An Evaluation of Temporal Changes in Shallow Groundwater Quality in Northeastern Illinois Using Historical Data

by
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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. Water sources most likely to be developed in this region during the next few decades are shallow aquifers. Since shallow aquifers are vulnerable to surface-derived contaminants, the increase in developed land may be escalating the rate at which groundwater quality is being degraded. A statistical study of historical groundwater quality data was undertaken to determine if urbanization activities have affected shallow groundwater quality. Of the major ions, chloride (Cl^-) concentrations have shown the largest increases in the region, due primarily to road salt runoff. In the majority of shallow public supply wells in the western and southern collar counties of DuPage, Kane, McHenry, and Will, Cl^- concentrations have been increasing since the 1960s. About 43 percent of wells in these counties have rate increases greater than 1 milligram per liter per year (mg/L/yr) and 15 percent have increases greater than 4 mg/L/yr. Approximately 24 percent of samples collected from public supply wells in the Chicago area in the 1990s had Cl^- concentrations greater than 100 mg/L (35 percent in the western and southern collar counties), compared with median values of less than 10 mg/L prior to 1960. The greater increase in Cl^- concentrations in the western and southern collar counties compared to Cook and Lake Counties is likely due to both natural and anthropogenic factors, including the presence of more significant and shallower sand and gravel deposits and less curbing of major highways and streets.

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Introduction

Population and infrastructure have grown rapidly in the Chicago, Illinois, metropolitan area in recent decades. The population has increased from about 5 million in 1950 to 8 million in 2000 and is projected to increase to more than 10 million by 2030 (Northeastern Illinois Planning Commission [NIPC], 2007). Most of the growth is occurring in Kane, McHenry, and Will Counties, where the projected population increase from 2000 to 2030 is between 75 and 115 percent (NIPC, 2007). The amount of developed land also has been expanding; residential acreage increased by 46 percent 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 percent from 1980 to 1992 (Kirk et al., 1982; Avery, 1999), and demand is expected to continue to grow as the regional population increases. Dziegielewski et al. (2004) projected an increase in water demand of 20 percent between 2005 and 2025, or an additional 275 million gallons per day. Because Illinois has legal constraints on withdrawals from Lake Michigan (capped at 3200 cubic feet/second by the U.S. Supreme Court in 1967) and withdrawls from deep bedrock aquifers exceed estimated recharge rates, shallow bedrock and overlying sand and gravel aquifers are expected to be the main sources of water to meet increased demand. Groundwater withdrawn from these shallow aquifers can be replaced by natural processes at considerably higher rates than is possible from deep bedrock aquifers (e.g., Schicht et al., 1976).

Shallow aquifers are vulnerable to surface contamination, however, and there are many potential sources of contamination to shallow groundwater 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 enormous, including various organic classes (e.g., petroleum compounds, solvents, pesticides), toxic metals (e.g., cadmium, lead, chromium), mercury, chloride (Cl^-), sulfate (SO_4^{2-}), nitrogen (nitrate, ammonium), and high total dissolved solids (TDS).

A consistent finding of urban groundwater quality studies is that water quality correlates with land use (Long and Saleem, 1974; Eisen and Anderson, 1979; Murray et al., 2004). For example, Eckhardt and Stackelberg (1995) found that population density and the amount of agricultural, commercial, or residential land were reliable predictors of the types and extent of groundwater contamination in suburban Long Island, New York. Bruce and McMahon (1996) found similar results in Denver, Colorado.

A difficulty in characterizing temporal degradation of groundwater quality is the lack of long-term chemical data. Because of this, the literature on long-term 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; Broers and van der Grift, 2004; Drake and Bauder, 2005).

