

TEMPORAL CHANGES IN SHALLOW GROUNDWATER QUALITY IN NORTHEASTERN ILLINOIS

Walton R. Kelly and Steven D. Wilson
Groundwater Section
Illinois State Water Survey
Champaign, IL 61820

ABSTRACT

The rapid increase in population and developed land in the Chicago metropolitan area has placed a heavy demand on water resources. Owing to legal restrictions and natural limitations on the availability of additional water from Lake Michigan and the region's deep aquifer system, the most cost-effective option for future water development in the region is likely to be the shallow aquifer system. The shallow aquifers of the region are vulnerable to surface-derived contaminants, and the increase in developed land may be increasing the rate at which groundwater quality is being degraded. Historical shallow groundwater chloride (Cl^-) concentrations from the Chicago metropolitan area have been evaluated for data quality and temporal trends. Chloride concentrations are increasing in municipal wells in the outermost counties of the Chicago metropolitan area, with road salt runoff likely the largest source of contamination. In the vast majority of municipal wells in DuPage, Kane, McHenry, and Will Counties, Cl^- concentrations have been increasing. More than half of the wells in these four counties have rate increases greater than $1 \text{ mg L}^{-1} \text{ yr}^{-1}$ and approximately 13% have increases greater than $4 \text{ mg L}^{-1} \text{ yr}^{-1}$. On the other hand, Cl^- concentrations have not been increasing in most municipal wells in Cook and Lake Counties. Approximately 16% of the samples collected from municipal wells in northeastern Illinois in the 1990s had Cl^- concentrations greater than 100 mg L^{-1} ; median values were less than 10 mg L^{-1} prior to 1960, before extensive road salting.

INTRODUCTION

Population and infrastructure have grown rapidly in the Chicago metropolitan area in recent decades. The population has increased from about 5 million to greater than 7.7 million from 1950 to the present, and is projected to increase by 25% by 2020 (NIPC, 1999). Most of the growth is occurring in the outer "collar" counties of Kane, McHenry, and Will, where the projected population increase is 70 to 100% by 2020 (NIPC, 1999). The amount of developed land also has been expanding; residential acreage increased by 46% between 1970 and 1990 (NIPC, 1996). The growth in population and development has placed a heavy demand on water resources. Water use increased about 27% from 1980 to 1992 and demand is expected to continue to grow as the population of the region increases (Kirk et al., 1982; Avery, 1999). Owing to legal restrictions and natural limitations on the availability of water from Lake Michigan and the region's deep aquifer system, the most cost-effective option for future water development in the region is likely to be the shallow aquifer system. This aquifer system consists

of unconsolidated sand and gravel aquifers contained within the glacial drift together with the upper portion of the underlying bedrock. A considerable amount of water (500 million gallons day⁻¹) is estimated to be available in these shallow aquifers (Schicht et al., 1976).

Shallow unconfined aquifers, however, are vulnerable to surface contamination, and there are a large number of potential sources of contamination in urban and suburban areas. Some common sources include landfills, sewage treatment plants, industrial effluents, atmospheric deposition, septic fields, gasoline storage tanks, and road runoff. The list of potential contaminants is long, including various organic classes (e.g., petroleum compounds, solvents, pesticides), toxic metals (e.g., cadmium, lead, chromium), mercury, chloride (Cl⁻), sulfate (SO₄²⁻), nitrogen (nitrate, ammonium), and dissolved solids.

The Illinois State Water Survey (ISWS) has performed a number of studies in the Chicago region that have provided data on shallow groundwater quality. In 1979, Sasman et al. (1981) sampled 282 shallow wells finished within the dolomite in DuPage County. Water quality was good in undeveloped and newly developed areas, but was relatively poor in developed areas. Visocky (1990) examined data from 30 wells in sand and gravel aquifers in Kane County as well as some wells from deep bedrock aquifers. Except for barium and radium, the concentrations of dissolved constituents, including total dissolved solids (TDS), Cl⁻, SO₄²⁻, and iron, were significantly higher in the shallow aquifers than the deep bedrock aquifers. Roadcap et al. (1993) sampled 186 shallow wells in Will and southern Cook Counties in 1990-91. They found that about 75% of the samples exceeded the secondary drinking water standard for TDS (500 mg L⁻¹); SO₄²⁻ and iron also were found to be elevated in most of the region. Shallow groundwater in the industrialized Calumet region of south Chicago is heavily polluted with many contaminants (Kelly and Roadcap, 1994; Duwelius et al., 1995). Groundwater from almost all of the shallow wells in the Calumet region displayed significant contamination, and Cl⁻ concentrations in wells next to Interstate 94 exceeded 1,000 mg L⁻¹.

Chloride is a useful indicator of aquifer contamination. It is a conservative solute, not reactive or significantly adsorbed to soil or aquifer materials, and thus is often an early indicator of contamination. Although not a primary threat to human health, elevated levels of Cl⁻ make water non-potable, and thus there is a secondary drinking water standard of 250 mg L⁻¹. Chloride is a common contaminant (Long and Saleem, 1974; Schicht, 1977; Eisen and Anderson, 1979), and increases in Cl⁻ concentrations in urban areas are generally the result of anthropogenic inputs, usually road-salt runoff, sewage effluent, or brine-waste disposal. Road salt has been linked to groundwater degradation in many urban and roadside areas in northern climes (Huling and Hollocher, 1976; Pilon and Howard, 1987; Amrhein et al., 1992; Howard and Haynes, 1993). Once in groundwater, Cl⁻ and other contaminants can persist for long periods due to slow groundwater travel times. Howard et al. (1993) estimated that, even if road salting were stopped immediately in the Toronto area, it would be decades before the Cl⁻ concentrations returned to pre-1960 levels.

A difficulty in determining temporal degradation of groundwater quality is the lack of long-term chemical data and thus an understanding of how water quality has changed or is changing.

Because of this, the literature on temporal variations in groundwater quality is limited, especially in urban areas (Long and Saleem, 1974; Gibb and O'Hearn, 1980; Hull, 1984; Montgomery et al., 1987; Yee and Souza, 1987; Spruill, 1990). Some of these studies consider only two points in time (Long and Saleem, 1974) or one particular parameter (Spruill, 1990).

The purpose of this study is to examine historical groundwater quality data over a period of several decades from the Chicago metropolitan area and to determine the changes in water quality that have occurred over that period. The likelihood that shallow aquifers will be used increasingly as sources of drinking water in the Chicago region underscores the importance of assessing the water quality of these aquifers. In this paper, we focus on Cl⁻ concentrations in municipal wells. Additional objectives are to identify potential contaminant sources and determine if changes in chemistry are correlated with geological and land-use parameters.

