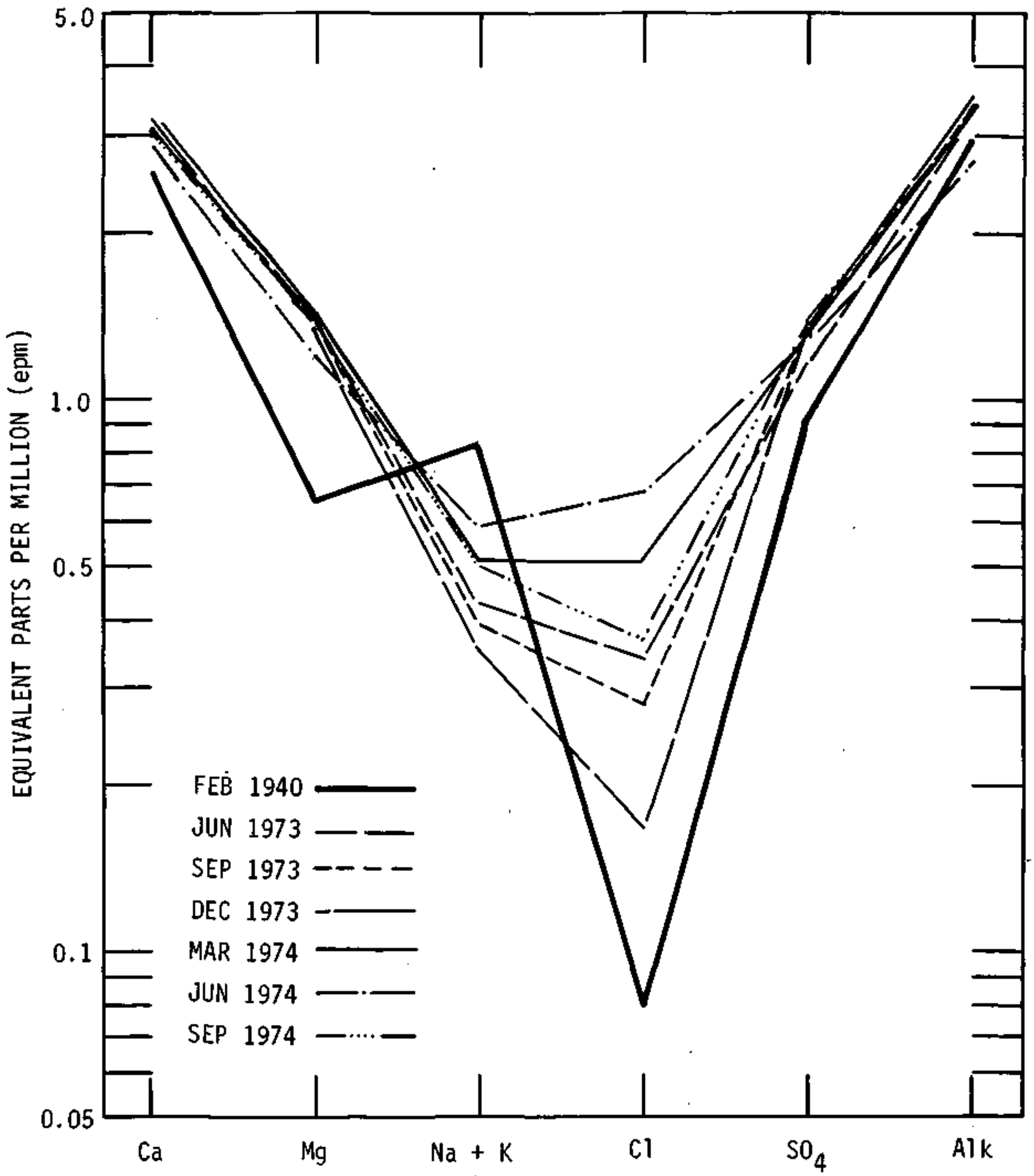


Figure 24. Schoeller plots for site 13.1d.

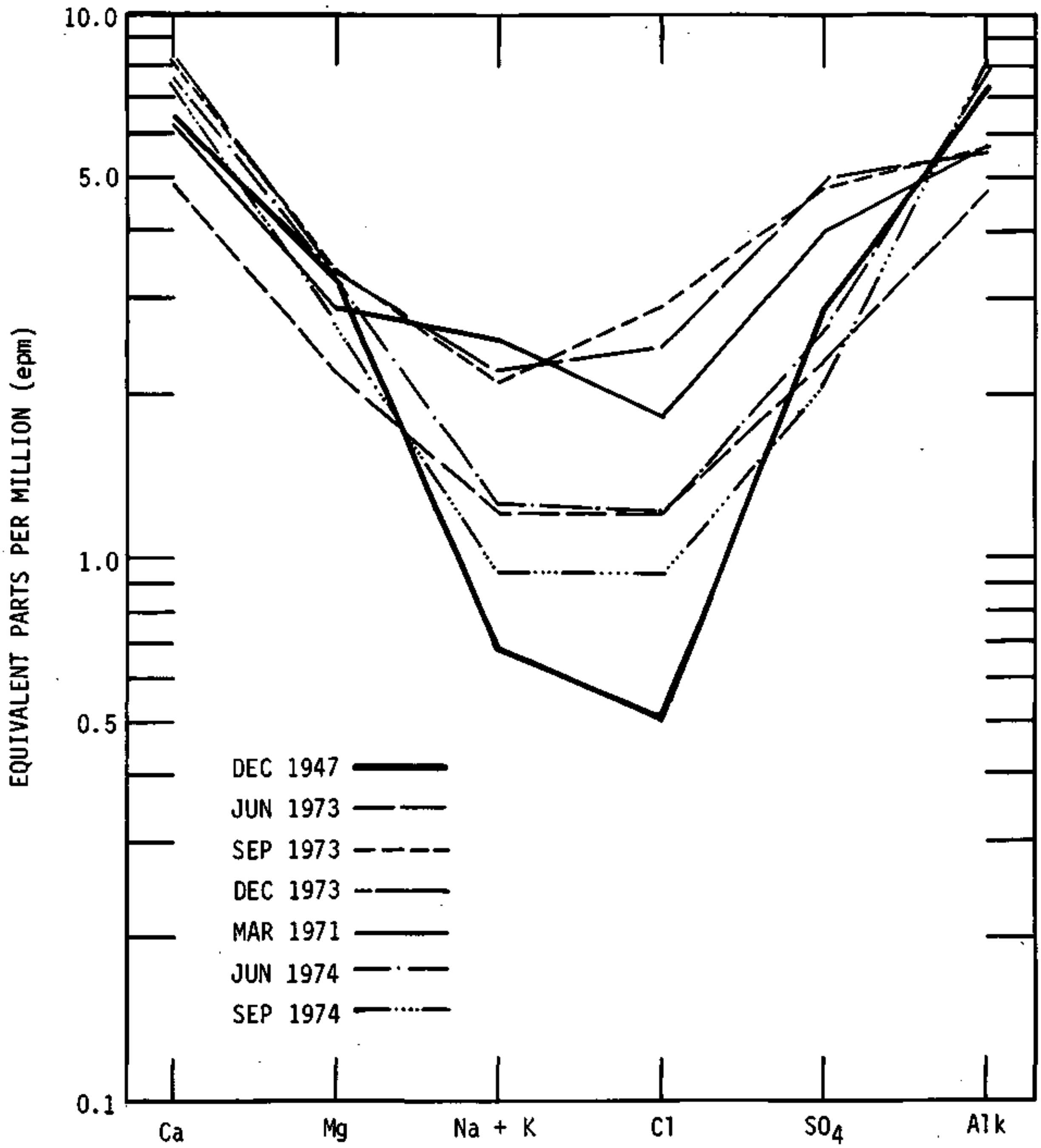


Figure 25. Schoeller plots for site 26.8a.

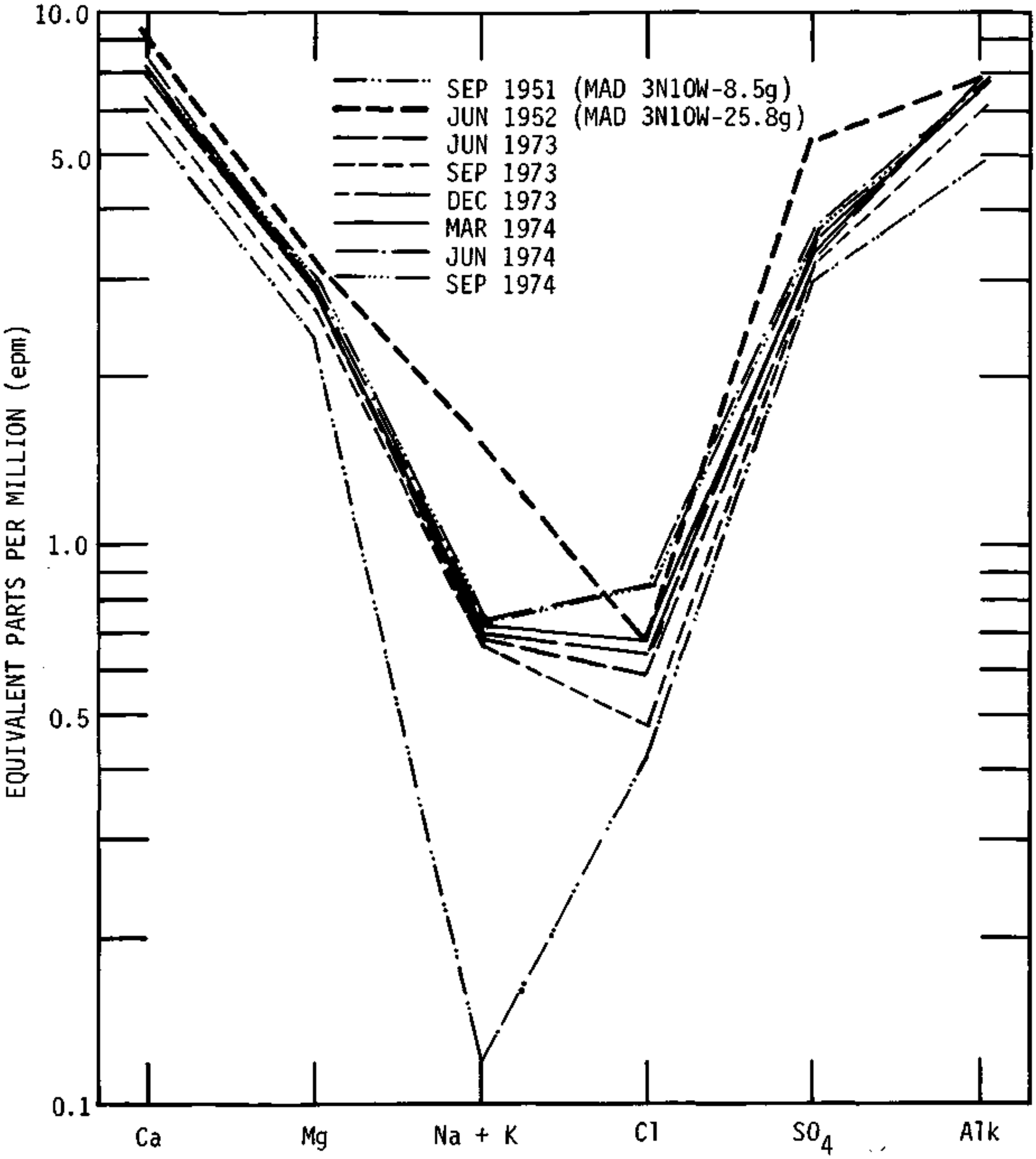


Figure 26. Schoeller plots for site 13.1b.

and in the historic data comparison. The large degree of variability is believed due to the well's location in a large pumping center where the cone of depression extends to the Mississippi River and induces river water to flow into the aquifer. A portion of the groundwater at this site is, therefore, contributed by the river and its variable quality merely reflects that of the river itself. Figures 27 and 28 illustrate the variability of the water quality in the Mississippi River found in samples at Keokuk, Iowa, and at East St. Louis.

The results of groundwater sampling at the three sites lead to the following conclusions:

1) Although differing from one another in total concentration, groundwater samples at the three sites were all similar in general character —that of a Ca-Mg-HCO_3 -SO_4 type.
2) Ca/Mg ratios for all samples were also very similar, and were consistent throughout the study with deviations generally less than 10%.
3) Water from sites 13.1b and 13.1d showed little basic change —except for variations in the proportions of minor ionic constituents —throughout the study. Variations in the proportions of these same constituents were observed at site 26.8a; however, such changes could reasonably be explained by contributions of Mississippi River water at that site.
4) The samples generally indicated not only a low degree of variability in water type throughout the study but also —when compared with historical data —an apparent temporal stability that might not have been reasonably expected in an area of such intensive industrial development.

LONG-TERM CHANGES IN GROUNDWATER QUALITY

Early Groundwater Quality Data

Groundwater quality data collected since the early 1900's were investigated to determine any long-term changes. Since chlorides and sulfates are two constituents for which analyses are commonly made, long-term changes for these constituents were studied.

Few groundwater quality data are available for the area before industrialization, the earliest being that tabulated by Bowman and Reeds (1907). Schicht (1965) indicated there were significant groundwater withdrawals for industrial use before 1900.

