TEMPORAL CHANGES IN SHALLOW GROUNDWATER QUALITY IN NORTHEASTERN ILLINOIS

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ABSTRACT

The rapid increase in population and developed land in the Chicago, Illinois, metropolitan area has placed a heavy demand on water resources. The water sources most likely to be developed in this region over the next few decades are shallow aquifers. These shallow aquifers 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 concentrations from the Chicago metropolitan area have been evaluated for data quality and temporal trends. Chloride concentrations are increasing both regionally and for individual wells in the outermost counties of the Chicago metropolitan area, probably due to road salt runoff. Chloride concentrations have increased by over 2 mg L^{-1} yr^{-1} in 20 of 28 municipal wells in DuPage County, and by over 4 mg L^{-1} yr^{-1} in 5 wells. On the other hand, chloride concentrations are not increasing significantly in most municipal wells in Cook County.

INTRODUCTION

Population and infrastructure have grown tremendously in many urban/suburban areas in recent decades. This has placed a heavy demand on water in these areas, a demand that is expected to continue to increase into the foreseeable future. The population of the Chicago, Illinois, metropolitan area 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, 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). Water use has 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).

The principal sources of water for the Chicago metropolitan area are Lake Michigan and groundwater. Illinois has used or exceeded its annual allotment of Lake Michigan water in recent years and an increased allocation in the future is extremely unlikely (Daniel Injerd, Illinois Dept. of Natural Resources, personal communication). Pumping of deep bedrock aquifers in the region has been at or above estimated sustainable limits since the early 1990s (Visocky, 1997; Burch, in press). The main sources of water that potentially can meet the anticipated increased demand are the shallow bedrock and overlying sand and gravel aquifers. A considerable amount of water (500 million gallons day^{-1}) is estimated to be available in these shallow aquifers (Schicht et al., 1976); only a fraction of this water is being used presently.

Shallow unconfined aquifers, however, are vulnerable to surface contamination. Because of the relatively long residence time of groundwater, the impact of long-term groundwater contamination is often not recognized until large volumes of water are affected. If shallow aquifers are going to be used more for drinking water in the Chicago region, it is important to determine if their water quality has been or is being degraded and to what extent. A baseline of information is necessary in the development of strategies that might protect these aquifers in the future.

Urban regions typically have many contamination sources. Because of large populations, landfills and septic systems are abundant in relatively small areas. Urban areas are generally centers of industrial activity, and thus a wide variety of waste effluents are produced. A major source of contamination in many northern U.S. urban areas is road salt. Kelly and Roadcap (1994) identified many of these sources for causing degradation of shallow groundwater quality in the Lake Calumet area, an industrial center in south Chicago. Some common contaminants found in urban/suburban areas include chloride (Cl^-), sulfate (SO_4^{2-}), nitrogen (nitrate, ammonium), total dissolved solids (TDS), various heavy metals, and volatile organic compounds (VOCs).

Two of the most useful indicators of aquifer contamination are Cl^- and TDS. Increases in Cl^- concentrations in urban areas are generally the result of anthropogenic inputs, usually road-salt runoff, sewage effluent, or brine-waste disposal. Total dissolved solids are a measure of the amount of material dissolved in water, and is a measure of the "freshness" of water; increasing levels in an aquifer are an indication that the aquifer is contaminated. The secondary drinking water standards for Cl^- and TDS are 250 and 500 mg L^{-1}, respectively. A preliminary conclusion of Kelly (2001) was that Cl^- concentrations were increasing in the shallow aquifers in northeast Illinois, especially in the outermost counties (DuPage, Kane, McHenry, and Will). The increasing concentrations were attributed to road salting that began in the 1950s and 1960s.

The purpose of this study is to examine historical groundwater quality data over a period of several decades from the Chicago metropolitan area, and determine the changes in water quality that may have occurred over that period. In this paper, we focus on Cl^- concentrations. Additional objectives are to identify potential contaminant sources and determine if changes in chemistry are correlated with geological and land-use parameters.

LITERATURE REVIEW

Groundwater Quality of Urban/Suburban Areas

A number of studies have investigated groundwater quality in urban areas and attempted to determine sources of contamination. A consistent finding is that water quality in urban areas is correlated with land use. For example, Eckhardt and Stackelberg (1995) and Bruce and

McMahon (1996) found land use to be correlated with groundwater quality in suburban Long Island, NY, and Denver, CO, respectively.

One of the most common contaminants is Cl^- (Long and Saleem, 1974; Schicht, 1977; Eisen and Anderson, 1979). The source of Cl^- is often road salt, which has been linked to groundwater degradation in many urban and roadside areas (Huling and Hollocher, 1976; Pilon and Howard, 1987; Amrhein et al., 1992; Howard and Haynes, 1993). Because groundwater travel times are relatively slow, contaminants can persist for long times in the groundwater environment. For example, 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.