PROCEDURES

For the purposes of this study, the Chicago metropolitan area is considered to encompass six counties in northeastern Illinois: Cook, DuPage, Kane, Lake, McHenry, and Will (Figure 1). This is an area of approximately 3,700 square miles with a population of approximately 8 million.

The shallow aquifers in northeastern Illinois are fractured dolomite and overlying sand and gravel units. In most of the area, the surficial deposits belong to the Wedron Formation and consist of unconsolidated deposits of Wisconsinan-age glacial till and outwash ranging in thickness from less than a foot to more than 400 feet (Willman and Frye, 1970). The glacial deposits are thickest in northwestern McHenry County, but deposits in excess of 200 feet also are found in central and eastern McHenry County, most of Lake County, northern Kane County, north-central DuPage County, and northwestern and west-central Cook County. The thinnest deposits are generally found in the central part of the study area, notably central DuPage and Cook Counties and northern and western Will County. Moderate to large supplies of groundwater generally are found in sand and gravel aquifers in the area. These units are found either at the surface or underlying or interbedded with glacial till. The most productive water producing units tend to be the basal units, just above and in contact with bedrock, which in most of the region is Silurian dolomite.

Groundwater quality data evaluated in this study come primarily from two major groundwater chemistry databases, the ISWS water-quality database and the Illinois Environmental Protection Agency (IEPA) ambient water-quality database. The ISWS database contains approximately 50,000 groundwater samples from more than 25,000 wells in Illinois dating back to the late 1890s. The IEPA database includes approximately 2,110 samples from 933 public wells in the six-county area, from 1980 to 1998. In this project, we used only those wells that are less than 200 feet deep.

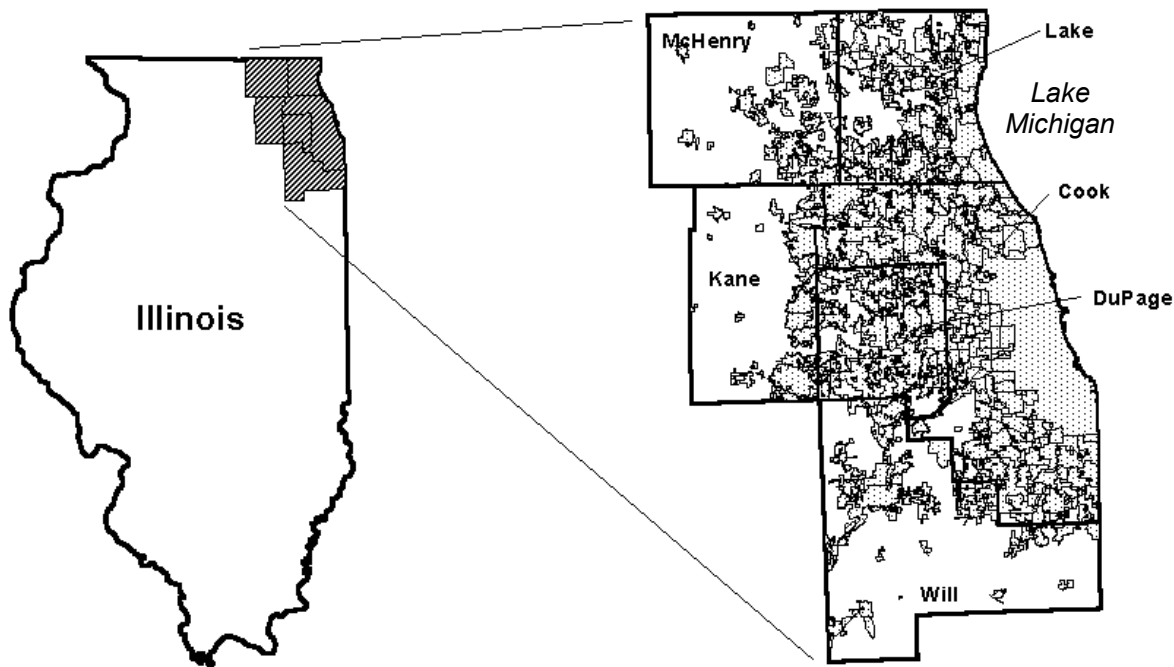


Figure 1. Study area. Dotted regions are incorporated areas.

Complete analyses (i.e., having data for all major ions) from the ISWS and IEPA databases were evaluated using the cation-anion balance:

$$\%E = (\sum \text{cations} - \sum \text{anions} / \sum \text{cations} + \sum \text{anions}) * 100$$

where %E is percent error and the ion sums are calculated in milliequivalents per liter. Major cations include calcium, magnesium, sodium, and potassium, and major anions include Cl^- , SO_4^{2-} , and bicarbonate. Other ions (e.g., iron, manganese, ammonium, nitrate, fluoride, strontium) were included in the balance when their concentrations were significant. A percent error greater than $\pm 20\%$ was assumed to indicate an analytical or reporting error and the result would not be considered in statistical analyses. All complete samples in both databases passed this test. A small percentage of the samples ($< 5\%$) had incomplete major ion analyses and could not be evaluated with the ion balance. These data were still used for analysis but their lower reliability was noted. Data from the ISWS database reported herein also have been evaluated using the cation-anion balance, and almost all complete analyses passed; those samples that did not pass were discarded.

There are several quality concerns with the ISWS and IEPA databases that are currently being addressed. These include: (1) incomplete data (e.g., no well depth or date); (2) ambiguous data (e.g., different well depths for a single well); (3) duplicate records; and (4) discrepancies between data for identical records in the IEPA and ISWS databases. Problematical digital records were compared with paper records where possible. Data were not used in analyses when quality concerns could not be resolved.

Temporal trends in the Cl⁻ data were estimated by linear regression, using the software program SigmaPlot[®] version 6.00 (SPSS, 2000). Both individual wells with multiple samples and samples on a county-wide basis were evaluated. For individual wells, the criterion for performing regressions were at least three samples over a period of five years or more. For wells that had samples from prior to 1960, regressions were performed only on the post-1960 data; no changes in Cl⁻ concentrations were observed for these wells prior to 1960 (Kelly, 2001).

The effects of geological and land-use data on Cl⁻ concentrations in the shallow aquifers were evaluated using geospatial data, specifically depth to aquifer and location of major roads. These data were downloaded from the Illinois Natural Resources Geospatial Data Clearinghouse (<http://www.isgs.uiuc.edu/nsdihome/ISGSindex.html>). Chloride trend data were plotted on these maps to observe potential relationships.