Chloride is a particularly useful indicator of aquifer 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 milligrams per liter (mg/L). Chloride is a common contaminant that behaves conservatively in the environment (i.e., doesn't react and thus is transported at the same velocity as water) and has numerous sources in urban areas. Increases in Cl^- concentrations in urban areas are generally the result of anthropogenic inputs, usually road-salt runoff, sewage effluent, landfill leachate, or brine-waste disposal. Road salt has been linked to groundwater degradation in many urban and roadside areas in snowy climates (Huling

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and Hollocher, 1976; Pilon and Howard, 1987; Amrhein et al., 1992; Howard and Haynes, 1993, Williams et al., 2000; Bester et al., 2006). Significant road salt application began after World War II and accelerated rapidly across the United States starting in the 1960s (Figure 1) (Salt Institute, 2008). Once in groundwater, Cl^- and other contaminants can persist for a long period due to slow travel times. Howard et al. (1993) estimated that, even if road salting was stopped immediately in the Toronto, Canada, area, it would be decades before Cl^- concentrations in shallow groundwater returned to pre-1960 levels.

The Illinois State Water Survey (ISWS) has conducted several shallow groundwater quality studies in the Chicago region. In 1979, Sasman et al. (1981) sampled 282 shallow public, commercial, and private domestic wells finished within the shallow dolomite bedrock 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 public supply wells in Kane County. Although the water quality was generally good, concentrations of TDS, Cl^-, and SO_4^{2-} were significantly higher in shallow aquifers than in bedrock aquifers. Roadcap et al. (1993) sampled 186 shallow public, commercial, and private domestic wells in Will and southern Cook Counties in 1990-1991. They found that about 75 percent of samples exceeded the secondary drinking water standard for TDS (500 mg/L); SO_4^{2-} and iron concentrations 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 (<20 feet) monitoring wells, and wells next to Interstate 94 had Cl^- concentrations in excess of 1,000 mg/L. Kelly (2005) sampled 70 shallow private wells (< 250 feet [75 meters (m)]) throughout
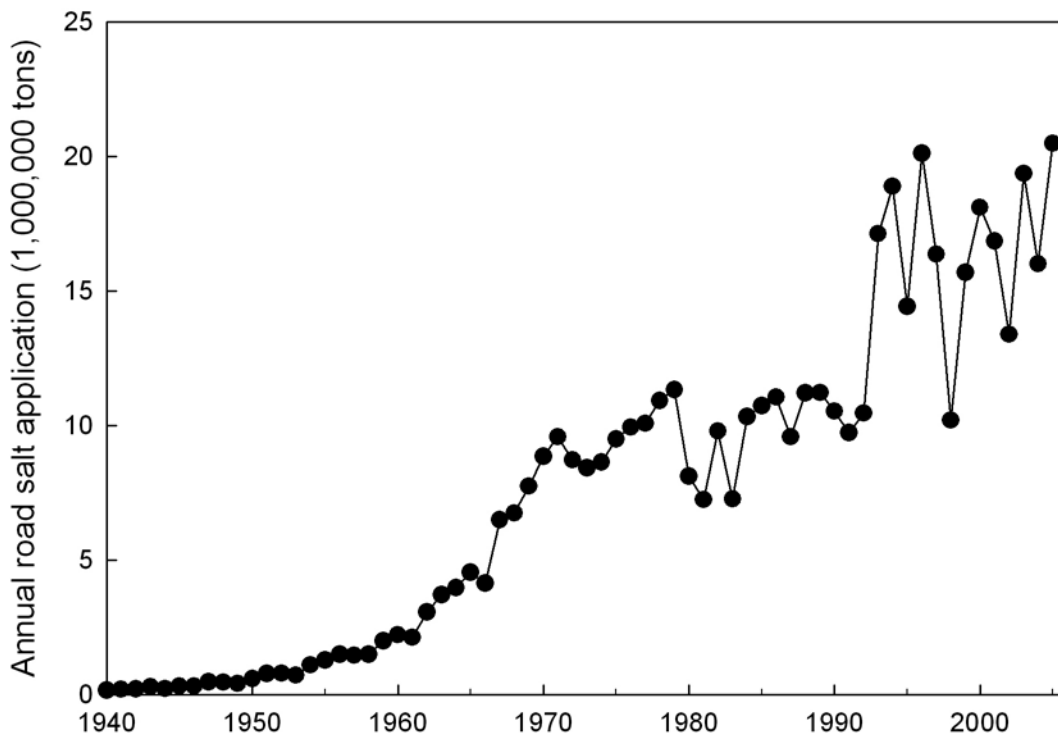
Figure 1. Annual road salt application in the United States (data from Salt Institute, 2006).