Landfill leachates can be sources of many contaminants to groundwater, although the affected areas are relatively limited (Christensen et al., 1994). Concentrations of organic compounds can be very high in leachates (Rügge et al., 1995) and decreases in the oxidation-reduction potential (ORP) can mobilize toxic metals (Bjerg et al., 1995). Soils in industrial areas commonly are contaminated with heavy metals, which may potentially leach into shallow groundwater (Kelly et al., 1996). Industrial activity also may be a source of volatile organic compounds (VOCs) to groundwater (Wehrmann et al., 1988).

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).

Groundwater Quality in the Chicago Metropolitan Area

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 sand-and-gravel wells in Kane County. While the water quality was generally good, TDS and concentrations of Cl^- and SO_4^{2-} were significantly higher in the shallow aquifers than the 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}); SO_4^{2-} 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). Significant contamination was found in almost all of the shallow wells. Contaminants included heavy metals, organic compounds (VOCs and methane), and inorganic ions (Cl^-, SO_4^{2-}, sodium (Na)). Groundwater in certain parts of the Lake Calumet region also has the unusual problem of being

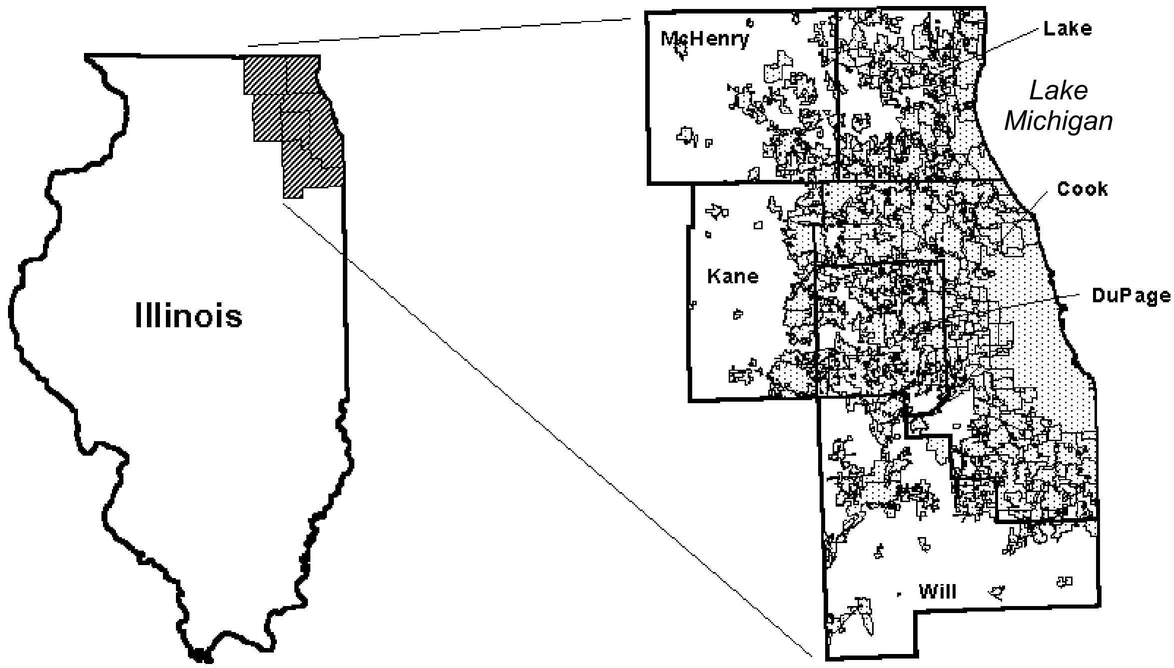

Figure 1. Study area. Dotted regions are incorporated areas.

extremely basic (pH > 11) due to dissolution of steel mill slag used as fill material (Kelly and Roadcap, 1994).

PROCEDURES

Study Area

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

The shallow aquifers are fractured dolomite and overlying sand and gravel units. The surficial deposits in northeastern Illinois 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 sands and gravels in the Wedron Formation 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.

Data Sources

Results presented here 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 use only those wells that are less than 200 ft deep.

Data Analysis

As reported previously (Kelly, 2001), complete analyses (i.e., having data for all major ions) from the ISWS and IEPA databases were evaluated using the cation-anion balance. A percent error greater than ±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.

Data from the ISWS database reported herein also have been evaluated using the cation-anion balance, and almost all complete analyses passed. There are several other quality concerns with the ISWS database that are 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. For the last concern, the IEPA database is assumed to have the correct data. For the other concerns, the records were compared with paper records where possible. Data for which quality concerns could be resolved were used in data analyses.