In the first year of this project, we focused on municipal wells and major ion data from the IEPA database (Kelly, 2001). In the second year, we reported on additional analyses using Cl⁻ concentration data from the ISWS database, primarily from individual municipal wells in Cook and DuPage Counties (Kelly and Wilson, 2002). In addition, geological information and well characteristics from all six counties were evaluated with respect to changes in Cl⁻ concentrations. In this paper, we report on Cl⁻ data from individual municipal wells in Kane, Lake, McHenry, and Will Counties, and evaluate changes in Cl⁻ concentrations as a function of well location and depth, presence of shallow sand units, and location of major roads for all six northeastern Illinois counties.

RESULTS AND DISCUSSION

Kelly and Wilson (2002) identified 21 and 28 municipal wells in Cook and DuPage Counties, respectively, having at least 3 samples over a period of five years or more. A total of 135 municipal wells meeting this criterion have been identified for the other four counties in northeastern Illinois (Tables 1-4), for a total of 184 wells. The number of municipal wells per county are: Kane County (34), Lake County (43), McHenry County (40), and Will County (18). Graphical representations of Cl⁻ concentrations as a function of time are presented in Kelly (2001) for some of these wells.

There are temporal increases in Cl⁻ concentrations for the majority of the wells in all six counties. Lake County had the lowest percentage of wells with increasing Cl⁻ concentrations (60%), with the other counties having at least 86% showing an increase (Table 5). Wells in DuPage and Kane Counties have the largest increases; in DuPage County, 86% and 14% of the wells had an increase of at least 1 and 4 mg L⁻¹ yr⁻¹, respectively, while in Kane County the percentages for those rates were 50% and 15%. Chloride concentrations increased by at least 4 mg L⁻¹ yr⁻¹ in about 10% of the wells in the entire region (Table 5).

The latest sample available for many of these wells dated from the 1980s. Eighty of the 184 wells had at least one sample collected in the 1990s, with the latest date available at the time of

Table 1. Trends in Cl⁻ concentrations in selected municipal wells in Kane County. n is number of samples. Rate of change and r² values determined by linear regression for post-1960 samples only. Final Cl⁻ is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L ⁻¹ yr ⁻¹)	r ²	n	initial date	final date	final Cl ⁻ (mg L ⁻¹)
Burlington	1	108	<-0.01	<0.001	4	1941	1985	2
Carpentersville	3	72	2.33	0.756	8	1971	1986	44
Carpentersville	5	183	1.12	0.538	11	1966	1998	37
Carpentersville	6	179	1.88	0.861	23	1973	1998	61
Citizens River Grange Div	1	180	0.70	0.779	6	1972	1986	13
East Dundee	2	69	2.08	0.963	5	1958	1991	78
East Dundee	3	128	1.59	0.818	10	1968	1991	64
Elburn	2	153	-0.01	0.083	6	1937	1985	1
Fox Riv Wtr Rclm Dist-Skyline	1	131	1.50	0.738	5	1973	1991	31
Fox Riv Wtr Rclm Dist-Skyline	2	135	2.42	0.864	4	1980	1991	31
Glenwood	3	113	0.37	0.522	23	1962	1983	25
Glenwood	4	100	8.76	0.998	3	1977	1982	54
Highland Subdivision	1	152	3.06	0.749	7	1975	1986	47
Maple Park	2	134	0.06	0.530	6	1946	1985	5
Maple Park	3	185	0.06	0.306	6	1971	1980	1
Ogden Gardens Subdivision	1	185	0.22	0.829	6	1973	1986	4
Ogden Gardens Subdivision	2	176	0.10	0.350	6	1973	1986	2
Ogden Gardens Subdivision	3	185	<0.01	<0.001	7	1972	1986	1
Patterson Mobile Home Park	1	80	3.27	0.824	5	1986	1998	87
Subdivision Water Trust No 1	1	147	0.22	0.766	6	1972	1988	6
Subdivision Water Trust No 1	2	180	0.30	0.826	7	1973	1988	9
Subdivision Water Trust No 1	3	196	0.38	0.849	9	1976	1998	14
South Elgin	4	109	3.10	0.952	3	1982	1997	98
South Elgin	5	68	2.25	0.698	4	1983	1997	92
St. Charles	7	173	0.77	0.812	8	1962	1989	29
St. Charles	9	86	0.96	0.244	7	1979	1989	34
Sugar Grove	2	107	-2.05	0.355	11	1973	1992	64
Sugar Grove	3	110	2.27	0.852	3	1960	1986	76
Sleepy Hollow	1	40	12.9	0.788	4	1972	1979	152
Sleepy Hollow	2	44	6.57	0.973	3	1968	1980	100
Utl Inc Ferson Creek	2	186	0.95	0.983	4	1975	1991	18
Utl Inc Ferson Creek	3	175	0.55	0.974	6	1978	1991	11
Utl Inc Lake Marion Water Co	3	75	5.66	0.966	6	1980	1997	124
West Dundee	2	87	4.96	0.901	6	1969	1985	106