Kane County in October 2003. Concentrations of TDS, Cl$^-$, and the other major ions were significantly greater in the eastern third of Kane County, where most land use is urban and residential, compared to both the western and central thirds, where land use is still predominantly rural. The median Cl$^-$ concentration in the eastern third was 42.0 mg/L, compared to 3.8 and 6.6 mg/L in the western and central thirds, respectively.

Objectives

Although shallow aquifers are commonly used for water supply by many municipalities, industries, and domestic well owners in the Chicago metropolitan area, a comprehensive assessment of the quality of these aquifers has never been done. With the likelihood that shallow aquifer use will increase in coming decades, it is critical to characterize the degree and geographic extent of chemical degradation of these aquifers regionally. Such baseline data are necessary for water-supply planning and to develop strategies to protect these aquifers.

The purpose of this study was to examine historical shallow groundwater quality data to characterize temporal changes in water quality in the Chicago metropolitan area. We examined major ions (calcium [Ca], magnesium [Mg], sodium [Na], Cl$^-$, SO$_4^{2-}$, and bicarbonate [HCO$_3^-$]) and TDS, especially focusing on Cl$^-$. Additional objectives were to identify potential contaminant sources and determine if chemistry changes correlate with geological setting and land-use parameters.

Procedures

Study Area

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 2). This is an area of approximately 3700 square miles (9580 square kilometers [km^2]) with a population of 8 million.

The aquifers that are the subject of this study consist of shallow bedrock and overlying sand and gravel units. The shallow bedrock in northeastern Illinois is primarily Silurian and Ordovician sedimentary rock, with the most productive aquifers being fractured Silurian dolomites. The surficial deposits consist of unconsolidated Quaternary deposits of intertonguing diamicton and sand and gravel outwash ranging in thickness from less than a foot (0.3 m) to more than 400 feet (120 m) (Hansel and Johnson, 1996). These glacial deposits are thickest in northwestern McHenry County, but thicknesses exceeding 200 feet (60 m) also are present in central and eastern McHenry County, most of Lake County, northern Kane County, north central DuPage County, and northwestern and west central Cook County. Quaternary deposits are generally thinnest in the central part of the study area, notably central DuPage and Cook Counties and northern and western Will County. Moderate to large groundwater supplies are located in sand and gravel deposits contained within the Quaternary glacial materials in the area. These sand and gravel deposits are present either at the surface, or underlying or interbedded with diamicton. The most productive water-producing units tend to be basal sand and gravel deposits, just above and in contact with shallow bedrock, which are generally thicker and more coarse-grained than other sand-and-gravel deposits.
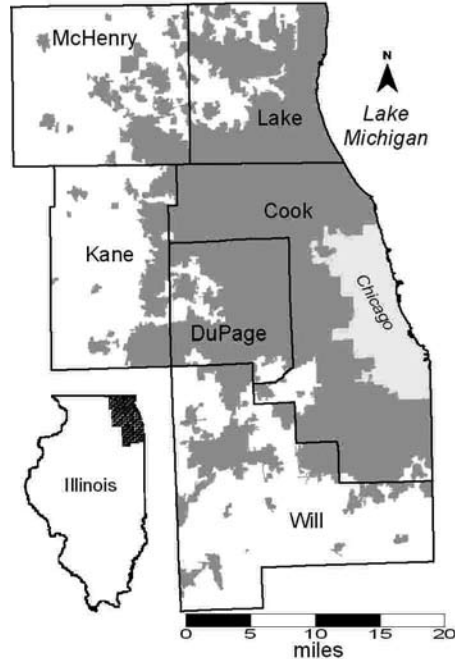
Figure 2. Chicago metropolitan area. Light gray area indicates Chicago city limits. Dark gray areas are other incorporated municipalities.