Preliminary analyses reported by Kelly (2001) focused on municipal wells and major ion data from the IEPA database. In this paper we report on additional analyses using Cl^- concentration data from the ISWS database. These data include Cl^- concentrations from municipal wells in Cook and DuPage Counties and private wells in DuPage County. In addition, geological information and well characteristics from all six counties were evaluated with respect to changes in Cl^- concentrations.

Kelly (2001) identified 54 municipal wells for which Cl^- was analyzed three or more times over at least a five-year period. Data for municipal wells in Cook and DuPage Counties from the ISWS database that have passed quality assurance checks were added to the IEPA data; most of these data are older (< 1980) than those found in the IEPA database. There were 4 wells from Cook County and 9 from DuPage reported by Kelly (2001). The addition of data from the ISWS database have increased those numbers to 21 and 28 wells, respectively. These data were plotted and linear regressions were performed using the software program SigmaPlot® version 6.00 (SPSS, 2000) to determine temporal trends in the Cl^- data for individual wells. For wells that had samples from prior to 1960, regressions were performed only on the post 1960 data. For these wells, no changes in Cl^- concentrations were observed prior to 1960 (see Kelly, 2001).

Private well data from DuPage County in the ISWS database that passed quality tests were added to the municipal well data to examine temporal changes in Cl^- concentrations. This was done by plotting concentration data from different time periods covering a period of approximately 30 years. Two-year periods were selected primarily based on the amount of data available. The periods selected were 1964-65, 1979-80, and 1990-91. When there was more than one sample for an individual well in a particular time period, the latest value was used.

The effects of geological and land-use data on Cl^- concentrations in the shallow aquifers were evaluated using well-log and geospatial data. Well logs were obtained for 38 of the 54 municipal wells evaluated by Kelly (2001). The logs vary considerably in detail and quality, but can contain information such as screen location, aquifer depth and thickness, aquifer type, thickness of overlying till, etc. Chloride trend data were plotted as a function of several of these parameters. Geospatial data, such as drift thickness, depth to aquifer, soil leaching sensitivity, location of major roads, etc., 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.

RESULTS AND DISCUSSION

All shallow groundwater samples in DuPage County from the ISWS and IEPA databases having Cl^- concentrations are plotted in Figure 2. This was done in order to get a "snapshot" of how Cl^- concentrations changed across the county from the early 1960s to the early 1990s. Generally speaking, Cl^- concentrations increased during this time period. In 1964-65, concentrations were relatively low (generally < 20 mg L^{-1}) throughout the county, with a few exceptions (Figure 2a). There were much more data in 1979-80, and it is apparent that Cl^- concentrations had increased (Figure 2b). Elevated concentrations were mainly in the southern and eastern parts of the county. There were still many areas with low concentrations, especially in the west. By 1990-91, almost all the samples had elevated Cl^- concentrations (Figure 2c). Although there were considerably fewer data during the early 1990s, there were almost no low values (< 20 mg L^{-1}). The fact that the spatial coverage in 1964-65 and 1990-91 is significantly less than for 1979-80 means these comparisons can only be qualitative. The major roads (interstate, U.S., and state highways) are shown in Figure 2, although not all of the roads existed at the earlier time periods. Most of the areas with elevated Cl^- concentrations are near the major roads in the southern and eastern part of the county.

Kelly (2001) identified 54 municipal wells having at least 3 samples over at least a 5 year period, including 4 in Cook County and 9 in DuPage County. Forty-six of those wells had positive rates of change in Cl^- concentrations, with 31 having rates greater than 1 mg L^{-1} yr^{-1} and