Chloride and sulfate contents in groundwater from wells completed in the valley fill, as described by Bowman and Reeds (1907), are given in Table 8 and Fig. 29. The highest concentrations of chlorides and sulfates are in two shallow dug wells located in T2NR8W along the bluffs. Construction features of shallow dug wells would make them susceptible to contamination from surface seepage. There are several mined-out areas of coal in the Pennsylvanian strata beneath the uplands immediately east of the bluffs. Coal mining operations and coal mine wastes are a common source of sulfate pollution, whereas domestic and industrial wastes can contribute large amounts of chlorides to groundwater.

As shown in Table 8, chemical analyses with three exceptions are from wells owned by industries. It is probable that groundwater quality in the vicinity of the industries is affected by industrial activity.

Chloride and sulfate contents in municipal wells in the valley fill outside of the East St. Louis area (areas not affected by industrial activity) are given on page 32. Chloride and sulfate contents are from recent analyses in Water Survey files.

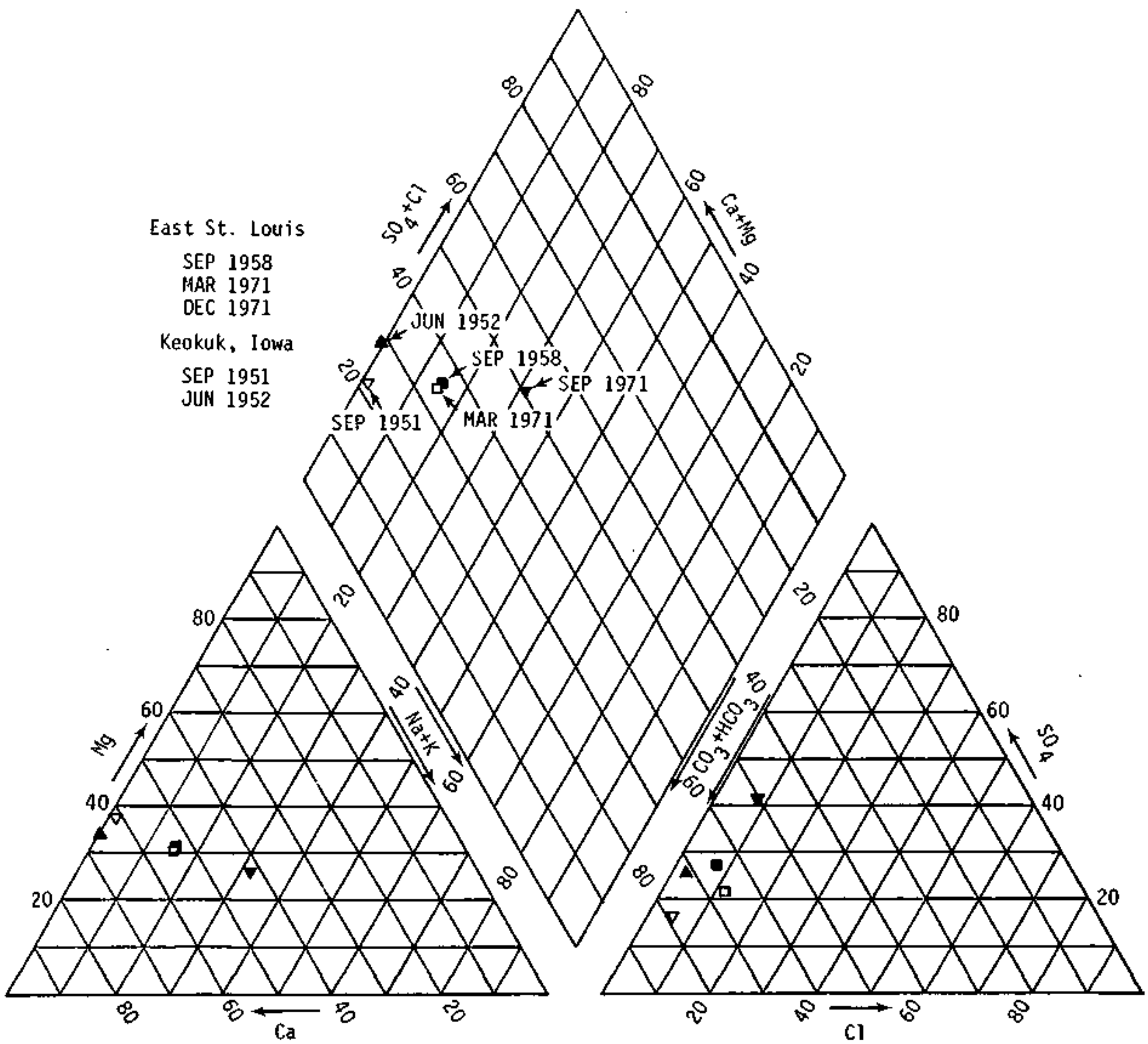


Figure 27. Piper trilinear diagrams for Mississippi River water analyses.

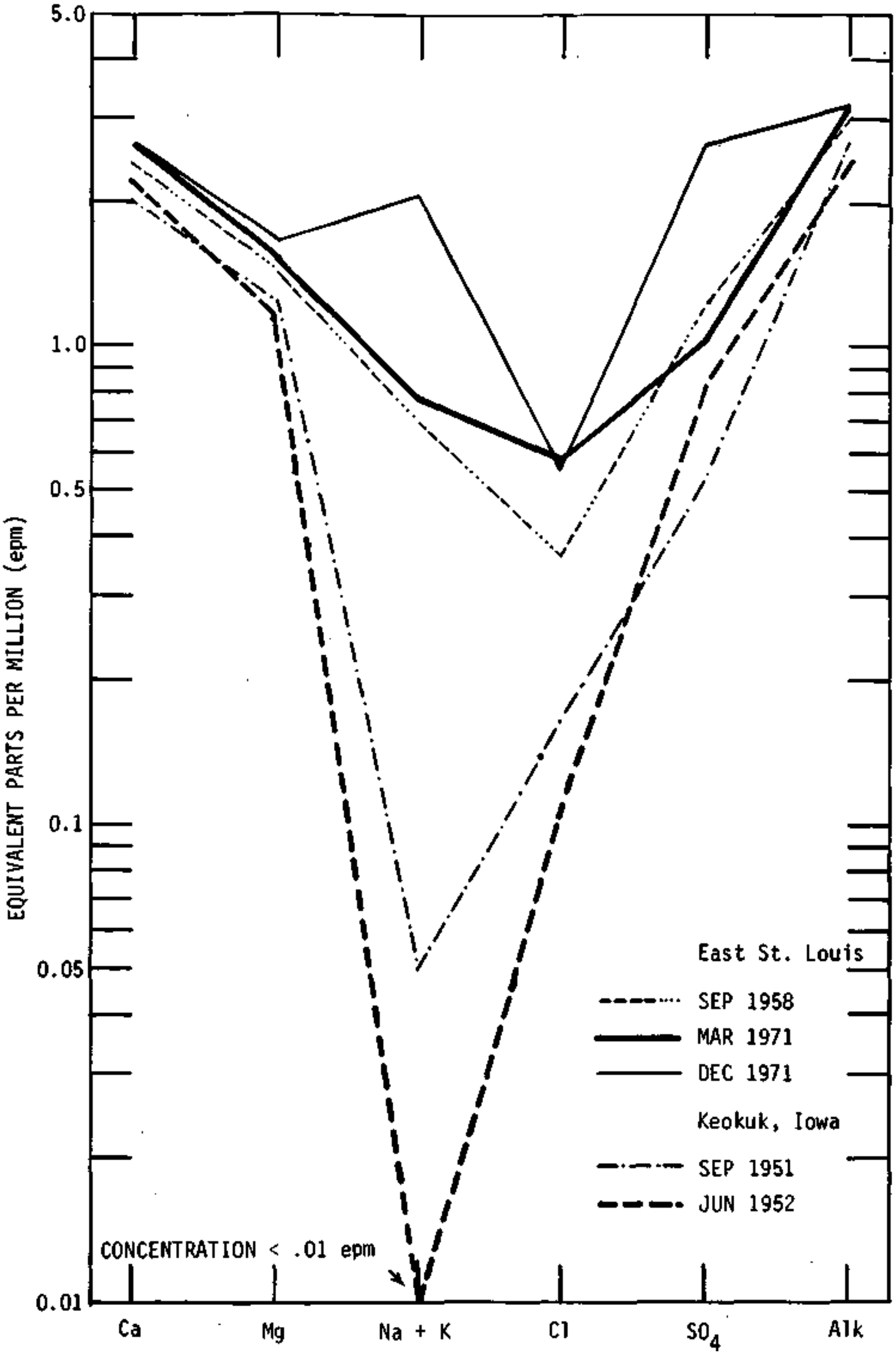


Figure 28. Schoeller plots for Mississippi River water analyses.

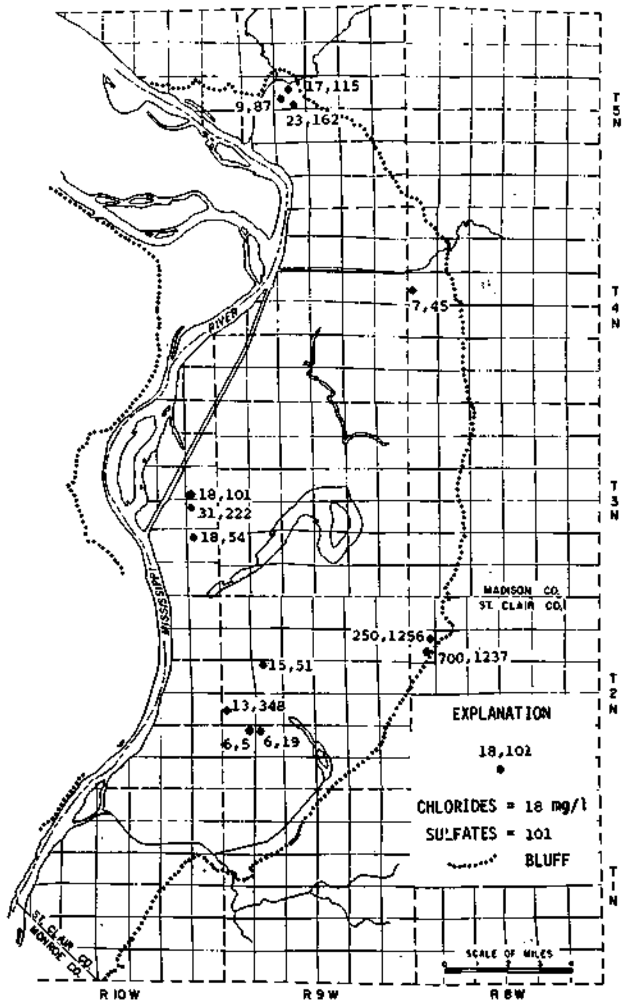


Figure 29. Chloride and sulfate content in water samples during 1906 from wells in the valley fill (from Bowman and Reeds, 1907).

Table 8. Chloride and sulfate concentrations in water samples collected during 1906 from wells in the valley fill (from Bowman and Reeds, 1907).

Owner	*Location*	*Well depth (ft)*	*Chlorides (mg/l)*	*Sulfates (mg/l)*
Beal Brothers	T5NR9W	37	9	87
Big Four Railroad Co.	T5NR9W	54	23	162
Union Cap & Chemical Co.	T5NR9W	35	17	115
Corn Products	T3NR10W	80	18	101
American Steel Foundries Co.	T3NR10W	80	31	222
American Car & Foundry Co.	T3NR10W	66	18	54
Unknown	T2NR8W	25	700	1237
Unknown	T2NR8W	40	250	1256
Pittsburgh Reduction Co.	T2NR8W	140	6	19
Illinois Mineral Milling Co.	T2NR9W	57	13	348
Railway Steel Spring Co.	T2NR9W	80	15	51
Pittsburgh Reduction Co.	T2NR9W	120	6	5
Village of Edwardsville	T4NR8W	*	7	45

• Core sample

Owner	*Chlorides (mg/l)*	*Sulfates (mg/l)*
Village of Valmeyer	91	113
Village of Prairie du Rocher	3	0
Village of Grand Tower	8	46
McClure-East Cape Girardeau Water District	13	32
Village of Thebes	18	40
Anna State Hospital	2,4	10,13

It is difficult to generalize groundwater quality under natural conditions. However, sulfates are usually less than 100 mg/l and chlorides less than 25 mg/l.

Groundwater Quality Data from a Municipal Well Field

Infrequent analyses for chlorides and sulfates are available since 1906 (Table 9) from the village of Edwardsville's municipal well field at Poag in Madison County in Section 13, T4NR9W. The well field is located in a rural area. Groundwater withdrawals (Fig. 30) have increased gradually from 0.2 mgd in 1900 to 1.3 mgd in 1974. As shown in Fig. 30, sulfate concentrations have increased gradually since 1906. Chloride concentrations do not show a gradual increase, but increase significantly in the 1970's.

It is difficult to attribute the changes in sulfates and chlorides to precipitation scavenging of urban pollutants on the basis of data collected during this study, as discussed previously.

Changes in water quality in the area have been attributed to upward movement of highly mineralized water from the bedrock formations that are immediately beneath the sand and gravel aquifer (Bruin and Smith, 1953).

According to Bergstrom and Walker (1956), rocks of Pennsylvanian age form the bedrock surface in the vicinity of the Edwardsville well field. Miller et al. (1974) indicate that waters having a high sulfate content are, for the most part, limited to the area underlain by rocks of Pennsylvanian age. On the basis of data in the Water Survey files, water levels in the Pennsylvanian bedrock below the valley fill are at a higher elevation than-water levels in wells in the sand and gravel aquifer

Table 9. Chloride and sulfate concentrations in water samples collected from Edwardsville wells near Poag.