Groundwater recharge rates in the Chicago area are not precisely known, but are estimated to range between 2 and 12 inches/year (50 and 300 millimeter per year [mm/yr]) (Roadcap et al., 1993; Arnold et al., 2000). The highest rates are generally in the southern and northwestern parts of the study area. Assuming an average porosity of 0.3, groundwater flow rates based on the reported recharge rates vary between 0.56 and 3.3 feet/year (0.17 and 1.0 m/yr). Estimation of recharge is complicated by the fact that urban areas can increase groundwater recharge due to leaking water mains, storm water, and sewer pipes (Sharp et al., 2003). Water quality would be high in recharge from water mains, while storm and sewer water quality would tend to be poor. Chicago has been replacing old water mains at a rate of 50 miles per year (out of a total 4000 miles), and is in the midst of a massive engineering project (generally known as TARP) to divert storm water and sewage into temporary underground storage reservoirs during large rain or snow melt events. Water main replacement between 1990 and 2001 was estimated to have reduced water losses by about 120 million gallons per day (City of Chicago, 2003).

Methods

This study entailed compiling and evaluating all available water quality data, performing exploratory data analyses, and then conducting trend analyses. The entire data set was initially used for exploratory data analyses, then data from individual wells. Trend analyses were based on time series data from individual wells. The study was limited to wells no more than 200 feet (60 m) deep to include aquifers most vulnerable to surface contamination.

Data Sources

Groundwater quality data evaluated in this study were obtained primarily from a database maintained by the Illinois State Water Survey (ISWS). The database contains results from approximately 50,000 groundwater samples from more than 25,000 wells in Illinois dating back to the late 1890s. Two Illinois state agencies, the ISWS and the Illinois Environmental Protection Agency (IEPA), primarily compiled the data. The IEPA began collecting samples from public supplies for ambient water quality analysis starting in the early 1970s. Prior to this time, the Illinois Department of Public Health collected samples from public supplies, and a few of these records are included in the database. IEPA sampling frequency varies greatly over time, peaking in the early 1980s. Starting in the mid-1990s, a random probability-based scheme stratified by aquifer type, geologic susceptibility, and well depth has been used to select about 350 wells in Illinois for sampling each year. Samples collected by water plant operators are subject to IEPA's quality assurance and quality control (QA/QC) procedures during analysis.

Almost all data in the ISWS database prior to the early 1970s, dating back to the 1890s, were generated by the ISWS Public Service Laboratory (PSL). The PSL has continued to analyze public water supply samples on request even after IEPA began their sampling program, but the number of PSL samples is much fewer than the IEPA data. The PSL also analyzes samples from private wells. Although these samples undergo rigorous QA/QC once they reach the PSL, there is less control of sample collection procedures. Sample bottles are sent to the water plant operator or well owner with instructions on how to collect samples and return them to the PSL in containers with ice packs, but whether the person collecting the sample adheres to those instructions cannot be verified. Samples that undergo metals analysis are acidified on receipt at the PSL to ensure the metals are dissolved. If samples are received after their proscribed holding time, PSL analysts note this on the QA/QC report. However, this is not generally an issue for parameters of interest in this study.

Several additional data sources in the database include (1) IEPA Bureau of Land samples from wells up-gradient of landfills and regulated clean-up sites; (2) water quality data from the Lake County Health Department (primarily nitrate and some other inorganic ions collected from new wells); (3) nitrate data from the McHenry County Health Department; and (4) data from two ISWS research projects: samples from about 40 non-community wells collected in 2003 throughout the Chicago area (Wilson et al., 2004), and samples from approximately 70 private wells collected in Kane County in 2003 (Kelly, 2005).

At the time of this study, results were available from more than 2100 samples in the ISWS database from private wells less than 200 feet deep in the six-county area, collected between 1907 and 2005, as well as results from more than 2500 samples from approximately 1000 public wells in the six-county area, collected between 1906 and 2005.

Parameters considered include the major ions Ca, Mg, Na, HCO_3^-, Cl^-, and SO_4^{2-}, and TDS. Bicarbonate is typically not measured, but is instead calculated from measured alkalinity, thus we used alkalinity as a surrogate for HCO_3^- in data evaluations. Major ions comprise the bulk of dissolved material in groundwater, and their analysis has been routine for many years. Although the metals iron and manganese have been analyzed routinely for years, they were not considered in this study because most submitted samples are unfiltered. By not filtering out particulate matter, many samples may include iron and manganese not native to the groundwater (e.g., rust and scale in distribution systems or clays suspended by pumping). In addition, trace metals and other minor constituents were not considered because results are relatively limited

with virtually no data prior to 1970. Concentrations of many trace constituents are commonly present at or below detection limits, and detection limits have varied considerably over time, making determination of temporal changes difficult.