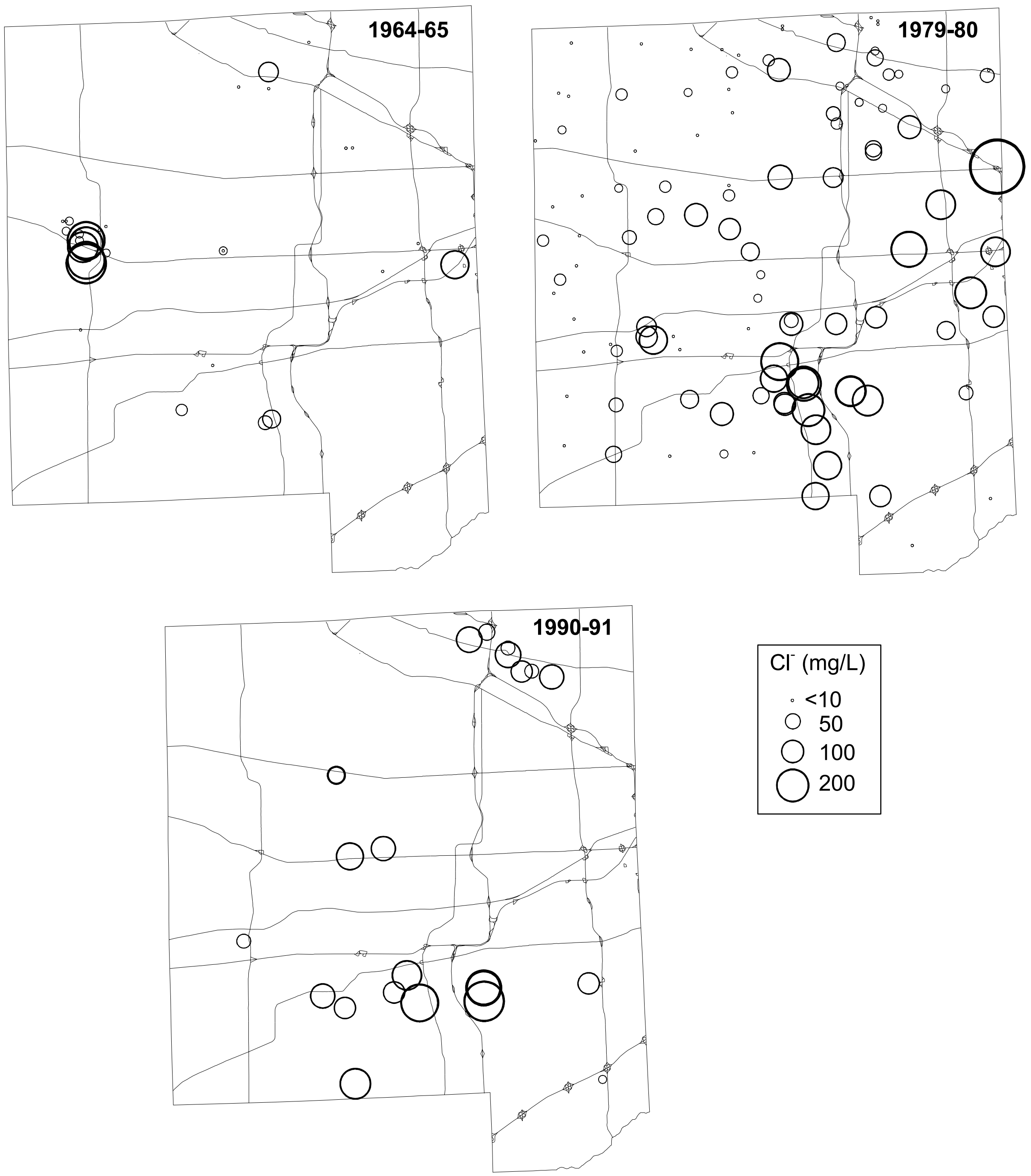

Figure 2. Chloride concentrations for all samples in DuPage County from 1964-65, 1979-80, and 1990-91. Increasing circle size represents increasing concentration.

9 having rates greater than 4 mg L^{-1} yr^{-1}. Using the ISWS database, we identified 17 additional wells in Cook County and 19 in DuPage Counties meeting the criteria (Tables 1 and 2). Of the

Table 1. Trends in Cl^- concentrations in selected municipal wells in Cook County. Rate of change and r^2 values determined by linear regression; n is number of post-1960 samples and initial is first post-1960 sample. Final Cl^- is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L^{-1} yr^{-1})	r^2	n	initial	final	final Cl^- (mg L^{-1})
Barrington Woods	2	140	0.61	0.400	4	1977	1985	11
Bartlett	1	200	0.86	0.754	9	1982	1998	35
Bartlett	2	200	0.76	0.336	9	1974*	1991	28
Bartlett	3	97	0.19	0.135	13	1960	1985	10
Elk Grove Village	13	75	4.56	0.997	3	1979	1985	55
Hanover Park	6	129	0.43	0.574	6	1978	1985	7
Hoffmann Estates	18	182	-0.41	0.738	6	1978	1985	1
Hoffmann Estates	20	192	1.08	0.817	5	1978	1985	20
Hoffmann Estates	21	122	1.51	0.945	3	1983	1990	33
Hoffmann Estates	22	119	0.87	0.872	12	1984	1992	25
Lake Run Apts	1	200	1.50	0.965	3	1984	1990	60
Mission Brook Sanitary Dst	4	170	-0.01	0.000	5	1985	1995	14
Schaumburg	10	116	0.16	0.247	6	1969	1985	6
Schaumburg	14	163	0.81	0.771	3	1980	1985	16
Schaumburg	7	96	0.92	0.812	5	1968	1985	18
Streamwood	1	120	3.10	0.780	5	1967*	1976	72
Streamwood	4	115	1.25	0.369	6	1968	1985	13
Streamwood	5	136	2.22	0.705	6	1971	1985	41
Streamwood	6	145	-0.91	0.100	5	1977	1986	40
Streamwood	7	146	3.64	0.925	8	1972	1985	62
Utl Inc County Line Water	1	138	0.01	0.003	10	1963	1992	3

* Sample(s) prior to 1960 not included in regression.

additional wells in Cook County, 15 had positive trends. Of these, seven were greater than 1 mg L^{-1} yr^{-1} and one greater than 4 mg L^{-1} yr^{-1}. For DuPage County, all 19 additional wells had positive trends, with 18 having rates greater than 1 mg L^{-1} yr^{-1} and four greater than 4 mg L^{-1} yr^{-1}. The median rates of increase were 0.86 and 2.82 mg L^{-1} yr^{-1} for the 21 wells in Cook County and the 28 wells in DuPage County, respectively.