Table 2. Trends in Cl⁻ concentrations in selected municipal wells in Lake County. n is number of samples. Rate of change and r² values determined by linear regression for post-1960 samples only. Final Cl⁻ is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L ⁻¹ yr ⁻¹)	r ²	n	initial date	final date	final Cl ⁻ (mg L ⁻¹)
Antioch	3	141	0.25	0.662	7	1983	1997	12
Antioch	4	129	0.32	0.938	3	1983	1997	10
Antioch	5	129	0.45	0.940	3	1982	1997	14
Barrington	3	148	1.16	0.896	9	1964	1992	37
Barrington	4	151	2.23	0.906	7	1980	1992	33
Countryside Manor Sbdv	1	168	0.29	0.632	3	1983	1997	25
DL Well Owners Assn	1	55	0.87	0.097	5	1972	1982	48
Elm Oak Mutual Wtr Syst	1	146	0.46	0.631	8	1973	1986	13
Elm Oak Mutual Wtr Syst	2	133	0.16	0.342	6	1976	1986	7
Fields of Long Grove	1	165	-2.88	0.466	4	1993	1998	24
Fox Lake	2	135	0.76	0.523	14	1941	1985	21
Fox Lake	3	95	3.28	0.914	4	1975	1985	38
Fox Lake Hills Sbdv	1	130	-0.11	0.449	4	1974	1985	2
Fox Lake Hills Sbdv	2	126	0.30	0.755	8	1973	1985	7
Grandwood Park Sbdv	1	145	<-0.01	<0.001	7	1978	1997	3
Grandwood Park Sbdv	2	159	-0.11	0.742	5	1963	1986	2
Grandwood Park Sbdv	3	142	-0.07	0.232	11	1963	1998	1
Holly Hock Hill MHP	1	126	-0.12	0.961	4	1987	1996	6
Island Lake	1	115	1.73	0.910	6	1971	1985	30
Island Lake	2	95	1.01	0.398	8	1971	1986	28
Island Lake	3	120	2.42	0.709	6	1971	1982	35
Lake Barrington Shores Sbdv	1	127	0.55	0.893	5	1975	1985	9
Lake Villa	2	156	0.02	0.011	7	1961	1985	1
Lake Villa	4	153	-0.11	0.058	7	1971	1983	1
Lake Villa	5	150	-0.29	0.844	5	1992	1998	<1
Lindenhurst	1	165	-0.06	0.534	9	1971	1992	1
Lindenhurst	2	151	0.01	0.012	7	1976	1992	2
Lindenhurst	3	132	0.16	0.449	4	1980	1992	4
Lindenhurst	4	131	-0.04	0.702	4	1980	1992	1
Lindenhurst	5	133	0.03	0.379	4	1980	1992	2
Mundelein	5	140	-0.13	0.697	9	1959	1986	5
Mundelein	7	165	0.05	0.059	7	1959	1986	6
Pekara Sbdv	3	155	0.12	0.160	10	1960	1998	10
Pekara Sbdv	4	141	-0.19	0.461	3	1978	1987	7
Pekara Sbdv	5	150	<0.01	<0.001	7	1978	1998	7
Tower Lakes	1	186	0.92	0.910	7	1958	1982	23
Tower Lakes	2	67	6.52	0.925	6	1971	1993	247
Towners Sbdv	2	180	-0.08	0.298	8	1959	1987	5
Utl Inc Hilldale Manor Wat Co	1	123	4.11	0.956	6	1980	1998	81
Utl Inc Hilldale Manor Wat Co	2	123	1.90	0.740	5	1971	1987	39
Wildwood Sbdv	3	173	-0.08	0.081	6	1958	1987	3
Winthrop Harbor	4	138	-0.20	0.060	8	1971	1985	7
Winthrop Harbor	5	130	-0.11	0.595	6	1959	1982	6

Table 3. Trends in Cl⁻ concentrations in selected municipal wells in McHenry County. n is number of samples. Rate of change and r² values determined by linear regression for post-1960 samples only. Final Cl⁻ is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L ⁻¹ yr ⁻¹)	r ²	n	initial date	final date	final Cl ⁻ (mg L ⁻¹)
Algonquin	6	152	2.12	0.261	4	1993	1998	23
Algonquin	spring	0	0.73	0.928	4	1953	1987	46
Algonquin	1	165	0.51	0.826	14	1980	1992	12
Algonquin	5	131	0.84	0.696	4	1978	1986	13
Cary	3	155	0.71	0.776	8	1961	1986	25
Cary	8	105	5.29	0.963	5	1982	1997	101
Community Service Corp	2	108	0.71	0.758	6	1972	1986	24
Deering Oaks Sbdv	2	178	0.22	0.693	6	1953	1986	17
Fox River Grove	1	140	1.39	0.333	9	1947	1997	113
Fox River Grove	2	120	1.37	0.440	11	1956	1997	105
Harvard	3	71	5.18	0.668	8	1938	1985	101
Harvard	4	69	2.79	0.673	7	1963	1985	57
Harvard	5	68	2.65	0.846	11	1958	1985	84
Harvard	6	197	0.63	0.850	21	1965	1998	24
Hebron	4	125	4.27	0.661	6	1986	1998	100
Huntley	4	63	1.83	0.856	7	1918	1986	62
Huntley	5	95	0.35	0.135	8	1953	1985	31
Huntley	6	154	0.35	0.996	3	1979	1986	3
Island Lake	104	122	2.78	0.965	3	1982	1991	59
Lakeland Park	2	85	1.03	0.399	6	1958	1982	34
Marengo	4	100	-0.03	0.001	6	1962	1985	21
Marengo	5	85	0.57	0.075	7	1962	1986	35
Marengo	6	87	-0.19	0.328	7	1976	1986	28
McHenry	2	60	4.09	0.612	11	1960	1998	182
McHenry	5	95	0.57	0.840	5	1976	1998	22
McHenry	6	131	1.82	0.622	7	1982	1998	44
McHenry Shores Water Co.	1	180	0.82	0.102	8	1954	1986	5
McHenry Shores Water Co.	2	135	0.06	0.085	8	1970	1985	<1
Nunda Utility Co.	1	189	-0.08	0.060	7	1971	1987	4
Oakbrook Estates MHP	1	182	3.76	0.379	4	1986	1996	162
Richmond	1	170	0.27	0.213	9	1938	1985	30
Richmond	2	144	0.59	0.421	8	1956	1985	6
Terra Cotta Realty	2	60	3.25	0.571	6	1960	1982	101
Terra Cotta Realty	3	185	0.76	0.934	5	1971	1982	10
Terra Cotta Realty	6	131	<-0.01	0.343	3	1947	1982	8
Wonder Lake Water Co.	1	180	-0.06	0.394	7	1973	1991	2
Woodstock	1	196	0.29	0.897	6	1922	1985	9
Woodstock	5	189	0.21	0.252	7	1960	1985	7
Woodstock	6	193	0.83	0.557	7	1960	1985	27
Woodstock	7	114	1.45	0.414	8	1961	1992	80

Table 4. Trends in Cl⁻ concentrations in selected municipal wells in Will County. n is number of samples. Rate of change and r² values determined by linear regression for post-1960 samples only. Final Cl⁻ is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L ⁻¹ yr ⁻¹)	r ²	n	initial date	final date	final Cl ⁻ (mg L ⁻¹)
Beckwith Community Assn.	2	187	0.30	0.221	3	1978	1987	10.1
Beecher	1	164	-0.34	0.091	6	1917	1987	3
Bollingbrook	10	170	4.27	0.747	6	1983	1998	83
Citizens West Suburban Div.	12	157	3.17	0.782	7	1965	1998	156
Greenfield Cmty. Well Co.	1	120	0.95	0.550	8	1920	1987	74
Joliet	202	90	0.99	0.935	4	1947	1987	28
Joliet	203	83	0.20	0.839	4	1947	1987	9
Joliet	204	113	1.40	0.987	4	1947	1987	18
Joliet	205	94	0.53	0.795	8	1947	1985	15
Manhattan	2	156	0.12	0.119	11	1920	1992	7
Peotone	1	135	0.02	0.017	6	1910	1992	2
Ridgewood Subdivision	2	200	-1.99	0.111	4	1982	1987	51
Romeoville	1	160	1.25	0.635	6	1919	1985	28
Shawnta Terrace Water Assn.	1	183	0.36	0.377	6	1910	1992	18
Sunnyland Subdivision	1	132	1.92	0.730	6	1910	1992	70
Sunnyland Subdivision	3	150	0.40	0.246	6	1947	1992	70
Utl Inc Cherry Hill Water Co.	1	145	21.10	0.892	5	1980	1990	215
Utl Inc Cherry Hill Water Co.	2	192	2.76	0.359	6	1984	1996	68

Table 5. Number of municipal wells showing increases in Cl⁻ concentrations per county. n is number of wells having at least 3 samples over at least a 5 year period.