Date sample collected	*City well number*	*Chlorides (mg/l)*	*Sulfates (mg/l)*
11/19/06	Composite sample	7	45
6/19/14	Composite sample	4	32
2/19/40	2	3	44
11/17/48	2	5	52
9/19/51	2	6	54
5/14/58	4	6	51
11/6/61	2	2	
4/3/62	5	3	53
4/14/71	Composite sample	8	
12/18/72	7	21	60
6/5/73	4	12	56
12/4/73	Composite sample	5	63
6/4/74	Composite sample	14	64

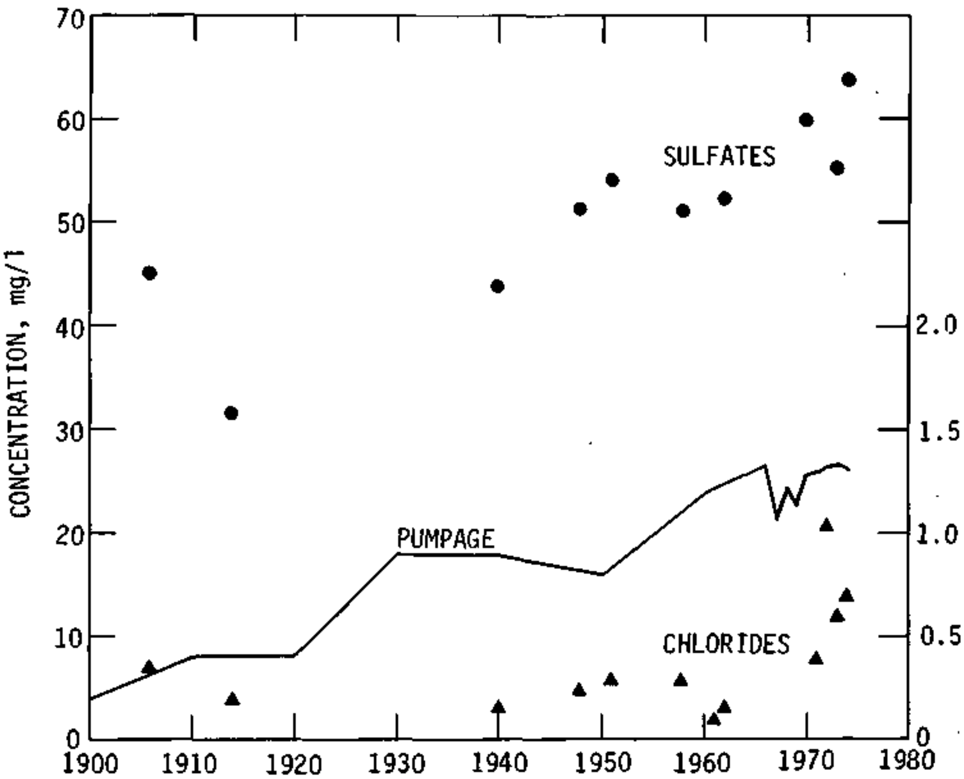


Figure 30. Sulfate and chloride content and groundwater withdrawals at site 13.1d, 1900-1974.

in the valley fill, which suggests that water from the Pennsylvanian bedrock moves upward into the valley fill. Development of groundwater supplies from the sand and gravel aquifer would increase the head differential, and with time the contribution from the bedrock would increase. As shown in Fig. 30, a gradual increase in groundwater withdrawals from the Edwardsville well field corresponds with the increase in sulfates, suggesting that the increase in sulfates could be attributed to the upward movement of water from the bedrock. There is no apparent reason for the recent increase in chlorides unless the use of road salt in the vicinity of the well field was initiated in recent years.

Changes in Sulfate and Chloride Contents

As shown in Figs. 7 and 10, except for the effects of the river on the water quality at site 26.8a, the chloride and sulfate contents remained relatively constant from June 1973 through September 1974; changes for that period are shown in Figs. 31 and 32. No distinct change patterns are evident. Changes in sulfates range from a decrease of 103 mg/l to an increase of 809 mg/1. Changes in chlorides range from a decrease of 65 mg/1 to an increase of 84 mg/1. Sulfate concentrations for June and September of 1973 and 1974 were shown in Figs. 17-20. In the southern part of the area in St. Clair County the 200 mg/1 contour shows little position change. In the northern part of the area the 50 and 100 mg/1 contours show some position change which is probably a result of the effects of the Mississippi River. Chloride concentrations for June and September of 1973 and 1974 were shown in Figs. 13-16. Areas of chloride concentrations greater than 50 mg/1 were delineated. According to the available data, these areas remained relatively unchanged.

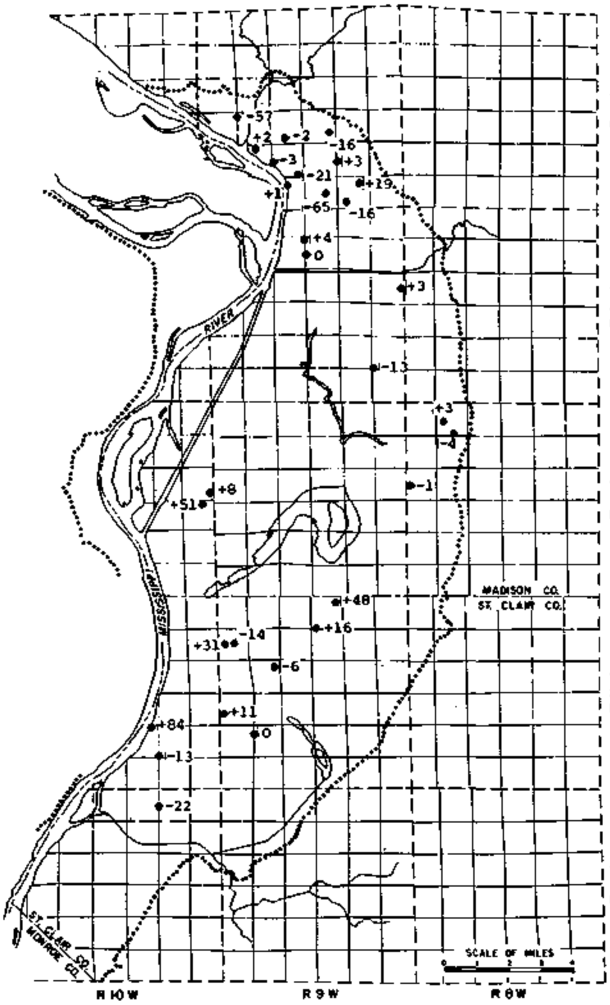


Figure 31. Change in chloride content (mg/l) June 1973 through September 1974.

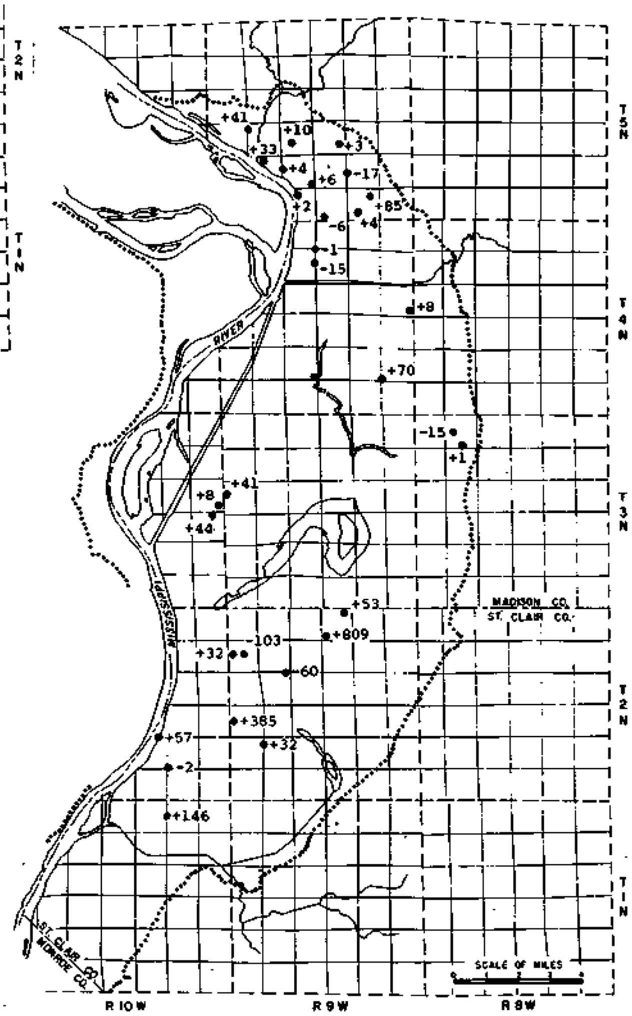


Figure 32. Change in sulfate content (mg/l) June 1973 through September 1974.

In addition to the analyses made for this study, there were a large number of analyses made during 1972 and during the period 1946 through 1958. Chloride and sulfate maps for 1946-1958 (Figs. 33 and 34) were compared with chloride and sulfate maps for 1972-1974 (Figs. 35 and 36), and change maps were prepared (Figs. 37 and 38). No great accuracy is intended since the contours that were used to prepare the change maps are highly interpretive. No attempt was made to contour the higher values of chlorides and sulfates.

As shown in Fig. 37, three areas have an increase in chloride greater than 30 mg/l. The area that parallels the Madison-St. Clair County line corresponds to a major highway, near which increases in chlorides could be attributed to the use of road salt. The other two areas correspond to urban-industrial complexes.

Four areas (Fig. 38) show an increase in sulfate content and all are associated with urban-industrial complexes.

Areas that show a decrease in chloride and sulfate content correspond to areas that are infleunced by infiltration of water from the Mississippi River.

Areas that show increases in chlorides and sulfates also correspond to major centers of groundwater withdrawal (Schicht, 1965), and vertical upward movement of highly mineralized water from the bedrock could be considered a contributor to the increases in chloride and sulfate content. In the areas for which the sulfate and chloride change maps were made the bedrock surface is formed by rocks of Mississippian age, except in the Wood River area where the Pennsylvanian-Mississippian subsurface contact roughly bisects the area.

In general, mineralization increases with depth. Water obtained from bedrock commonly is too highly mineralized to be acceptable for domestic or industrial use, particularly at depths greater than 370 to 420 feet below ground level on the floodplain (Bowman and Reeds, 1907, p. 56).

The analyses for bedrock wells (Table 10) from Bowman and Reeds (1907) show that the sulfate content in the bedrock is considerably less than the sulfate content in the valley fill, indicating that the increases in sulfate are not from upward vertical movement of groundwater. The bedrock could be a factor in the increase in chlorides, but outside of major pumping centers, the increase could be attributed to the use of salt for melting snow and ice on highways.

Table 10. Chloride and sulfate concentrations in bedrock wells (from Bowman and Reeds, 1907).

Owner	*Location*	*Well depth (ft)*	*Chlorides (mg/l)*	*Sulfates (mg/1)*
Central Brewing Co.	T2NR9W	360	220	86
American Steel Co.	T2NR9W	450	33	10
Republic Iron Works	T2NR10W	450	66	18
P. H.Traband	T2NR9W	782	92	39

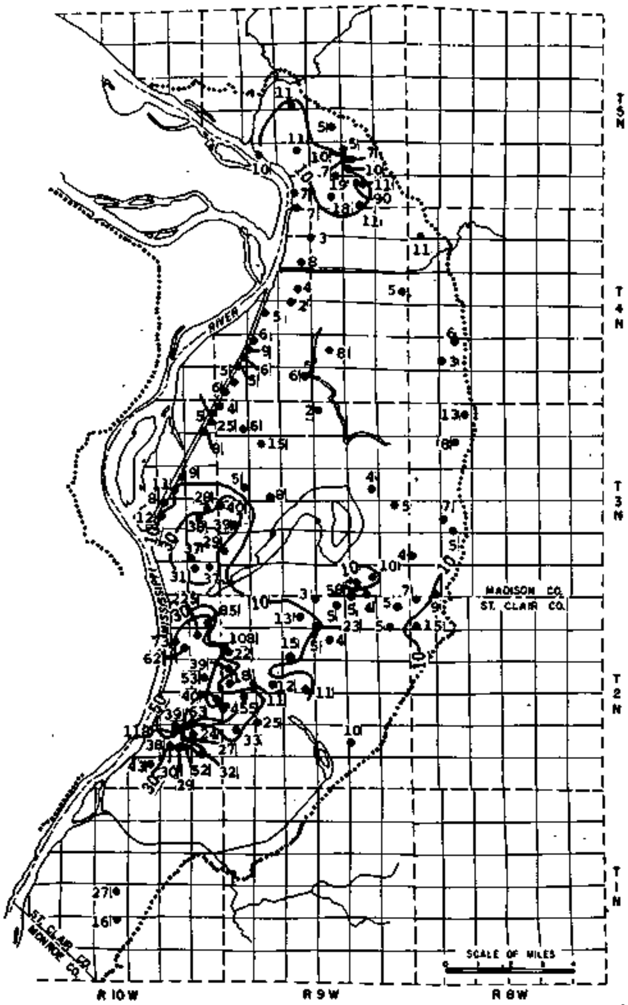


Figure 33. Chloride content (mg/l) 1946-1958.