The Cl^- concentrations in the municipal wells in the collar counties increased noticeably starting in the 1960s (Kelly, 2001). This can be seen for the data from DuPage and Cook Counties (Figures 3 and 4). As reported by Kelly (2001) and supported by the additional data for Cook and DuPage Counties, 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 for much longer than the other counties in the study area, and the streets and roads are generally 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} (Figure 4). It is not uncommon for shallow wells in the outermost counties to have concentrations greater than 100 mg L^{-1}. There is

Table 2. Trends in Cl^- concentrations since 1960 in selected municipal wells in DuPage County. Rate of change and r^2 values determined by linear regression; n is number of post-1960 samples and initial is first post-1960 sample. Final Cl^- is concentration at final date.

Municipality	Well #	Depth (ft)	Rate (mg L^{-1} yr^{-1})	r^2	n	initial	final	final Cl^- (mg L^{-1})
Addison	1	155	2.62	0.638	9	1961*	1985	62
Addison	2	115	0.31	0.999	3	1961*	1983	10
Addison	3	200	1.21	0.992	4	1968*	1978	19
Addison	4	165	2.04	0.650	7	1972	1987	48
Addison	5	155	4.20	0.637	8	1960*	1983	108
Addison	6	67	1.66	0.917	10	1965	1983	38
Addison	7	85	3.39	0.931	10	1965	1987	77
Addison	8	75	3.80	0.960	15	1967	1985	78
Addison	9	130	4.93	0.584	7	1974	1987	83
Addison	10	165	2.49	0.980	3	1977	1982	20
Belmont-Highwood PWD	1	148	1.25	0.684	5	1982	1995	141
Citizens DuPage Utility Div	1	200	3.12	0.738	3	1980	1992	182
Citizens DuPage Utility Div	3	180	10.80	0.837	3	1980	1992	199
Highland Hills	2	200	4.49	0.999	3	1983	1992	127
Itasca	5	190	1.18	0.116	6	1983	1991	108
Itasca	8	115	2.96	0.628	3	1983	1991	104
Maple Hill Improv. Assn.	1	117	2.68	0.744	3	1982	1994	167
Maple Hill Improv. Assn.	2	158	3.33	0.480	3	1982	1994	162
Naperville	4	178	3.62	0.980	7	1967*	1991	95
Naperville	5	190	4.78	0.726	9	1961*	1992	71
Pleasant Ridge MHP	2	168	3.56	0.902	5	1988	1998	117
Polo Dr/Saddle Rd Sbdv	2	200	0.51	0.084	4	1983	1997	144
SE Regional Water Facility	3	175	2.11	0.716	6	1961*	1982	45
Steeple Run	2	116	2.98	0.919	8	1972	1991	74
Vietzen MHP	1	135	-2.75	0.309	4	1988	1997	59
Vietzen MHP	2	135	-2.27	0.234	4	1988	1996	57
Warrenville	5	200	2.35	0.039	3	1983	1991	38
Wheaton	2	184	3.91	0.923	11	1964*	1992	94

* Sample(s) prior to 1960 not included in regression.

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.

Kelly (2001) reported that the median rate of increase in Cl^- concentrations was greater in the shallower wells (< 100 ft) compared to deeper wells (100 - 200 ft). This greater rate of change would be expected based on the fact that the shallower wells are, in general, more susceptible to surface contamination. However, the correlation between the change in Cl^- concentrations and depth is not strong for the municipal wells (Figure 5a). Using available well log information, there does not appear to be a correlation between the change in Cl^- concentrations and aquifer type (Figure 5b). However, there do appear to be weak correlations between the change in Cl^- concentrations and either till thickness ($r^2 = 0.096$) or depth to the top of the screen (or bottom of casing for wells finished in the shallow Silurian bedrock) ($r^2 = 0.16$) (Figures 5c and 5d). This