Data Quality Considerations

Data quality issues included samples with incomplete or incorrect information (well number, location, and depth) and concerns about the quality of the water-chemistry data itself. Most data problems were corrected by examining hard-copy sampling reports archived at the ISWS, when available, or by comparing database records with information in the ISWS Public, Industrial, and Commercial Survey (PICS) well database.

The most common water-chemistry problem was an unacceptable ion balance. Ion balances are calculated to ensure that positively charged ions (cations) are present in approximately the same amount as negatively charged ions (anions). Ion balances were calculated using the following equation:

$$\%E = [(\sum cations - \sum anions) / (\sum cations + \sum anions)] * 100 \qquad (1)$$

Ion concentrations are in milliequivalents per liter (meq/L), and %E is the percent error. Major ions typically make up more than 95 percent of the ionic charge in groundwater samples. In samples with substantial concentrations of other ions (e.g., potassium [K^+], nitrate [NO_3^-], ammonium [NH_4^+], iron [Fe^{2+}]), these ions were added to the ion balance. Samples with an ion balance error exceeding 10 percent were flagged and then compared to hard copies in ISWS records, when available. Transcription errors were found for many problem samples; when corrected, ion balances were usually acceptable. Samples that could not be corrected to produce acceptable ion balances were not used in data analysis.

TDS errors were found for a considerable number of samples. TDS was reported as a direct measurement for most samples, which included filtration, drying, and weighing of a known sample volume. It also can be calculated from a formula by adding major ion concentrations. The following equation was used to calculate TDS for samples for which complete major ion analyses were available (Hem, 1989):

$$TDS = Ca + Mg + K + Na + Cl^- + SO_4^{2-} + SiO_2 + (0.4917 * HCO_3^-) \qquad (2)$$

Concentrations are expressed as milligrams per liter (mg/L), and SiO_2 is silica. The HCO_3^- is converted by a gravimetric factor that assumes that half of it is volatilized as carbon dioxide (CO_2) and water (H_2O). TDS values calculated using Equation (2) were compared with directly measured TDS when the data were available.

We elected to use calculated values for TDS in our evaluations rather than directly measured values because there were substantial discrepancies between the two values for many samples. The difference between the two values often exceeded 10 percent, and many differed by more than 20 percent. This indicates either an error in the major ion or TDS values for these samples. An error in the major ion data is usually evident from a poor ion balance, but most samples with large differences did not have significant ion balance errors.

Instead of performing data analysis on TDS values calculated using Equation (2), we used a slightly modified equation. Some sample analyses, especially those conducted before 1970, include all major ions, but not K and/or SiO_2. Those two parameters are typically a small fraction

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of the TDS (<5 percent), and thus were removed from Equation (2) to calculate a modified TDS value, which we define as the summation (Σ) of major ions:

$$\Sigma Major\ Ions = Ca + Mg + Na + Cl^- + SO_4^{2-} + (0.4917 * HCO_3^-) \qquad (3)$$

Values from this revised calculation are slightly less than TDS values. However, the equation allows TDS trend evaluation over a longer time period, assuming that K and SiO_2 concentrations did not change substantially during the period of record.

Another important water chemistry data issue was inconsistencies in time series data, specifically in water samples from individual wells that appeared to be dramatically different from earlier and/or later samples collected from the same well. In general, temporal variation in groundwater chemistry is small unless there has been some major change to the system (e.g., introduction of contamination, major change in pumping rate). Inconsistent data were flagged and compared to hard copies in the ISWS records, if available. If the inconsistency for a particular sample could not be resolved, that sample was still included in the data analysis because the authors felt the rationale for removing such samples from consideration was too subjective.

Data Analysis Groupings

All data were examined as a function of time. Some wells had two or more samples collected in a single calendar year. To prevent these wells from unduly influencing exploratory data analyses, only one sample per year was used. The latest sample was arbitrarily selected unless there was a more complete analysis (i.e., more ions analyzed) from earlier in the year. Duplicate analyses were also removed from data sets.