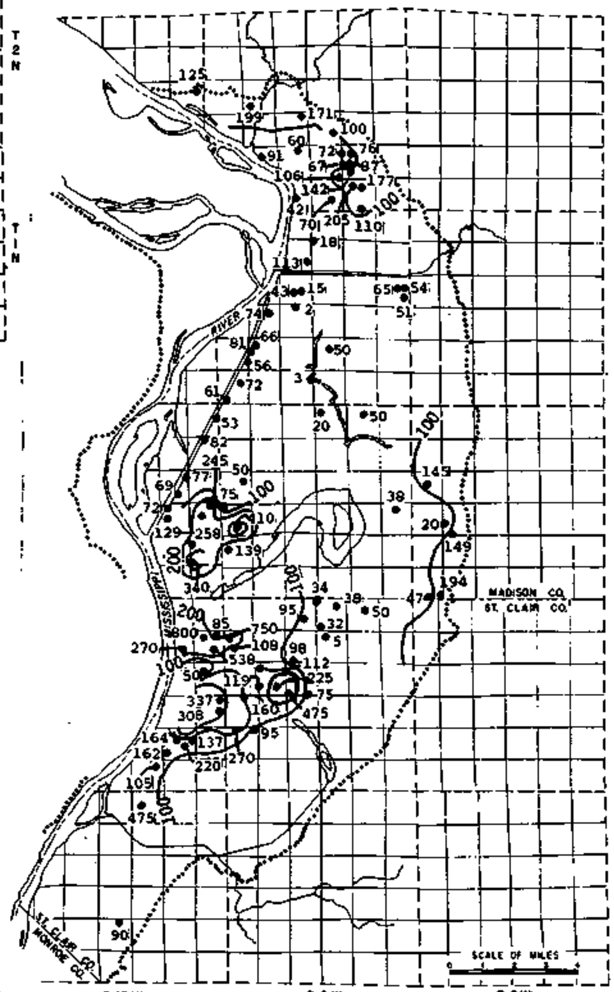


Figure 34. Sulfate content (mg/l) 1946-1958.

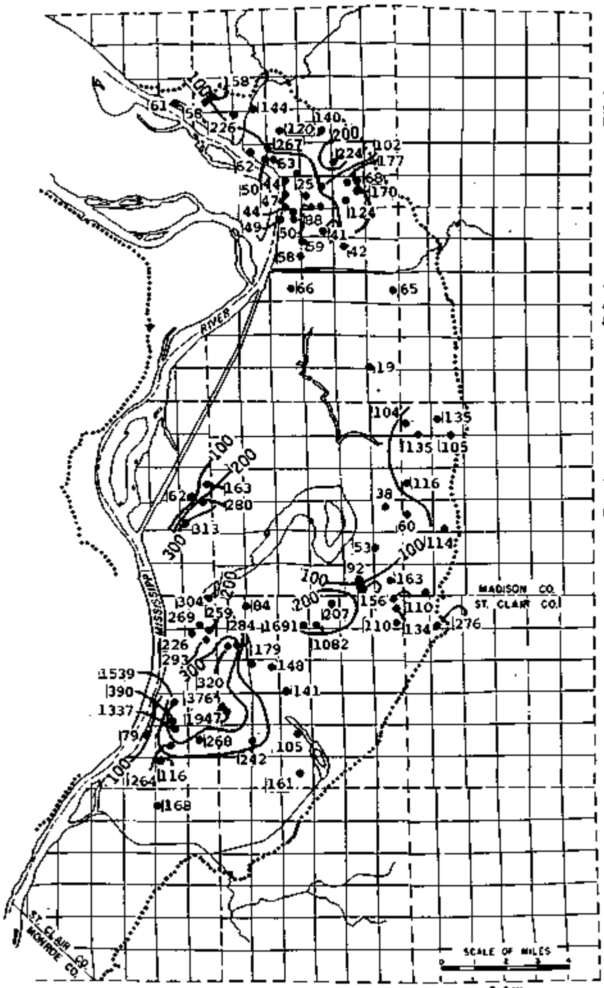


Figure 35. Chloride content (mg/l) 1972-1974.

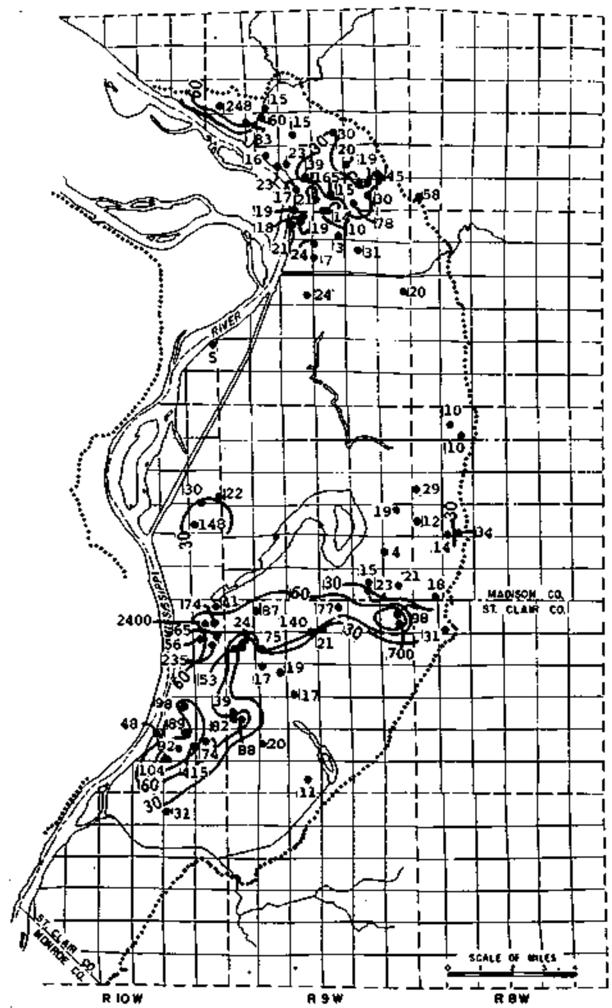


Figure 36. Sulfate content (mg/l) 1972-1974.

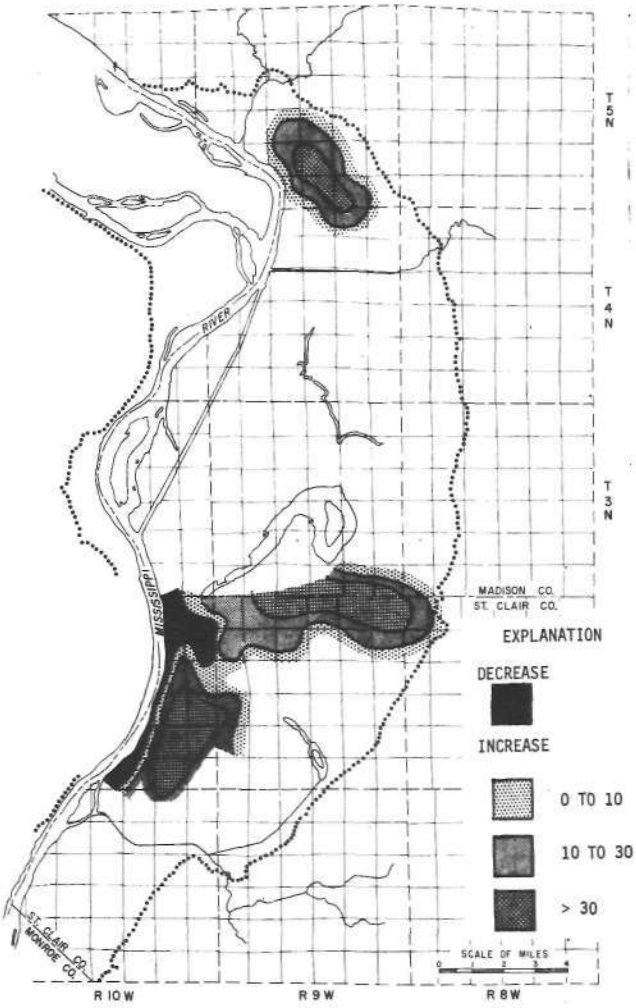


Figure 37. Change in chloride content (mg/l) between the 1946-1958 period and 1972-1974.

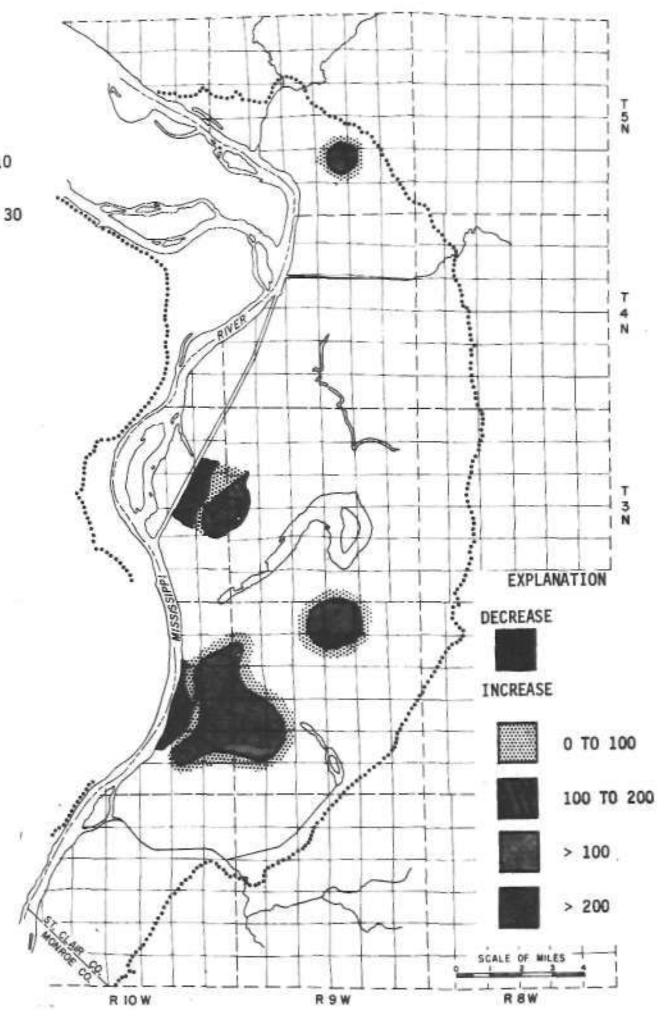


Figure 38. Change in sulfate content **(mg/l)** between the **1946-1958** period and 1972-1974.

SUMMARY AND CONCLUSIONS

A study was made to determine the general effects of precipitation scavenging of urban-industrial pollutants on groundwater quality in the East St. Louis area, Illinois. Groundwater and atmospheric deposition were sampled weekly from June 1973 through September 1974. A large number of groundwater samples were collected in June and September of 1973 and 1974.

Analyses were made for a number of chemical constituents in the groundwater and rain-water such as calcium, magnesium, sodium, potassium, zinc, total dissolved minerals, nitrates, chlorides, and sulfates.

Most of the groundwater analyses collected during the months of June and September were from two urban-industrial complexes, the Wood River-East Alton area in Madison County and the East St. Louis area in St. Clair County. Groundwater was more highly mineralized in the East St. Louis area. This was partly attributed to the effects of infiltration of less mineralized Mississippi River water in the Wood River-East Alton area.

Comparisons between concentrations of chemical constituents in atmospheric rainout and dry fallout and in groundwater were made. At the concentrations measured during this study, it is highly unlikely that precipitation scavenging of urban-industrial pollutants contributes significantly to the degradation of groundwater quality. The rainwater sampling sites were located downwind of the major urban-industrial areas. Supplementary data on rainwater chemistry within the urban-industrial areas are available from the METROMEX project to determine if concentrations of various chemical constituents are greater in the urban-industrial areas.

Trends in groundwater quality from analyses of weekly groundwater samples collected during the study were not evident.

Long-term changes in groundwater quality were investigated. Data on chlorides and sulfates from a municipal well field located in a rural area indicate a gradual increase in sulfates since the early 1900's that appears to correspond to a gradual increase in pumpage. Chloride concentrations show a significant increase after the 1960's. It was suggested that the increase in sulfates could be attributed to the upward movement of high sulfate water from the bedrock. There was no apparent reason for the increase in chlorides.

Changes in chloride and sulfate content in groundwater since the 1940's and 1950's were estimated. Three major areas had chloride increases greater than 30 mg/l. Industrial activity and the use of road salt were probably the major contributors to the increase in chloride content.

Four areas showed an increase in sulfate content. All were associated with urban-industrial complexes. In three areas increases in sulfate content exceeded 100 mg/1. In the fourth area the sulfate content increased more than 200 mg/1. Industrial activity was probably the major contributor to the increase in sulfate content. Sulfate in the atmosphere is partly derived from the oxidation of sulfur dioxide gas which is produced by the burning of coal and oil and by the smelting of ores. It is highly probable that the sulfate content in rainwater was higher during the period when high sulfur coal was the major energy source in the area. Whether the sulfate content in rainwater during this period was great enough to degrade groundwater quality is not known.

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APPENDIX A

CAUSE OF HIGH GROUNDWATER LEVELS IN SOUTHWESTERN MADISON COUNTY AND POSSIBLE SOLUTIONS

by
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1974

INTRODUCTION

This report was prepared in response to requests by State Senator Sam M. Vadalabene, 56th District; Mayor Paul Schuler, Granite City; and Professor Robert L. Koepke, Southern Illinois University at Edwardsville for a study on the cause of high groundwater levels in southwestern Madison County. The high groundwater levels are a major factor in causing sewer breaks and flooded basements.