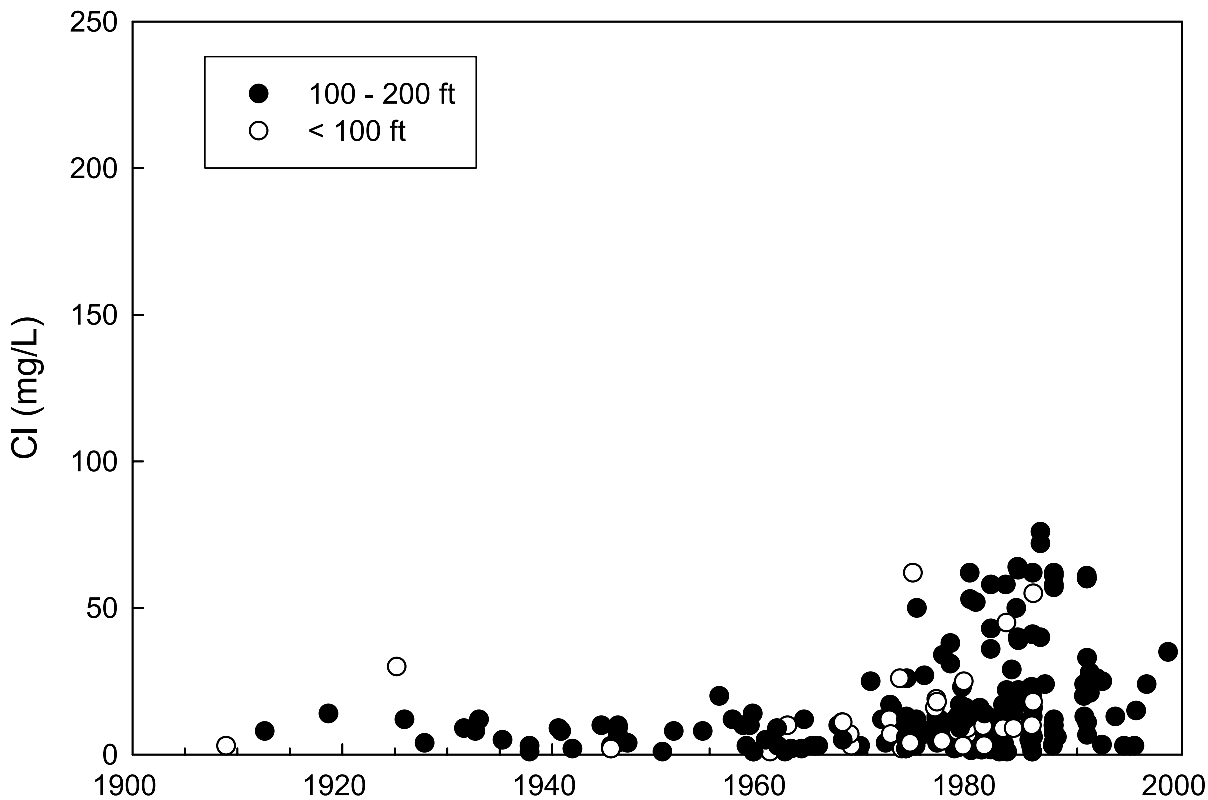

Figure 3. Chloride concentrations from municipal wells in Cook County as a function of time.

would be expected as the thinner the till and the shallower the screen, the more rapidly surface derived contaminants can travel from the land surface to the well.

There are significant sand deposits in the collar counties, especially McHenry and Kane (Hansel and Johnson, 1996). Areas where an aquifer is within 50 ft of the surface in northeastern Illinois are plotted in Figure 6. The rates of change in Cl^- concentrations for the municipal wells are superimposed on this figure as a bubble plot. Most of the wells with negative or low rates of change are found in Cook and Lake Counties where shallow aquifers are not present. However, as noted above, there are more curbed roads in these counties, so it is difficult to say if the relatively less contaminated groundwater here is due to natural or man-made conditions. Most of the wells in DuPage, Kane, McHenry, and Will Counties are in areas with shallow aquifers.