County	All wells				Wells with sample(s) in the 1990s			
	n	≥0.01 mg L ⁻¹	> 1 mg L ⁻¹	> 4 mg L ⁻¹	n	≥0.01 mg L ⁻¹	> 1 mg L ⁻¹	> 4 mg L ⁻¹
Cook	21	18 (86%)	8 (38%)	1 (5%)	7	6 (86%)	2 (29%)	0 (0%)
DuPage	28	26 (93%)	24 (86%)	4 (14%)	17	15 (88%)	14 (82%)	3 (18%)
Kane	34	30 (88%)	17 (50%)	5 (15%)	14	13 (93%)	10 (71%)	1 (7%)
Lake	43	26 (60%)	9 (21%)	2 (5%)	19	12 (63%)	4 (21%)	2 (11%)
McHenry	40	35 (88%)	16 (40%)	4 (10%)	14	13 (93%)	10 (71%)	3 (21%)
Will	18	16 (89%)	7 (39%)	2 (11%)	9	9 (100%)	5 (56%)	2 (22%)
TOTAL	184	151 (82%)	81 (44%)	18 (10%)	80	68 (85%)	45 (56%)	11 (14%)

this paper being 1998. For the wells with samples dating from the 1990s, the percentage of wells in each county showing increases in Cl⁻ concentrations was similar to the total data set, with a few exceptions. For the entire region of northeastern Illinois, the percentage of wells having increases of greater than 1 and 4 mg L⁻¹ yr⁻¹ was greater for the wells having data from the 1990s than for the entire data set (44% vs. 56% and 10% vs. 14%, respectively) (Table 5). This suggests that there has not been a leveling off in Cl⁻ concentrations in the 1990s.

Consideration of the Cl⁻ concentration data segregated by decade shows that the percentage of samples from municipal wells with elevated Cl⁻ concentrations has increased with time (Table 6). Prior to 1960, approximately two-thirds of all samples had Cl⁻ concentrations less than 10 mg L⁻¹, while by the 1990s, Cl⁻ concentrations in only 20% of the samples were less than 10 mg L⁻¹.

Table 6. Percentage of Cl⁻ concentrations greater than various values for municipal wells from northeastern Illinois counties by decade.

<u>Time period</u>	<u>≥ 10 mg L⁻¹</u>	<u>≥ 20 mg L⁻¹</u>	<u>≥ 40 mg L⁻¹</u>	<u>≥ 100 mg L⁻¹</u>
< 1960	32%	15%	8%	< 1%
1960s	41%	22%	7%	1%
1970s	53%	31%	15%	2%
1980s	60%	46%	30%	4%
1990s	80%	64%	46%	16%

Prior to 1970, fewer than 10% of the samples had Cl⁻ concentrations greater than 40 mg L⁻¹, while by the 1990s Cl⁻ concentrations in close to half the samples were greater than 40 mg L⁻¹, and concentrations in 16% of samples exceeded 100 mg L⁻¹.

Plots of Cl⁻ concentrations as a function of time show significant scatter, but for most counties a trend of increasing concentrations is apparent (Figure 2). As noted by Kelly (2001) and Kelly and Wilson (2002), the increases appear to be greatest in the western and southern counties (DuPage, Kane, McHenry, Will). The median Cl⁻ concentration prior to 1960 in all counties was less than 10 mg L⁻¹, but by the 1990s the median concentration was greater than 20 mg L⁻¹ in all counties except Lake, and close to 100 mg L⁻¹ in DuPage County (Table 7).

It should be noted that there are limitations in interpreting these data. For example, the data do not represent random samples, and some wells have a large number of samples compared to other wells. In addition, the number of samples varies considerably by year. Nevertheless, it is clear that Cl⁻ concentrations have been increasing in the shallow groundwater in many parts of northeastern Illinois, and that the increase started around 1960, when road salt began being applied in large volumes (Salt Institute, 2003).

As reported by Kelly (2001) and Kelly and Wilson (2002) and supported by these additional data, there appears to be some geographical control on the rate of change in Cl⁻ concentrations, with the outermost counties having the greatest increases in concentration. This may reflect the rapid changes in land use occurring in the outermost counties. Cook and Lake Counties have been urban and residential areas much longer than the other counties in the study area, and many of the major roads are curbed, which limits the recharge of contaminated surface water to groundwater. Chloride concentrations in Cook and Lake Counties tend to be relatively low, generally less than 40 mg L⁻¹, while it is not uncommon for samples from shallow wells in the outermost counties to have Cl⁻ concentrations greater than 100 mg L⁻¹ (Figure 2). There is less curbing in the outermost counties, and as increasing areas are being developed in the outermost counties, the quality of the recharge water is apparently being affected.

An alternative explanation for the greater increase in Cl⁻ concentrations in the collar counties is that sand and gravel deposits are thicker and closer to the surface in the collar counties, especially McHenry and Kane Counties (Hansel and Johnson, 1996). Areas where aquifer material (usually sand and gravel) is within 50 feet of the surface in northeastern Illinois are plotted in Figures 3 and 4. The rates of change in Cl⁻ concentrations for the municipal wells are