The area covered in this report is in the valley lowlands of the Mississippi River (Fig. A-1). The groundwater geology of the area has been described in detail by the Illinois State Geological Survey (Bergstrom and Walker, 1956). Reports which summarized water levels and pumpage were issued by the Illinois State Water Survey in 1953 (Bruin and Smith) and 1962 (Schicht and Jones). In 1965 the State Water Survey issued Report of Investigation 51 (Schicht, 1965) which described in detail the groundwater resources of the area. In order to validate the predictions of pumping center yields made in Report of Investigation 51 and to delineate problem areas an observation well network (Fig. A-l) to monitor groundwater levels daily and monthly is maintained. Public, industrial, and irrigation pumpage data are collected annually, and at 5-year intervals a piezometric contour map is prepared with data from a mass water level measurement in over 200 wells during a 2-week period in November. These data have been summarized in reports covering the periods 1962-1966 (Reitz, 1968) and 1967-1971 (Baker, 1972). As part of a separate study on water quality, piezometric surface maps have been prepared for June and September 1973. Considerable data on water quality are also available.

This report summarizes groundwater levels and pumpage in the area for the period 1954 through 1973, a period in which groundwater levels rose from record low stages in 1957 to the highest levels on record in 1973. The rise in groundwater levels is attributed to a drastic reduction in pumpage in the Granite City pumping center, high river stages over an abnormally long period in 1972 and 1973, and favorable conditions for groundwater recharge from rainfall during the years 1972 and 1973. The magnitude of the rise attributed to each of the above factors is given.

AQUIFER MODEL

Sufficient geohydrologic data for groundwater management on a regional basis have been collected and interpreted by the State Water Survey and State Geological Survey. Groundwater management is interpreted for the purpose of this report to mean maintaining low groundwater level elevations to eliminate many problems associated with the high groundwater levels. Pumping large capacity wells would be one means of lowering and maintaining groundwater level elevations.

A model of the aquifer to predict the effects of pumping wells on water levels is available. An electric analog model was incorporated with various electronic components (electric analog simulator) and is described in detail by Schicht (1965). Hydrogeologic maps and data presented by Schicht describing the following factors were used in constructing the analog model: 1) transmissivity of the aquifer, 2) coefficient of storage of the aquifer, 3) areal extent of the aquifer, 4) saturated thickness of the aquifer, and 5) location, extent, and nature of aquifer boundaries.

The accuracy of the electric analog simulator was determined by comparing the actual December 1956 piezometric surface map with a December 1956 piezometric surface map based on computer results. Fig. A-2 shows the close agreement between analog simulator results and the actual elevation of the December 1956 piezometric surface map. Schicht (1965) describes the method used to prepare the piezometric surface from analog simulator results.

The electric analog simulator dealt with a relatively simple problem; designing well fields to maintain low groundwater levels is a more complex problem. Since the water will be pumped to waste, plans for a minimum number of wells should be made. Recharge from precipitation as well as from the river will need to be introduced into the model. In the area of the well field a finer model grid will be needed. For these reasons and probably others, the digital computer, which can deal with problems of much greater complexity than is practical with electric analog methods, should be used to develop a groundwater level management scheme. The aquifer model developed for the electric analog simulator can be incorporated in a digital model with modifications. Digital computer techniques for groundwater resource evaluation are described in Illinois State Water Survey Bulletin 55 (Prickett and Lonnquist, 1971).

CAUSE OF HIGH GROUNDWATER LEVELS

Significant groundwater pumpage in the study area is from the wells centered at Granite City and Poag and near the base of the bluffs near Glen Carbon, Troy, and Caseyville (Fig. A-3). Additional large pumping centers outside the study area are located in the vicinity of Monsanto, National City, Fairmont City, Wood River, and Alton. Groundwater withdrawals from wells in the Poag, Glen Carbon, Troy, and Caseyville areas have had little effect on water levels in the study area except very locally. With the exception of pumpage from the National City area, pumpage from outside the area would have little effect on water levels in the study area. Pumpage from the National City area, however, has been relatively stable. Pumpage from wells in the Granite City area has had a significant effect on water levels in the vicinity of Granite City, Madison, Venice, and Pontoon Beach. Pumpage from wells in the vicinity of Granite City from 1954 through 1973 is given in Table A-1.

Table A-1. Groundwater pumpage in Granite City pumping center, 1954-1973.

(Pumpage in million gallons per day)

Year	*Pumpage*	*Year*	*Pumpage*	*Year*	*Pumpage*
1954	31.6	1961	10.1	1968	9.6
1955	30.1	1962	10.8	1969	9.3
1956	29.6	1963	11.2	1970	8.5
1957	23.0	1964	15.3	1971	6.8
1958	7.6	1965	10.6	1972	9.6
1959	7.8	1966	12.6	1973	5.0
1960	7.9	1967	10.6		

Maximum groundwater pumpage (31.6 mgd) in the Granite City area occurred in 1954. By 1973 pumpage declined to 5.0 mgd. The effect of the reduction in groundwater pumpage on water levels was estimated from the data generated by the electric analog simulator previously described. Water levels due to the reduction in pumpage recovered more than 40 feet in the center of the Granite City pumping cone to less than 5 feet in outlying areas as shown in Fig. A-4.

In addition to the rise in levels due to the reduction in pumpage, water levels rose in response to an increase in precipitation and a rise in the Mississippi River stage (Chain of Rocks Canal). During the period 1952-1956 when groundwater pumpage from the Granite City pumping center was greatest the area experienced a severe drought (Hudson and Roberts, 1955). Water levels declined appreciably during this period. The U.S. Weather Bureau records at Edwardsville indicate that rainfall averaged about 34.3 inches per year from 1952 through 1956, or about 6.5 inches per year below normal.

The estimated change in water levels for the period December 1956 through June 1973 is shown in Fig. A-5. The change map was made by comparing the December 1956 piezometric surface map (Fig. A-2) with the June 1973 piezometric surface map (Fig. A-6). As shown in Fig. 5 water levels during the period recovered from less than 5 feet in the eastern part of the area to more than 55 feet in the Granite City pumping center.

By comparing Figs. A-4 and A-5 a map (Fig. A-7) was prepared showing the December 1956 through June 1973 recovery due to precipitation and high river stages. Recovery attributed to these factors ranges from less than 5 feet in the eastern part of the area to more than 20 feet along the Chain of Rocks Canal and the Mississippi River. By studying the effect of the river on groundwater levels from data generated from the electric analog simulator about 5 feet or less of the rise in groundwater levels can be attributed to the increase in precipitation.

SUMMARY AND RECOMMENDATIONS

The high groundwater levels in southwestern Madison County were caused by the reduction in groundwater withdrawals, high river stages over an abnormally long period in 1972 and 1973, and favorable conditions for groundwater recharge from rainfall during 1972 and 1973. An aquifer model that can be used with digital computer techniques is available for development of a groundwater management scheme to maintain low groundwater levels.

If the purpose of the management scheme is to maintain low groundwater levels over a large area, a network of large capacity wells would be required. The water would be conveyed either by discharging directly to the present sewers, or by pipelines to a pumping station and then pumping to a receiving body of water. There are a number of disadvantages to this scheme. No economic use is made of the water. Wells and possibly pipelines will need to be constructed in residential areas. The wells may sit idle for years after the groundwater levels recede to more normal levels but would require periodic maintenance.

One alternative would be development of well fields for industrial use. A second alternative would be construction of new sewers that are compatible with the high groundwater levels.

We strongly recommend that an engineering firm be hired to make appropriate studies. The Water Survey would be happy to be of assistance.

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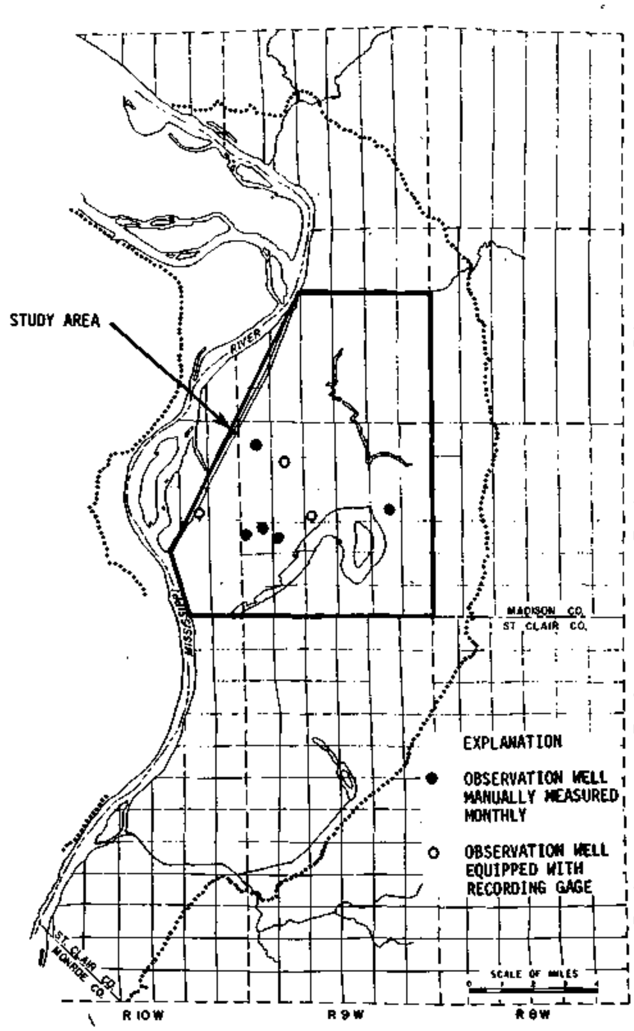

Figure A-1. Location of observation wells.

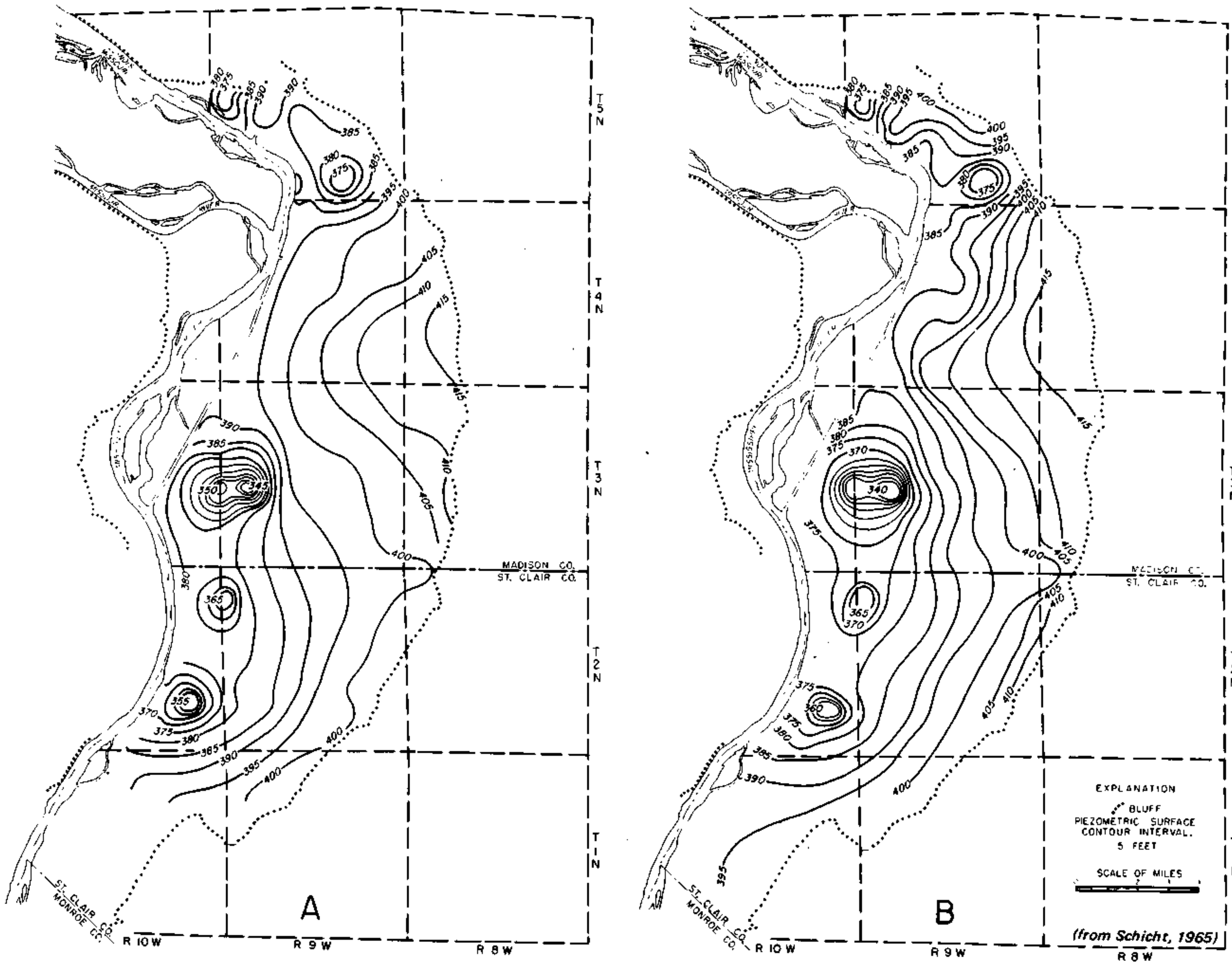

Figure A-2. Elevation of piezometric surface, December 1956, (A) actual; (B) based on analog computer results.