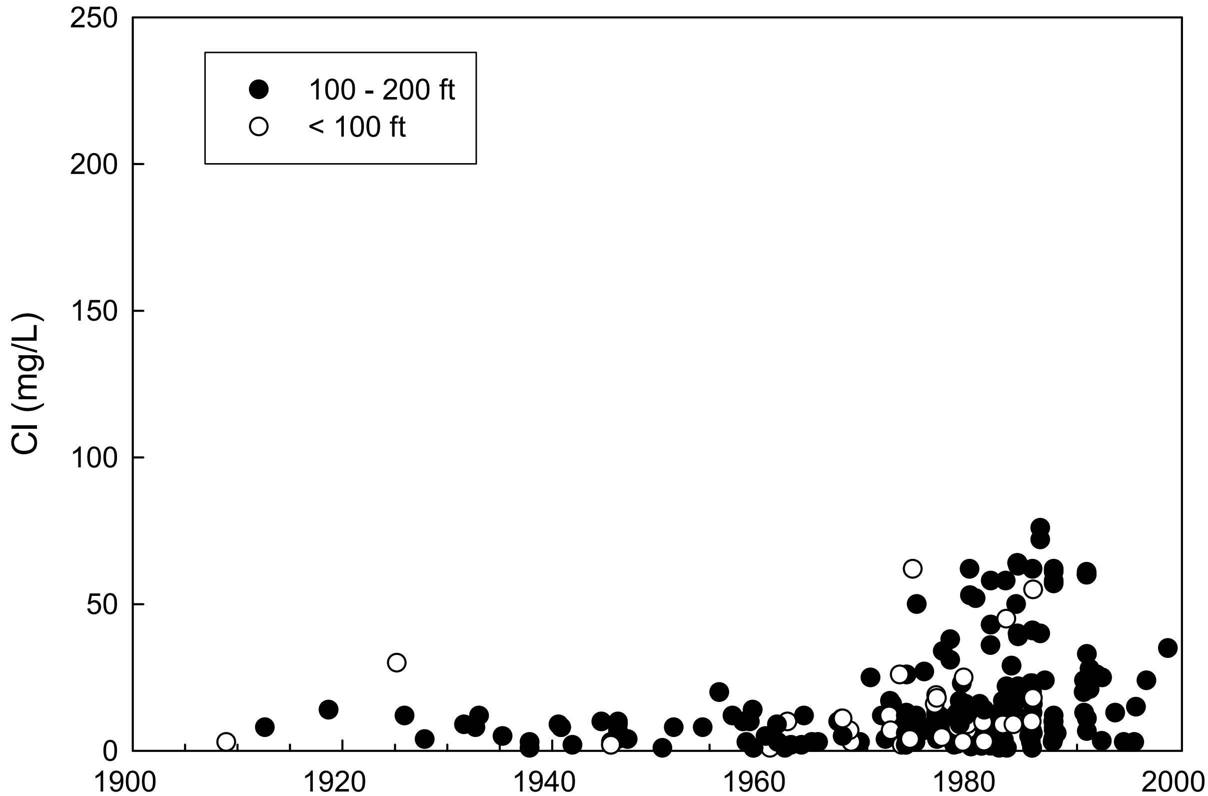

Figure 4. Chloride concentrations from municipal wells in Cook County as a function of time.

CONCLUSIONS

Preliminary results (Kelly, 2001) 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 DuPage County, concentrations are increasing for Cl^- both regionally and for individual wells; concentrations are increasing by over 4 mg L^{-1} yr^{-1} in 5 of the 28 municipal wells analyzed. In Cook County, the rates are much lower. 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 will almost surely 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 may be due to both natural and anthropogenic factors, including the presence of more significant and shallower sand deposits and less curbing of major highways and streets.

Additional work being planned as part of this project includes continued acquisition and evaluation of additional data, especially IEPA site data and county health department data, more