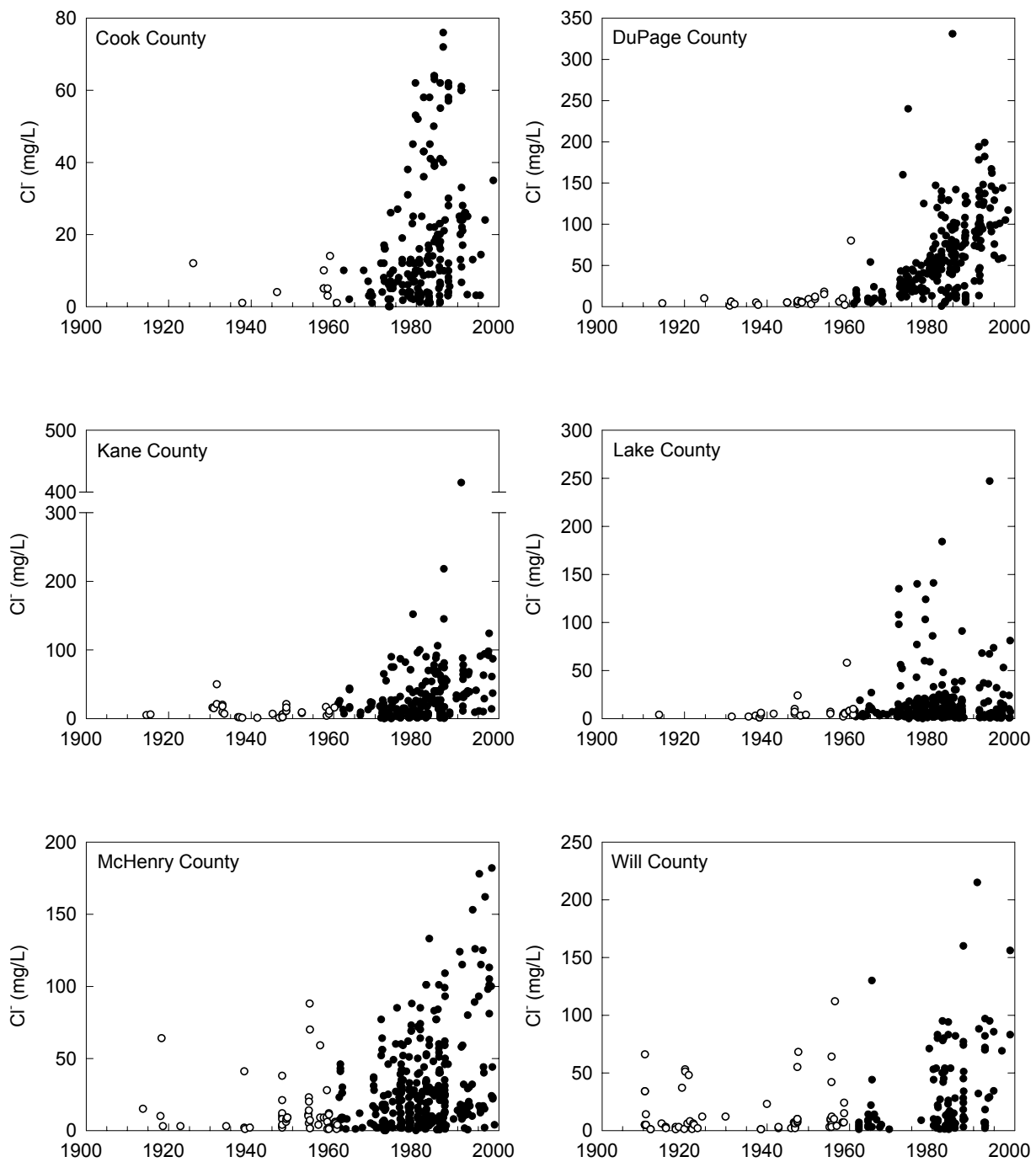


Figure 2. Chloride concentrations for municipal wells in northeastern Illinois. Open circles are samples prior to 1960, closed circles 1960 and later. Note different scales for the y axes.

Table 7. Median Cl⁻ concentrations (mg L⁻¹) for all samples from municipal wells less than 200 feet deep in each county of northeastern Illinois.

County	Median pre-1960	Median 1990s
Cook	5	24
DuPage	6	98
Kane	8	39
Lake	5	6
McHenry	8	22
Will	6	34

superimposed on these figures. Wells with the greatest rates of change are typically found in areas with aquifers within 50 feet of the land surface (Figure 3). Wells with negative or low rates

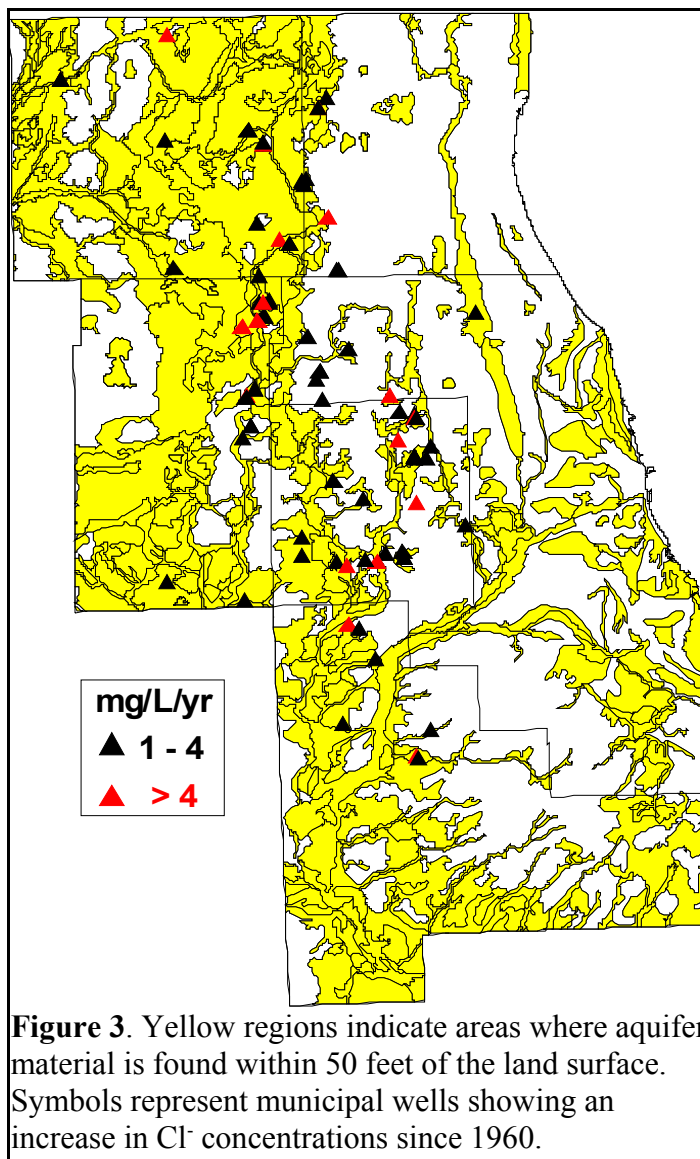


Figure 3. Yellow regions indicate areas where aquifer material is found within 50 feet of the land surface. Symbols represent municipal wells showing an increase in Cl⁻ concentrations since 1960.

of change in Cook and Lake Counties are usually located where aquifers are not present within 50 feet of the land surface (Figure 4). However, some wells with negative or low rates of change are found in the collar counties where aquifers are present within 50 feet of the land surface; thus the presence of aquifers near to the land surface is not the only control on Cl⁻ concentrations. In Kane and McHenry Counties, it appears that more of the wells that have low or negative rates of change are in the western section, where there is less urban and suburban development.