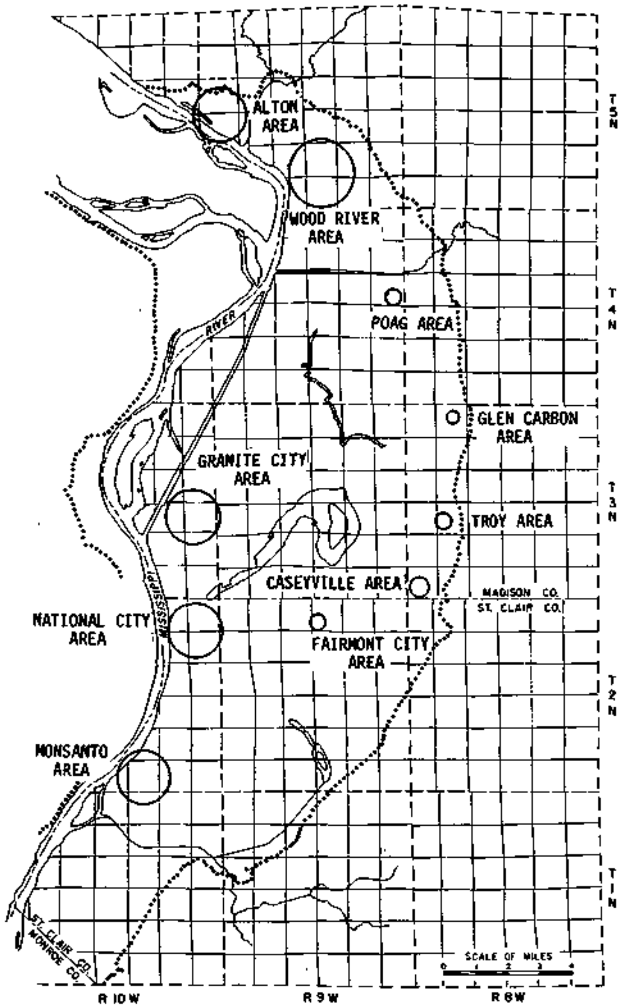

Figure A-3. Locations of pumping centers.

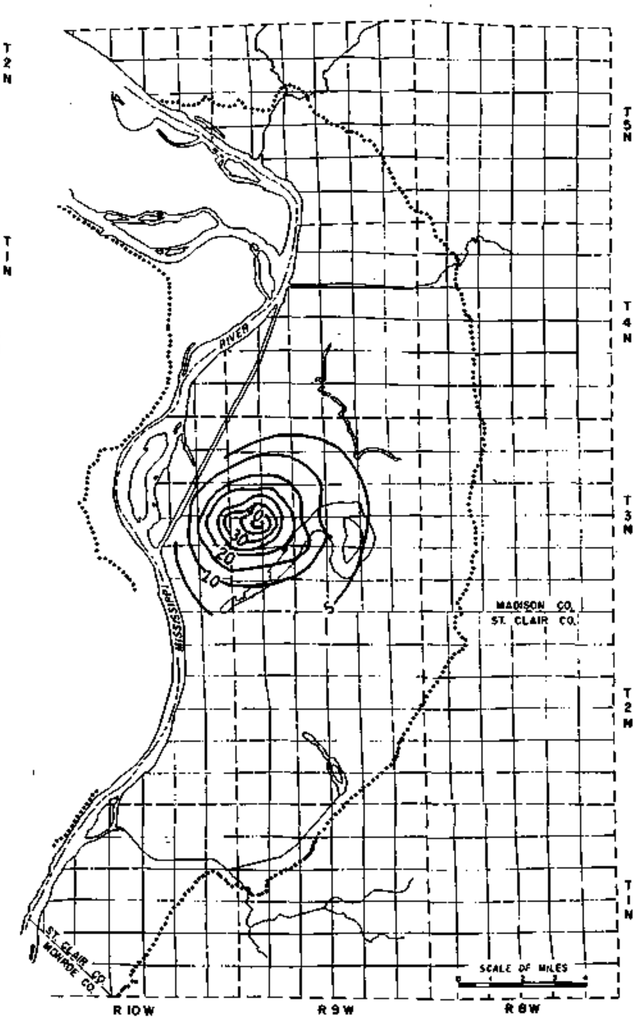

Figure A-4. Recovery in groundwater levels (feet) from December 1956 through June 1973 due to the reduction in pumpage in Granite City pumping center.

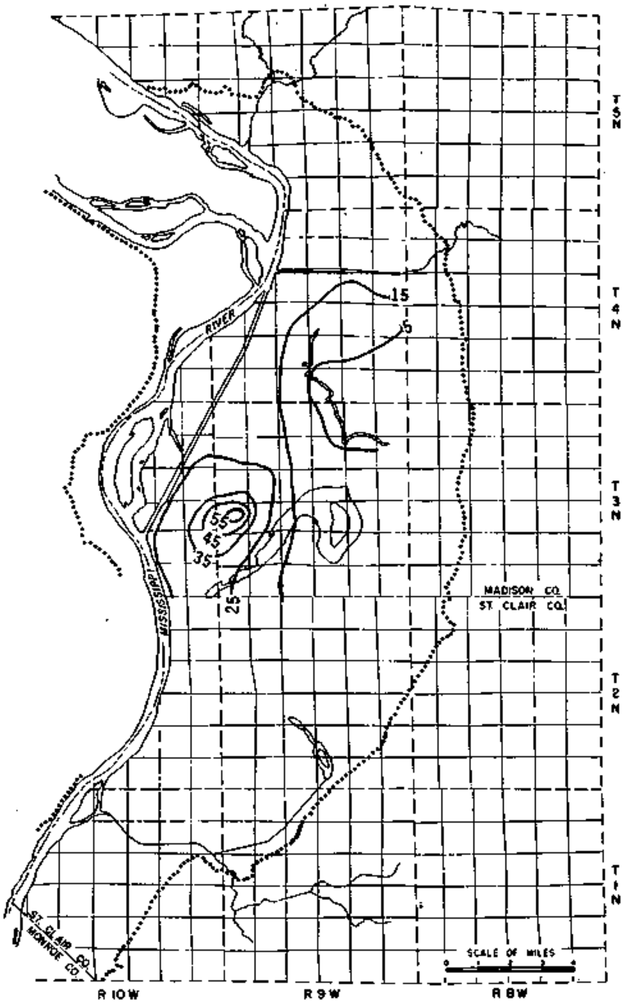

Figure A-5. Total recovery in groundwater levels (feet) from December 1956 through June 1973.

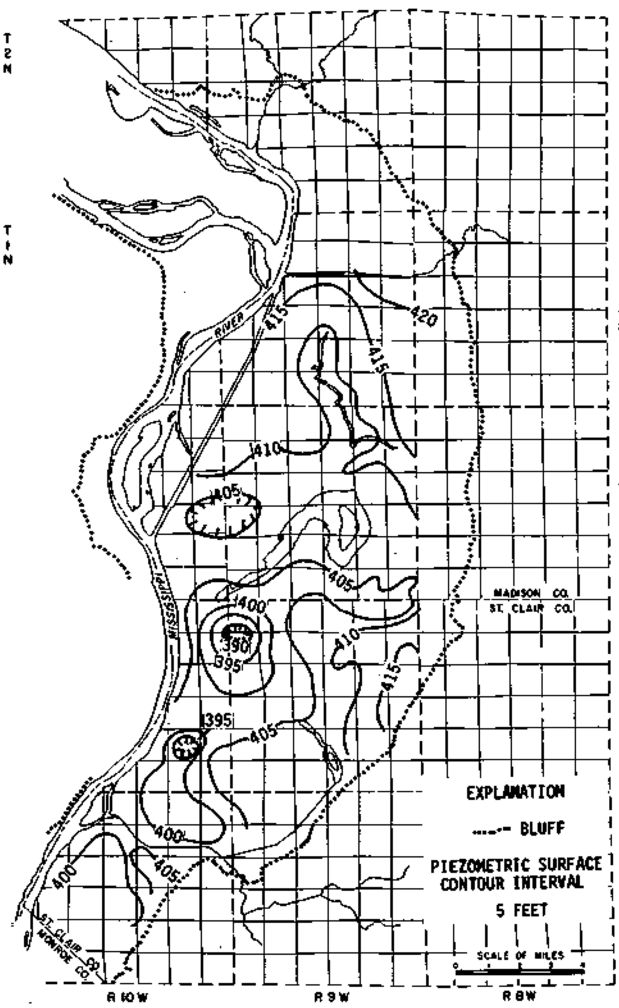

Figure A-6. Approximate elevation of piezometric surface, June 1973.

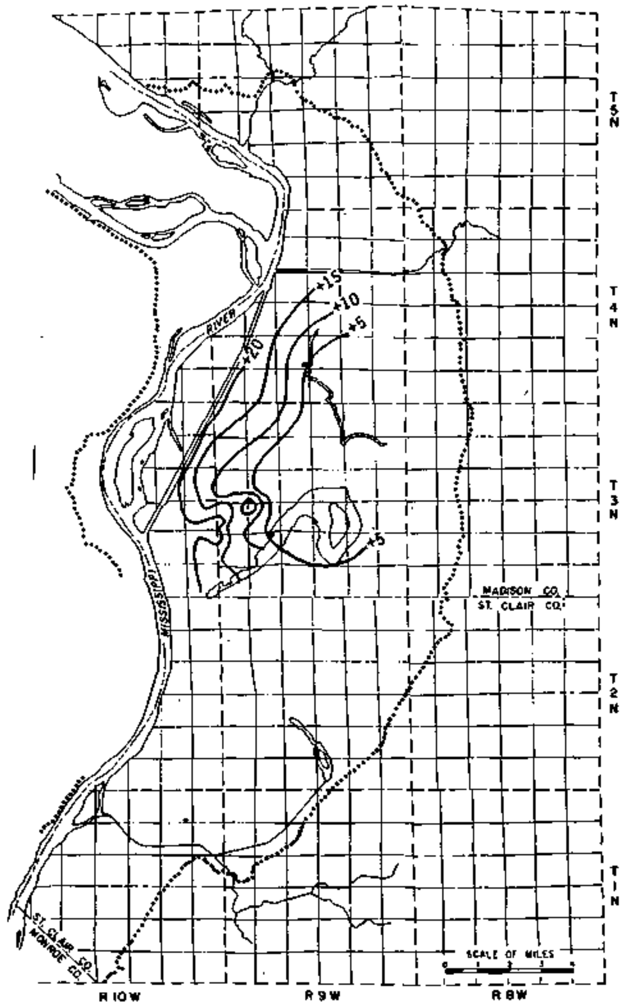

Figure A-7. Recovery in groundwater levels (feet) from December 1956 through June 1973 because of rainfall and high river stages.

APPENDIX B

THE EFFECTS OF THE 1973 MISSISSIPPI RIVER FLOOD ON GROUNDWATER LEVELS IN MADISON AND ST. CLAIR COUNTIES, ILLINOIS

by
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1974

High groundwater levels in the Mississippi River valley lowlands in St. Clair and Madison Counties associated with the Mississippi River floods during 1973 are one of the major factors causing widespread sewer damage. Federal assistance has been available to communities in the area to aid in meeting costs of repairing and replacing damaged sewer lines. The termination date for federal aid was December 1, 1973. This report was prepared in response to requests to provide substantiating data to show groundwater levels were still affected by the 1973 flood so that the termination date for federal aid could be extended.

Groundwater level data presented in this report were collected by William H. Baker, Hydrologist, Illinois State Water Survey, Collinsville Office, or by personnel directly under his supervision.

The November 1971 piezometric surface map (Fig. B-1) was prepared from water level data collected by Mr. Baker as part of a 5-year water level and pumpage summary to delineate problem areas and validate predictions of pumping center yields given in Illinois State Water Survey Report of Investigation 51. The piezometric surface maps for June and September 1973 (Figs. B-2 and B-3) were prepared from data collected by Survey field personnel as part of a National Science Foundation contract to study water quality in the area. The collection of water level data for the 1973 maps was not as intensive as for the 1971 maps, but was adequate for the purpose of this report. Water level change maps (Figs. B-4, B-5, and B-6) were prepared by comparing the appropriate piezometric surface maps. It should be emphasized that the piezometric and water level change maps are general in nature and should not be used to interpret water levels for a specific location. Water level hydrographs (Figs. B-7 through B-11) were prepared from data collected on a routine basis by Mr. Baker.

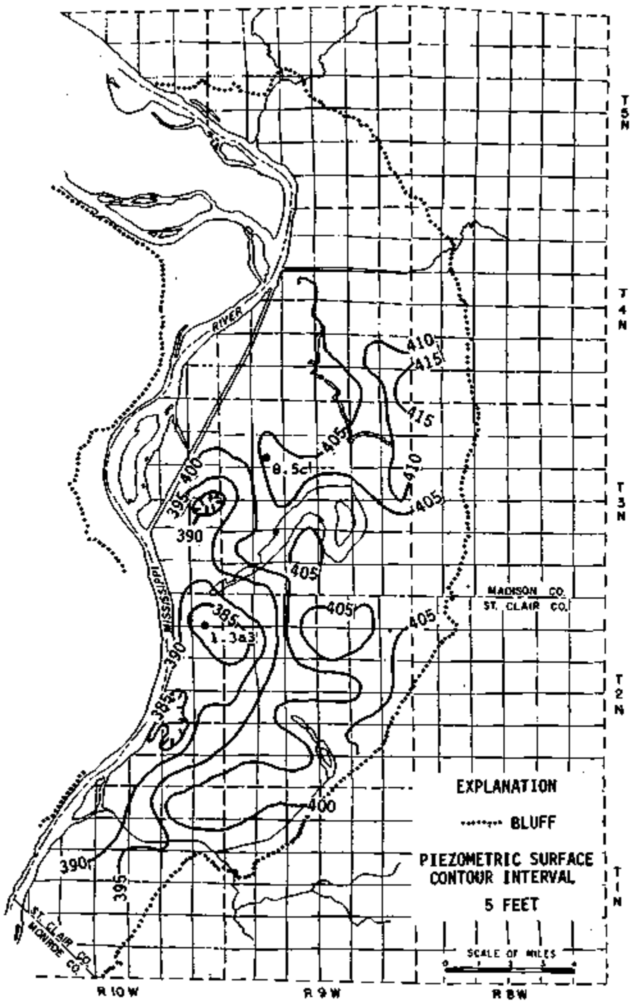
Rises in water levels from November 1971 to June 1973 (Fig. B-4) ranged from more than 15 feet near the Mississippi River and the Chain of Rocks Canal to less than 5 feet in the eastern part of the area. Most of the change is attributed to the high river stages during the 1973 floods. Largely in response to river stage decline after the spring 1973 flood peak, groundwater levels immediately adjacent to the Mississippi River and Chain of Rocks Canal declined appreciably. As shown in Fig. B-5 the water level decline from June 1973 to September 1973 adjacent to the river and canal was more than 15 feet (water levels rose in part of the area in response to local conditions).