Data were divided into time periods for analysis. Alkalinity and Cl^- data were divided into six groups: before 1950, 1950s, 1960s, 1970s, 1980s, and 1990-2005. For the other major ions and ΣMajor ions, data from the 1950s and 1960s were combined because these ions were not routinely measured during those two decades. When the data were subdivided by county, well type, and well depth (see below), data from the 1950s and 1960s were combined for alkalinity and Cl^- due to small sample sizes in those two decades. Wells were divided into two groups based on well type for additional analysis, public supply and private, primarily because public supply wells are much more likely to have been sampled multiple times. In addition, public supply wells tend to have much longer well screens than private wells and are pumped at much greater rates, thus their water quality tends to be more representative of an entire aquifer because groundwater from discrete intervals is often blended. Wells were further subdivided by depth, including less than 100 feet (30 m) and between 100 and 200 feet (30–60 m).

Statistical Analyses

Exploratory measures for both temporal and spatial data analysis included box-and-whisker plots, Kruskal-Wallis ANOVA on ranks, and Mann-Whitney rank sum tests (Helsel and Hirsch, 2002). Dunn's Method was used to determine whether differences between population pairs were significant when results from an ANOVA on ranks test indicated a significant difference. The data spread was measured by the interquartile range (IQR), the difference between the 75th and 25th percentiles. Non-parametric analyses were used because the data were generally not normally distributed.

Trends for individual wells were analyzed by determining the Kendall S statistic, a nonparametric test of the data, calculated by:

$$S = P - M \qquad (4)$$

P is the frequency of increases in a set of (x,y) pairs, or the frequency of $y_i < y_j$ for all $i < j$, and M is the frequency of y decreases as x increases, or the frequency of $y_i > y_j$ for all $i < j$, for all $i = 1, ... (n - 1)$ and $j = (i + 1), ... n$ (Helsel and Hirsch, 2002). In this study, x represents time (sample date) and y represents the concentration of a major ion or TDS. Kendall's S is basically a measure of how often the concentration is higher or lower than that of previous samples. The calculated S value is compared to a table of exact critical values to determine if the null hypothesis (no trend) can be rejected. A significance level (α) of 0.05 was used.

When the number of samples (n) exceeded 10, a large sample approximation was used (Helsel and Hirsch, 2002). The test statistic Z_s is calculated as:

$$Z_s = \frac{S - 1}{\sigma_s} \qquad (5)$$

when S > 0, and

$$Z_s = \frac{S + 1}{\sigma_s} \qquad (6)$$

when S < 0. When S = 0, $Z_s = 0$. The test statistic σ_s is calculated by:

$$\sigma_s = \sqrt{(n / 18) * (n - 1) * (2n + 5)} \qquad (7)$$

The null hypothesis was rejected at a 90 percent significance level when $|Z_s|$ exceeded Z_{crit}, the value of the standard normal distribution.

To estimate rates of changes in Cl^- concentrations for individual wells, regressions were performed to determine the slope coefficient (β_1), which for these data gives the change in concentration in milligrams per liter per year (mg/L/yr). Although regressions are parametric tests and thus not robust for data that are not normally distributed, β_1 can be tested, with the null hypothesis being $\beta_1 = 0$ (Helsel and Hirsch, 2002). The test statistic is the t-ratio in which r is the correlation coefficient:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \qquad (8)$$

The null hypothesis is rejected (i.e., β_1 is significantly different than zero) if $|t| > t_{crit}$, where t_{crit} is the point on the Student's t distribution with n – 2 degrees of freedom, and with a probability of exceeding $\alpha/2$; $\alpha = 0.10$ was used in this study. The β_1 and correlation coefficient values were determined using the SLOPE and CORREL worksheet functions, respectively, in Microsoft® Excel 2002. Both individual wells with multiple samples and samples on a county-wide basis were evaluated. For individual wells, β_1 was calculated if there were at least four samples collected over at least a five-year period with the most recent sample in the 1980s or later. A total of 239 public supply wells and three private wells met these criteria for at least one major ion. The number of wells per county was: Cook (29), DuPage (43), Kane (42), Lake (49), McHenry (53), and Will (26). For wells having samples collected prior to 1960, β_1 calculations

were performed only on the post-1960 data. This was when significant road salting began in the Chicago area, and no changes in Cl⁻ concentrations were observed for these wells prior to 1960 (Kelly, 2001).