Changes in Cl⁻ concentrations were plotted versus well depth (Figure 5). The shallowest wells (< 100 ft) appear in general to be more vulnerable, but even wells as deep as 200 feet deep show significant increases in Cl⁻ concentrations.

Locations of sites of increasing Cl⁻ concentrations were superimposed on a map showing major roads, where the majority of road salt is applied, to determine whether proximity to major

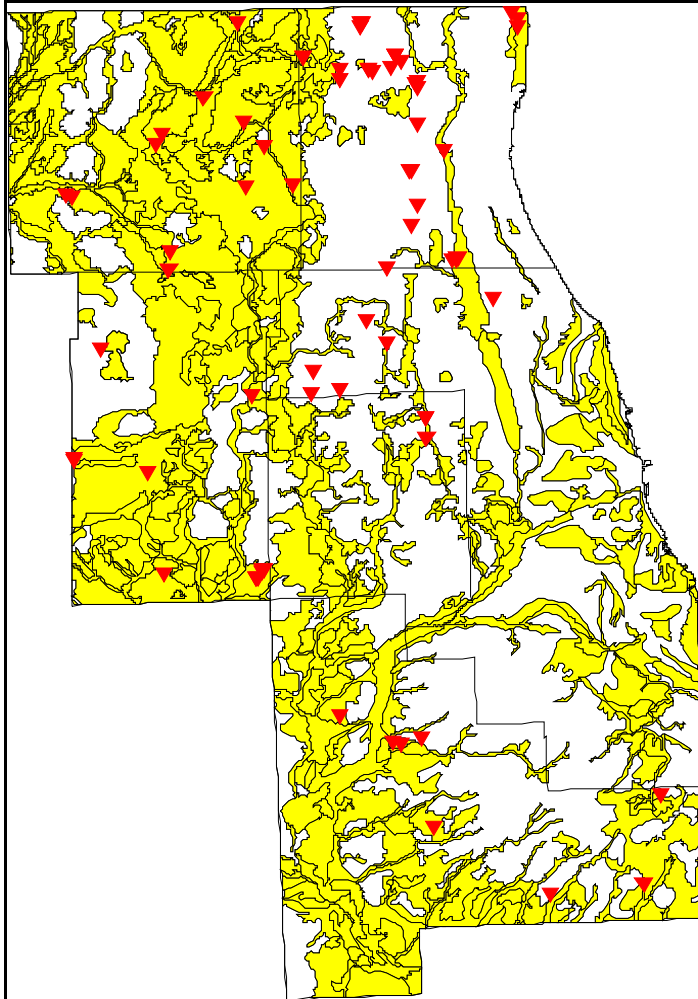


Figure 4. Yellow regions indicate areas where aquifer material is within 50 feet of the land surface. Symbols represent municipal wells that have an increase in Cl⁻ concentrations less than 0.5 mg L⁻¹ yr⁻¹ since 1960.

northeastern Illinois in the 1990s had Cl⁻ concentrations greater than 100 mg L⁻¹; median values were less than 10 mg L⁻¹ prior to 1960. Because of slow travel times and long residence times in groundwater, even if all sources of pollution were stopped immediately, peak concentrations of dissolved contaminants may be considerably higher in the future than they are now (Howard et al., 1993). The relatively greater increase in Cl⁻ concentrations in the outermost counties is likely due to both natural and anthropogenic factors, including the presence of more significant and shallower sand deposits, less curbing of major highways and streets, and increased development in some parts of these counties.

roads is correlated with incidence of increasing Cl⁻ concentrations (Figures 6 and 7). However, the high density of major roads in northeastern Illinois makes it difficult to draw any conclusions about the effect of proximity to major roads. While most wells with increasing Cl⁻ concentrations are located near major roads, so are most wells with negative or low rates of change.

CONCLUSIONS

Previous results (Kelly, 2001; Kelly and Wilson, 2002) suggested that there has been degradation of shallow groundwater quality in northeastern Illinois, especially in the outermost counties of the Chicago metropolitan area. Additional analyses confirm those conclusions. In the vast majority of municipal wells in DuPage Kane, McHenry, and Will Counties, Cl⁻ concentrations have been increasing. More than half of the wells in these four counties have rate increases greater than 1 mg L⁻¹ yr⁻¹ and approximately 13% have increases greater than 4 mg L⁻¹ yr⁻¹. Approximately 16% of the samples collected from municipal wells in