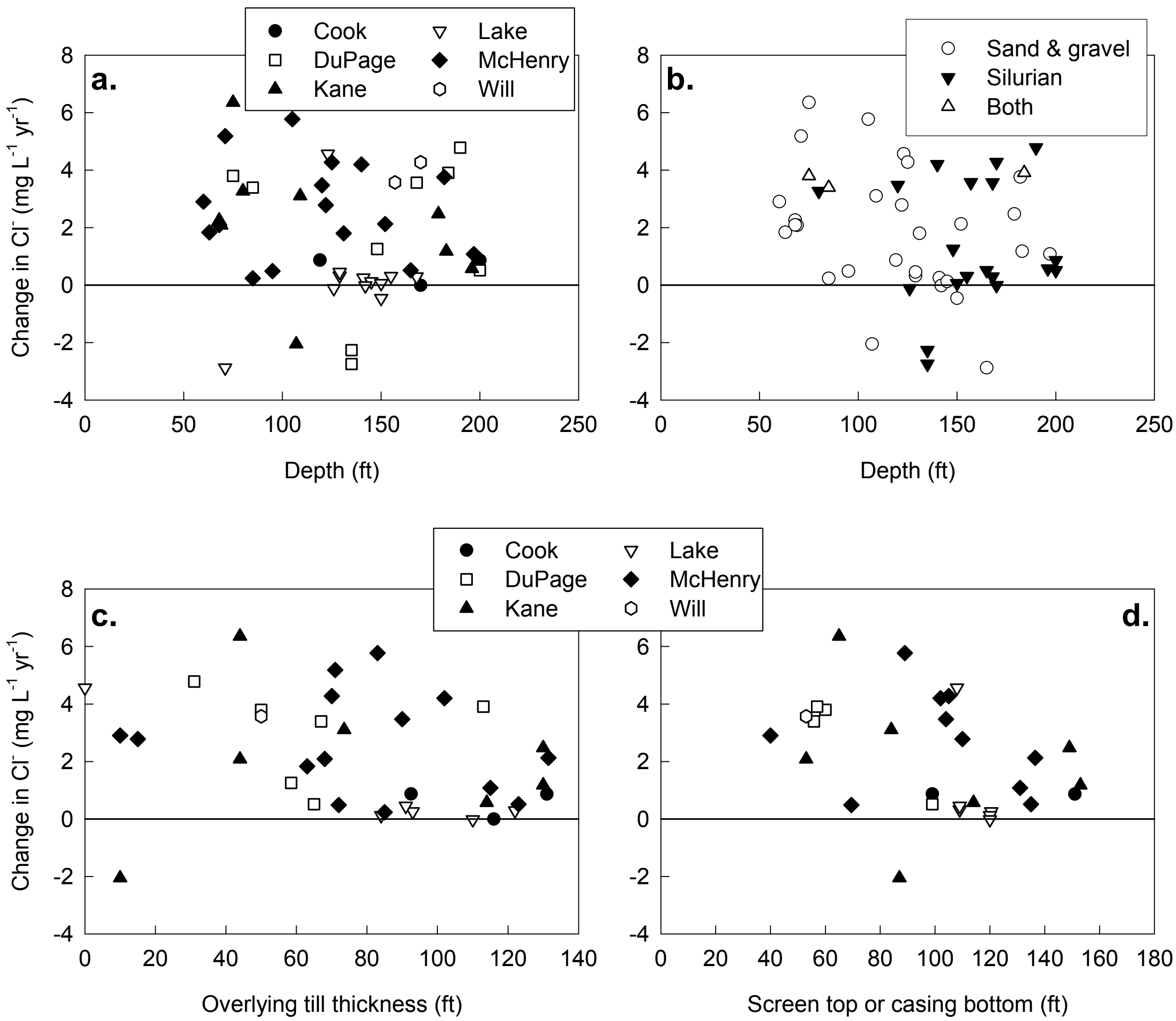

Figure 5. Rate of change in Cl^- concentration for municipal wells as a function of (a) depth, (b) aquifer type, (c) overlying till thickness, and (d) well screen top or casing bottom. Well construction and geologic data are from well logs.

detailed evaluations of geological and land-use effects on groundwater quality, and evaluation of changes for elements and species other than Cl^-.

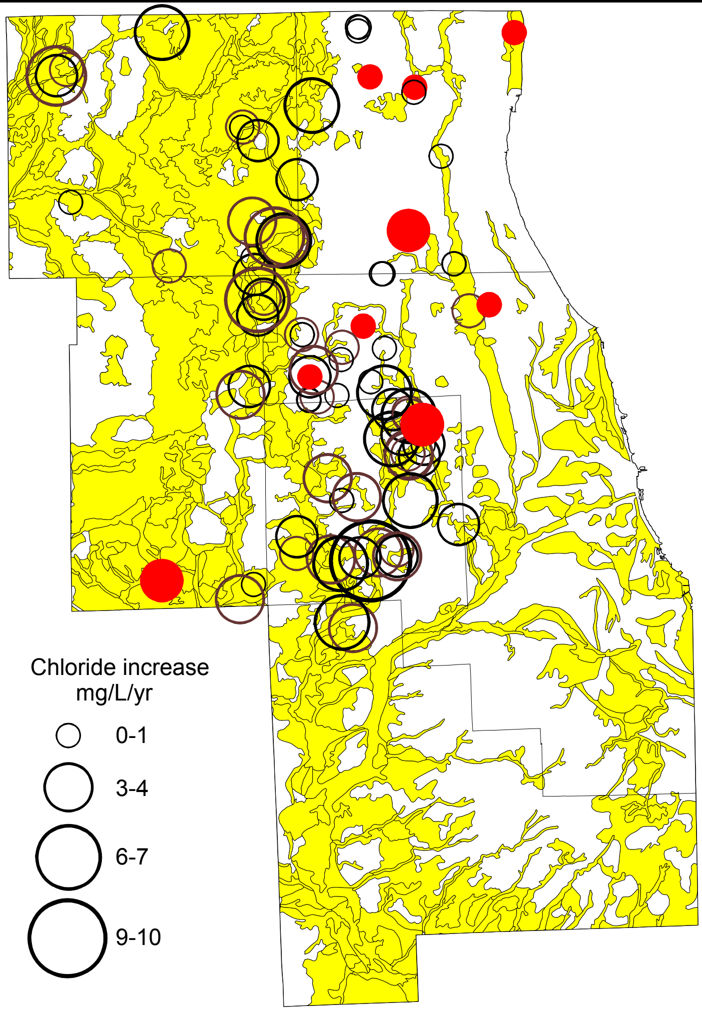

Figure 6. Rate of change in chloride concentrations for municipal wells in northeastern Illinois. Yellow areas are where there is an aquifer within 50 ft of the surface. Increasing circle size represents increasing concentration. Closed red circles represent negative rates.

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