The effects of geology on Cl⁻ concentrations in the shallow aquifers were evaluated using well-log data on file at the ISWS. The logs vary considerably in detail and quality, but can contain information such as screen location, aquifer depth and thickness, source aquifer, thickness of overlying till, etc. Some well log information (e.g., casing length, screen location, and/or overlying till thickness) was available for 200 of 242 wells examined individually. All of these wells had source aquifer information (shallow bedrock, unconsolidated sand and gravel, or both). Chloride trend data were plotted as a function of several of these parameters.

Geospatial data, such as till thickness, depth to aquifer, soil leachability, location of major roads, etc., were downloaded from the Illinois Natural Resources Geospatial Data Clearinghouse (http://www.isgs.uiuc.edu/nsdihome/ISGSindex.html). The geological data are from Keefer (1995a, 1995b) and Berg and Kempton (1988). Chloride concentrations and trend data were plotted on these maps to observe potential relationships. Relationships were tested using ANOVA on ranks and rank sum tests. Chloride concentration data from between 1998 and 2004 were used. For wells that did not have samples collected during this period, Cl⁻ concentrations were calculated from β_1 values for the year 2000.

Data and Statistical Limitations

There are a number of limitations in evaluating these data that need to be noted. First, these are generally not random samples, but are instead primarily either public supply wells required to be sampled or private wells sampled at the discretion of the well owner. Second, there is variability in location with time due to changes in population patterns and decisions regarding water sources. For example, prior to 1970, about 30 percent of samples in the Chicago region came from wells in Cook County, but that number has been dropping as users in Cook County increasingly use Lake Michigan water instead of groundwater for water supply. Between 1990 and 2005, only 8 percent of the samples came from Cook County. In contrast, the number of samples from Kane and McHenry Counties has been increasing as residential density has increased; the percentage of samples from these two counties combined increased from about 25 to 45 percent between 1950 and 2005. Thus, when looking at the bulk data without regard to location, earlier samples are more heavily weighted to locations close to Chicago, and later samples are more heavily weighted to locations relatively far from the city.

An additional limitation is that the rate of public supply well sampling has varied over time due to changes in funding and switching to a more statistically random sampling scheme. The peak sampling was during the late 1970s and early 1980s. Data groupings with the smallest number of samples are from the 1960s and in the less than 100 feet (30 m) well depth group for the 1990-2005 period. Also, the identity of the wells in each group is not necessarily the same. Many of the wells sampled in the 1980s were not sampled in the 1990s. Thus the analyses are not as rigorous as they would be if the same wells were being compared over the entire period.

Results and Discussion

Exploratory Data Analysis

Box-and-whisker plots for the major ions (alkalinity, Ca, Mg, Na, Cl⁻, and SO_4^{2-}) and
∑Major ions for all the data are plotted in Figure 3, and for each county in Figures 4–9. Median
and IQR values are reported in Tables 1–9, and a complete report of the basic descriptive statis-
tics is found in Appendix A. When all data in the six-county area are combined, the most obvious
trend in increased concentrations is for Cl⁻. The median Cl⁻ concentration steadily increased
from 6 mg/L prior to 1950 to nearly 20 mg/L in samples from 1990-2005, and each time period
had significantly greater concentrations than the previous time period except for the 1990-2005
group compared to the 1980s. The spread in concentrations (as indicated by IQR in Table 1 and
the 75th, 90th, and 95th percentile values in Figure 3) has also been increasing, indicating spatial
variability in sources of Cl⁻ contamination. Of the other parameters, Na concentrations have been
increasing since the 1960s, with the highest median value (31 mg/L) in the 1990-2005 period.
The 1990-2005 group had significantly greater Na concentrations than all groups from the 1950s
through the 1970s. For Ca, Mg, and ∑Major ions, the pre-1950 data were significantly less than all
later data groups, but there have been no obvious increases since then. Alkalinity was similar to
Ca, Mg, and ∑Major ions, although there is more evidence of an increasing trend; the 1990-2005
period had significantly greater concentrations than all data prior to the 1980s. The median value
for SO_4^{2-} was highest in the 1950s, and the 1990-2005 data were significantly lower than all data
groups between 1950 and 1990.