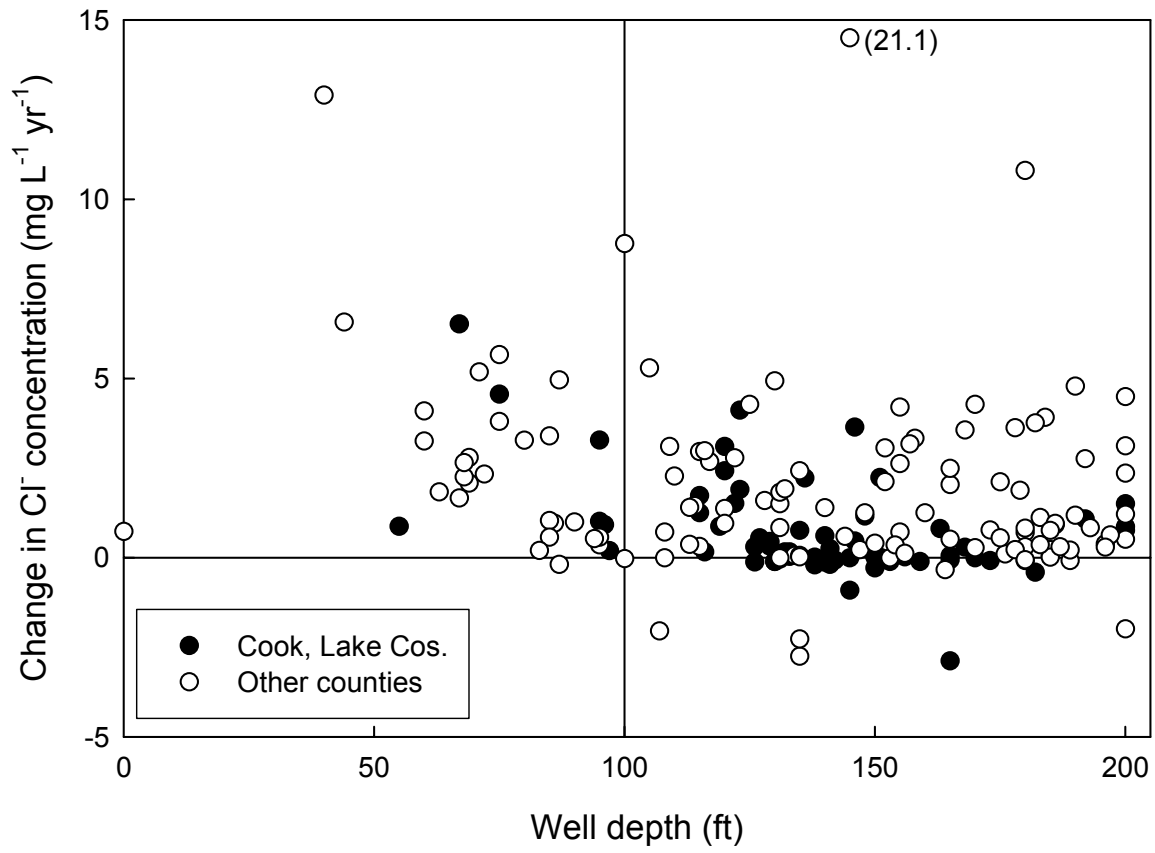


Figure 5. Change in Cl⁻ concentrations in municipal wells as a function of well depth.

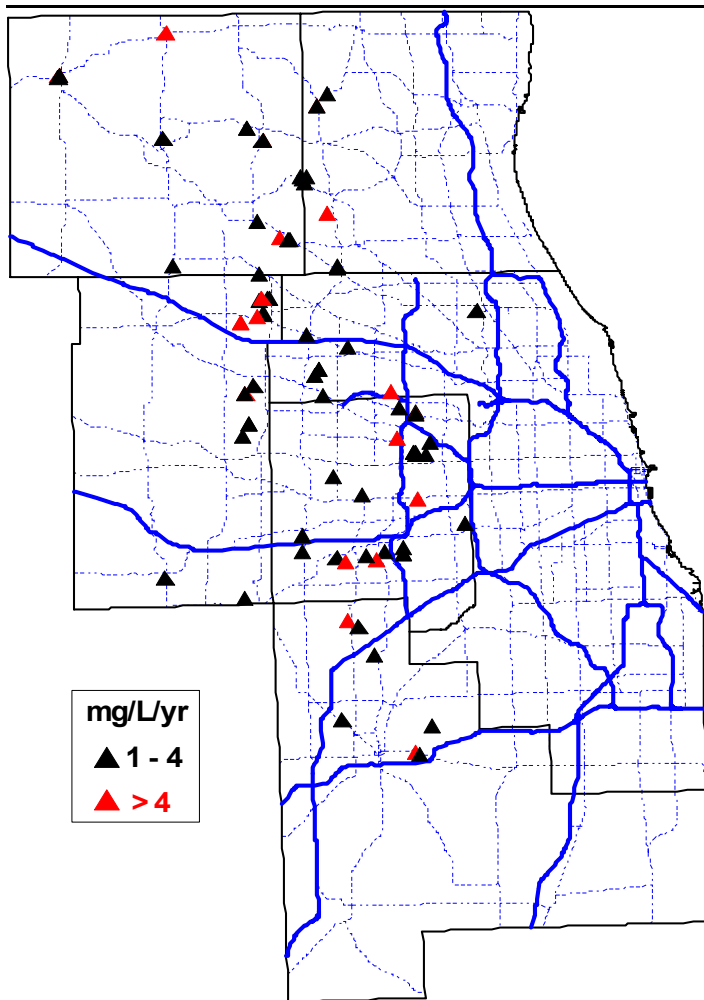


Figure 6. Interstates (solid blue lines) and major roads (dotted lines) in northeastern Illinois. Symbols represent municipal wells that show an increase in Cl⁻ concentrations since 1960.

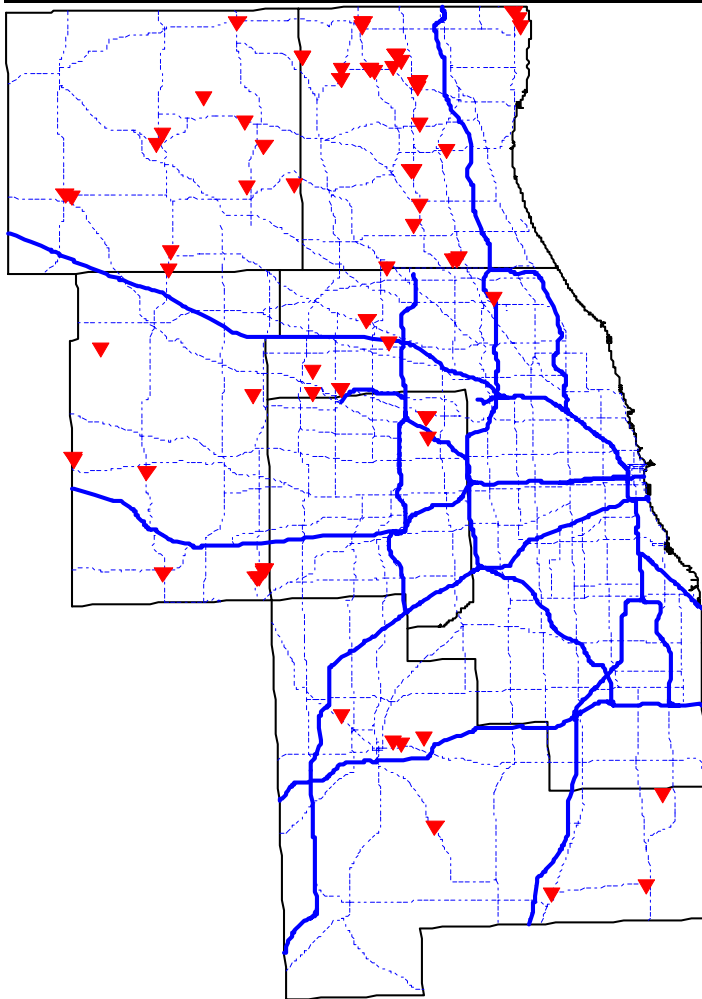


Figure 7. Interstates (solid blue lines) and major roads (dotted lines) in northeastern Illinois. Symbols represent municipal wells that have an increase in Cl⁻ concentrations of less than 0.5 mg L⁻¹ yr⁻¹ since 1960.

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