As indicated by the change in groundwater levels from November 1971 to September 1973 (Fig. B-6) groundwater levels in a large part of the area remained above the November 1971 levels. Groundwater levels in a broad band from near Mitchell southwest to Granite City and then south to Cahokia remained more than 5 feet above the November 1971 stages. Groundwater levels in these areas did not have sufficient time to respond to the decline in river stage.

Hydrographs of groundwater levels for two observation wells were selected to show the change in groundwater levels after the September 1973 piezometric surface map. The locations of the observation wells are shown in Fig. B-1. Fig. B-7 shows that groundwater levels in well STC 2N10W-1.3a3 rose after September 1973 in response to more normal groundwater recharge occurrences. Because of the high groundwater levels partly induced by the 1973 flood, groundwater levels in this well remained above 1971 stages. The 1971 water level hydrograph for well MAD 3N9W-8.5g is similar, but since it is a greater distance from the river the effects of the river are lessened.

In summary, groundwater levels would not be expected to return to what can be termed normal (e.g., 1971) until after a normal summer period occurs, a period when little groundwater recharge takes place. Thus, the late summer or early fall of 1974, say October 1, 1974, would appear to be the earliest termination date.

Figure B-1. Approximate elevation of piezometric surface, November 1971.



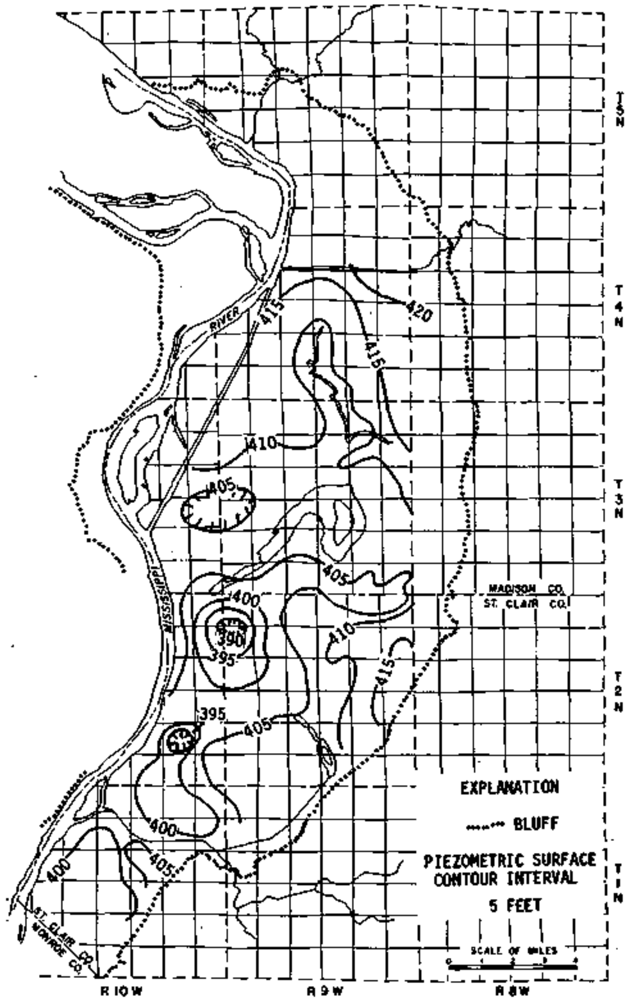


Figure B-2. Approximate elevation of piezometric surface, June 1973.

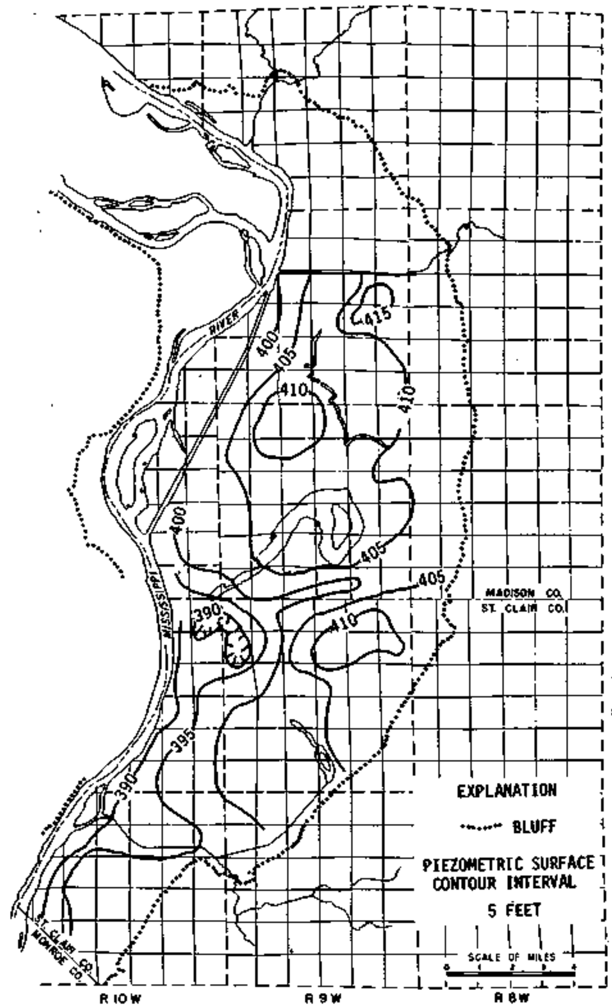


Figure B-3. Approximate elevation of piezometric surface, September 1973.

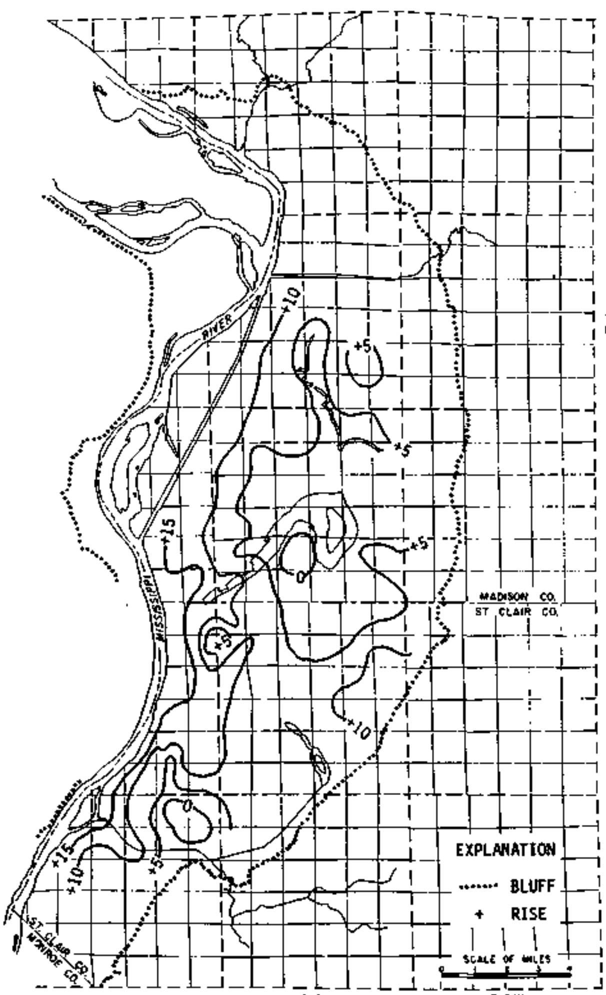


Figure B-4. Estimated change in water levels (feet), November 1971 to June 1973.

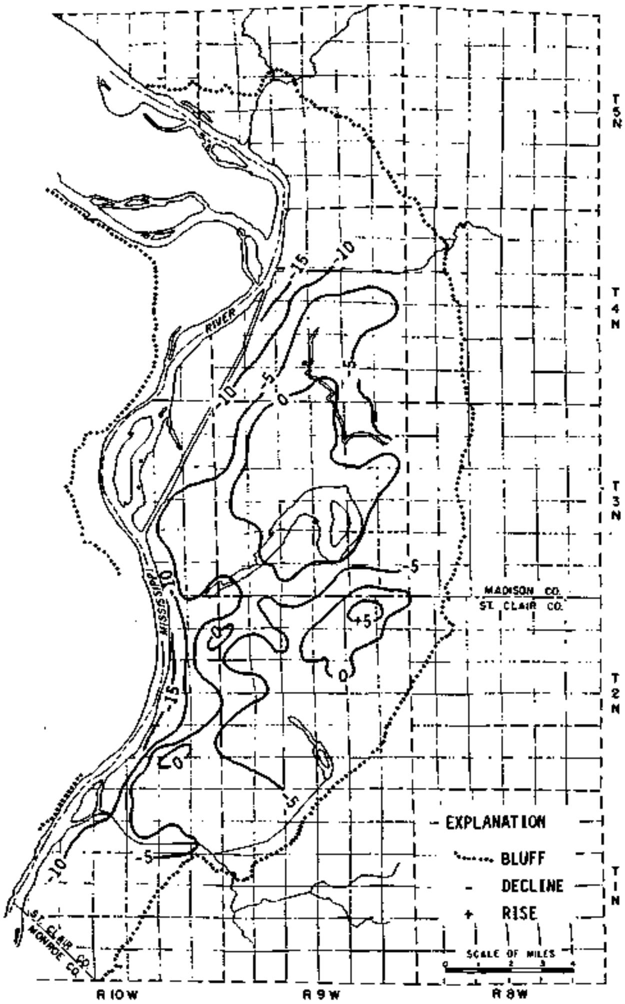


Figure B-5. Estimated change in water levels (feet), June 1973 to September 1973.

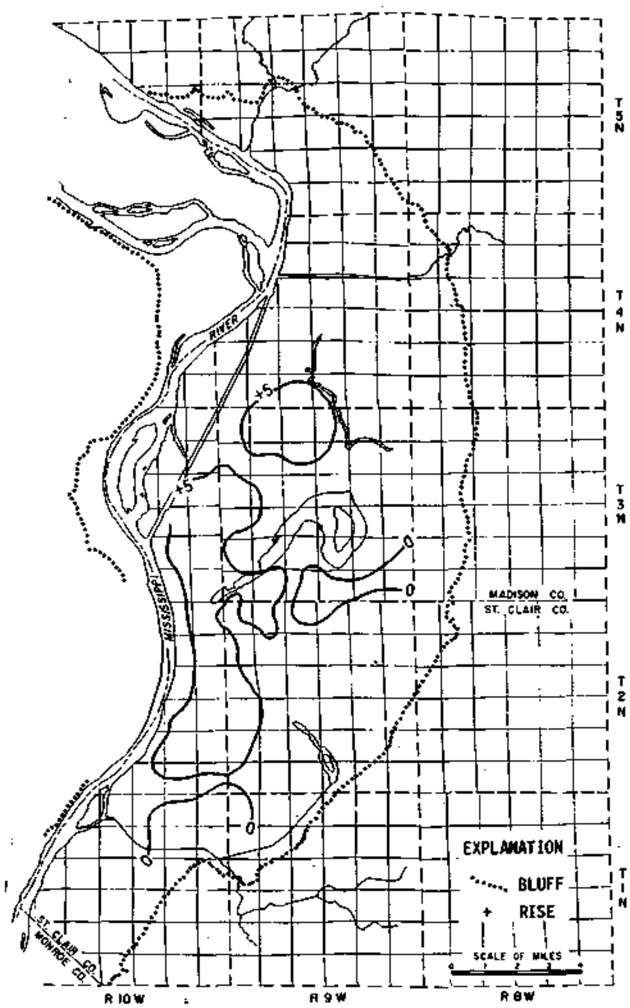


Figure B-6. Estimated change in water levels (feet), November 1971 to September 1973.

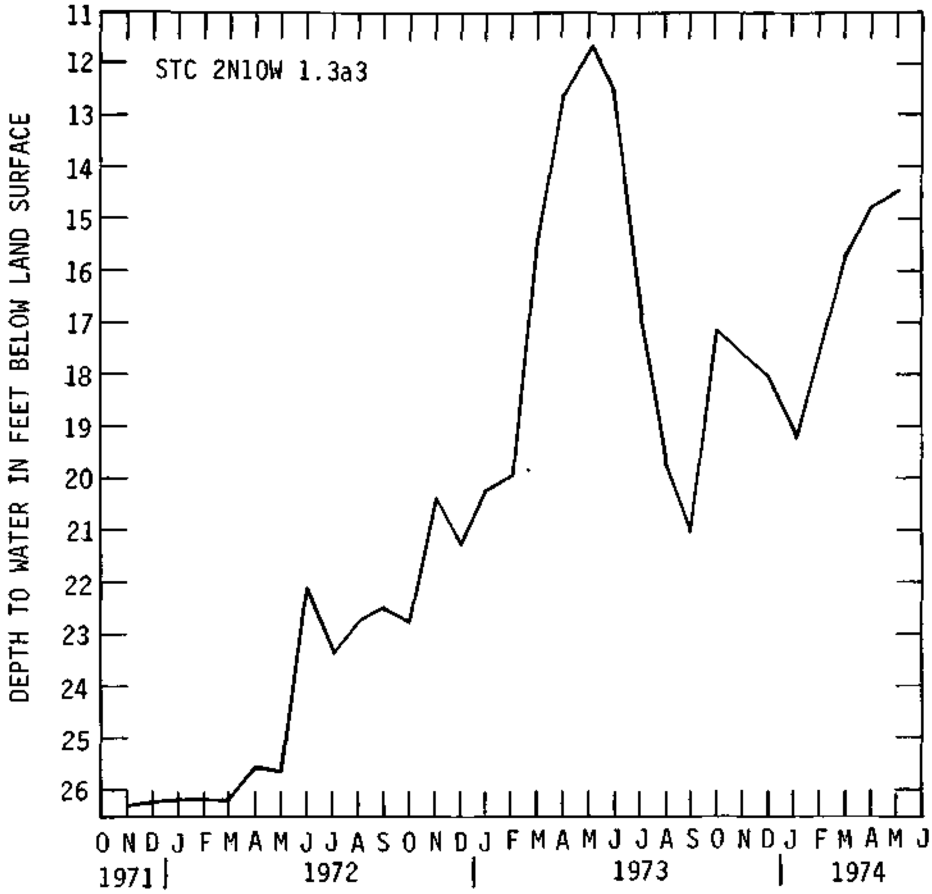


Figure B-7. Water levels in well STC 2N10W-1.3a3, November 1971 through May 1974.

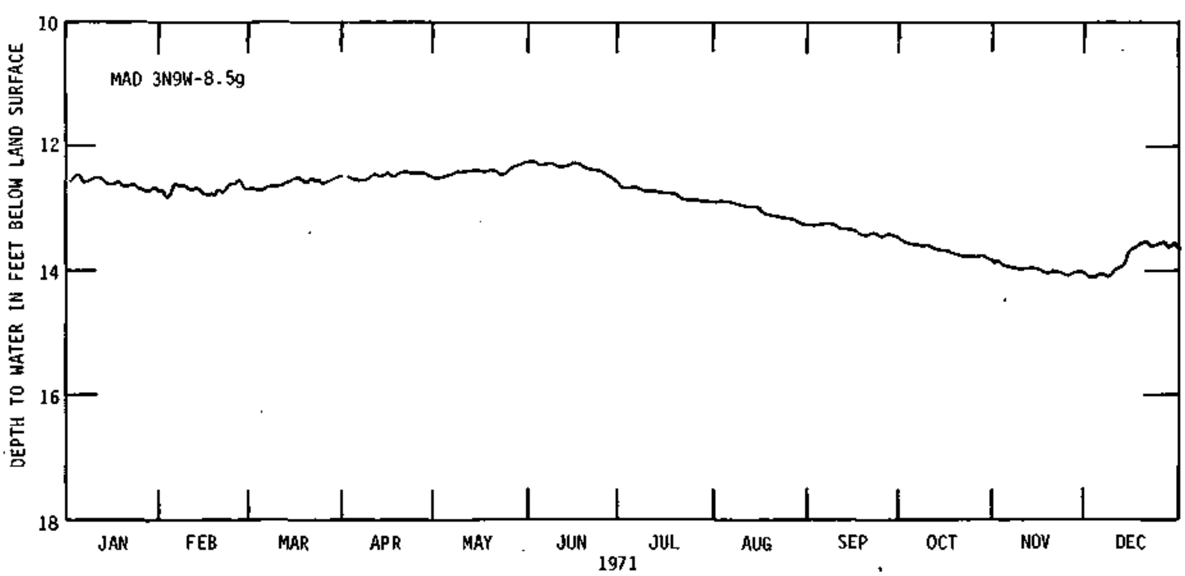


Figure B-8. Water levels in well MAD 3N9W-8.5g during 1971.

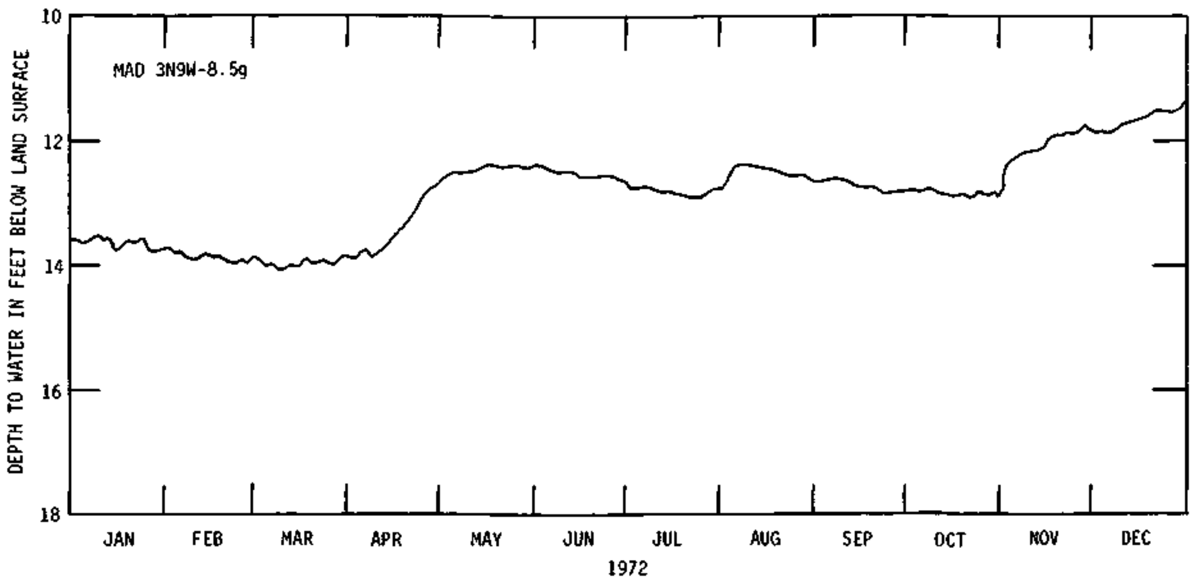


Figure B-9. Water levels in well MAD 3N9W-8.5g during 1972.

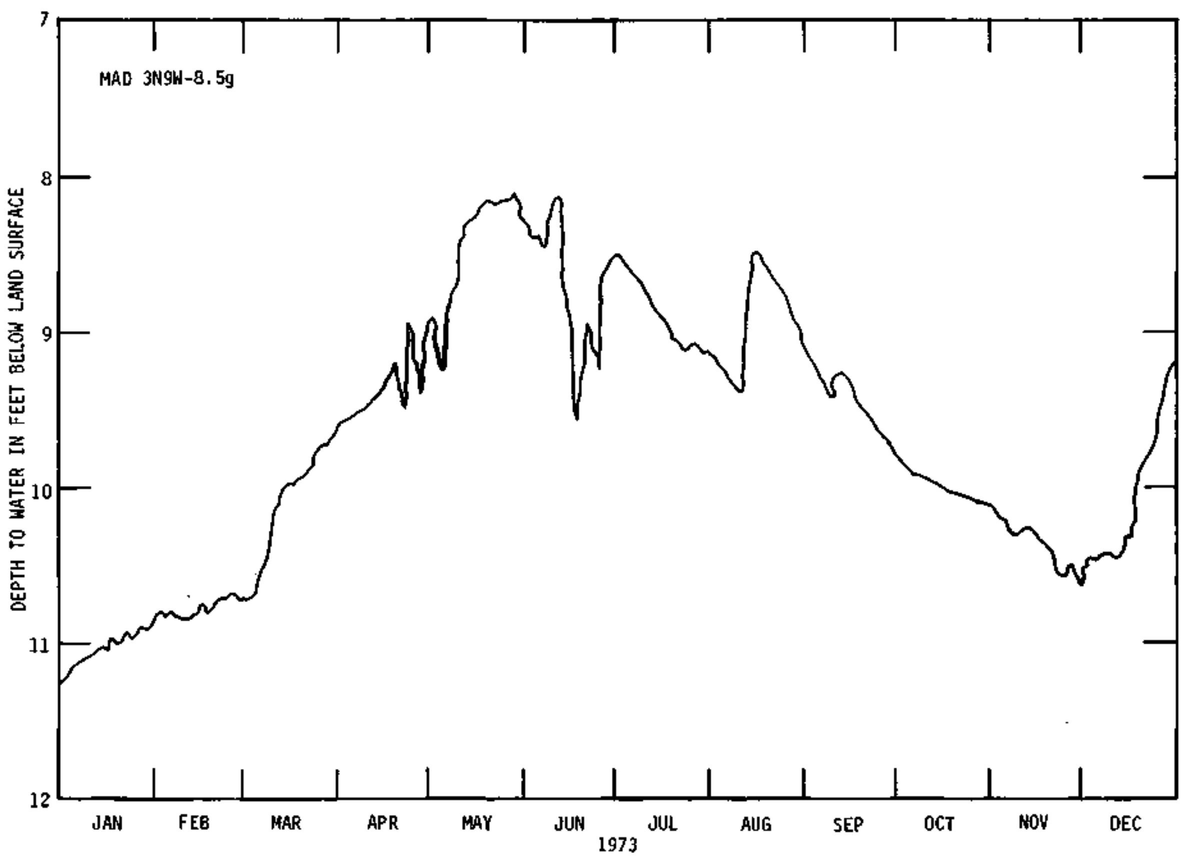


Figure B-10. Water levels in well MAD 3N9W-8.5g during 1973.

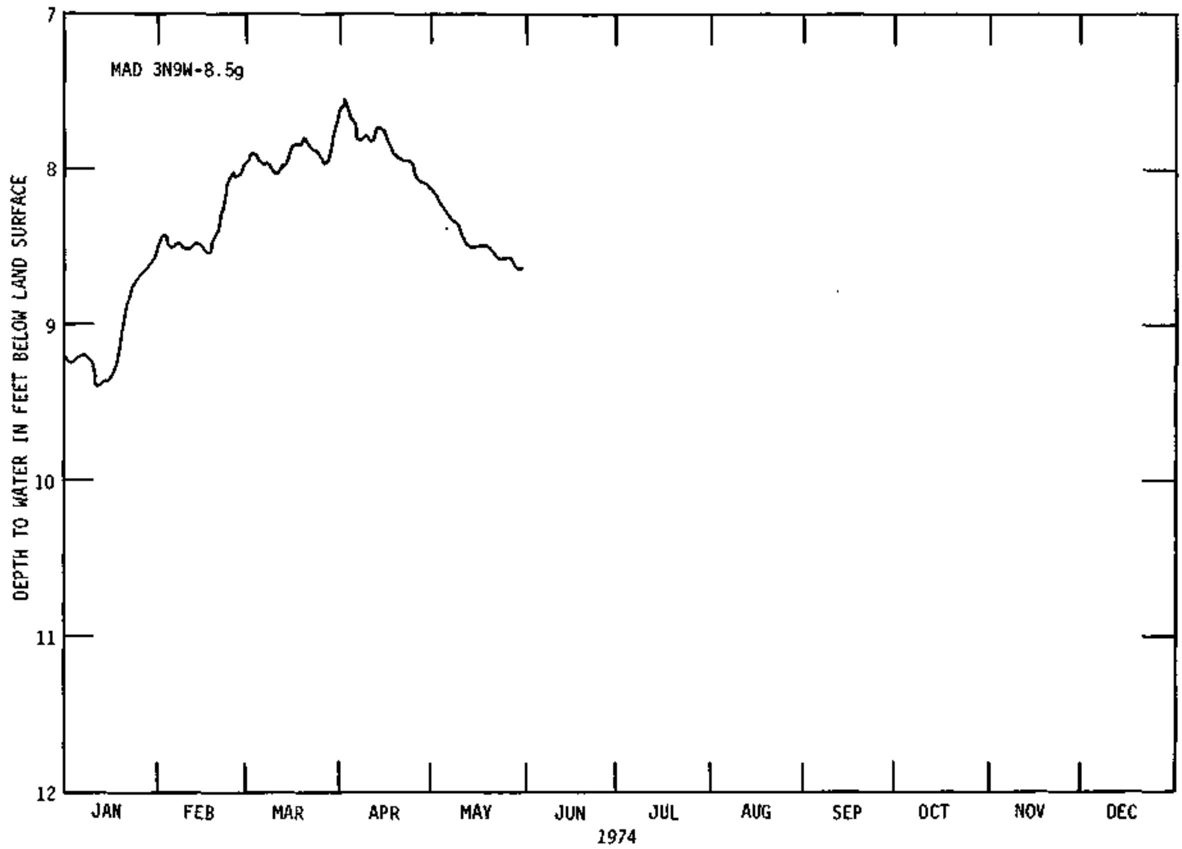


Figure B-11. Water levels in well MAD 3N9W-8.5g January through May 1974.