For individual counties (Figures 4–9, Tables 2–7), the greatest temporal changes were
generally found in the western collar counties, DuPage, Kane, McHenry, and, to a lesser extent,
Will County to the south. In DuPage County, the median values of all parameters tended to
increase, especially Cl⁻, which increased from 4 mg/L prior to 1950 to 101 mg/L in the 1990s and
later, an increase of more than 2500 percent. During the same period, median values of alkalinity
increased by 26 mg/L, Ca by 44 mg/L, Mg by 17 mg/L, Na by 41 mg/L, SO_4^{2-} by 118 mg/L, and
∑Major ions by 332 mg/L. The same trends were generally also observed in Kane and McHenry
Counties for most of the parameters, although the magnitudes of the changes were usually much
less. Chloride increased in Will County, but trends were less obvious for the other parameters.
Chloride in Cook County was highest in the 1990-2005 data group, but there was little change in
the previous groups. No significant change occurred in Cl⁻ in Lake County during the entire time
span. Sodium decreased in Lake County and stayed relatively constant in Cook County. ∑Major
ions increased slightly in Lake County, but there was no obvious trend in Cook County. The IQR
values for Cl⁻ increased in all counties except Lake (Tables 2–7). The decrease in SO_4^{2-} observed for
the entire data set appeared to be primarily due to decreases in Cook and, especially, Will Counties.

When data were separated based on well depth, there were differences for many param-
eters between the shallower (< 100 feet) and deeper (100-200 feet) wells (Tables 8–9 and Figure
10). With the exception of Na and SO_4^{2-}, all the ions and ∑Major ions had greater concentrations
in the shallower wells than the deeper ones for almost all date groupings. These differences were
statistically significant at most time periods for Cl⁻, alkalinity, and Ca. Chloride, alkalinity, and
Ca tended to have more spread in the shallower wells, as indicated by greater IQR values, while
SO_4^{2-} and Na had more spread in the deeper wells.

Concentration trends were generally the same for both the shallower and deeper wells. There were increasing trends for Cl⁻ concentrations for both shallower and deeper wells, with the median concentration increasing from 8 to 36 mg/L in the shallower wells and from 5 to 17 mg/L in the deeper wells from prior to 1950 to 1990-2005. The IQR values also increased over time. Sodium increased in both the shallower and deeper wells at similar rates since the 1950s, while the other cations (Ca and Mg) have remained fairly steady in both depth ranges since the 1950s. The increase in alkalinity has been greater in the shallower wells, while SO_4^{2-} has decreased at similar rates in both depth ranges.

It needs to be noted again that there are limitations to examining the entire data set due to spatial differences and temporal changes in sample locations. For example, there are relatively few samples from wells < 100 feet in DuPage County (only 7 percent of the total). If there were more samples from DuPage County, where trends are highest, we would anticipate greater trends in the entire data set than is shown. Also, there has been an increasing percentage of samples from Kane, McHenry, and Will Counties with time. Prior to 1970, about 43 percent of samples from wells < 100 feet came from Cook, Lake, and DuPage Counties, while only about 25 percent came from these counties in 1990-2005.

There were substantial differences for individual counties based on well depth (Appendix A), although some counties, such as Cook and DuPage, had very few samples from shallow wells (< 100 feet) during some time periods. Trends observed for the complete data sets for a particular county were generally observed for both shallow and deep (100–200 feet) well sets. In DuPage County, increases in all parameters were observed for both shallow and deep wells, and trends were usually significant. Increasing trends were also observed for all parameters except SO_4^{2-} in the shallow wells in Kane County. For the deep wells, the increases tended to be less pronounced, and Na and SO_4^{2-} remained fairly steady or decreased slightly. McHenry County was similar to DuPage County in that most of the parameters increased steadily for both shallow and deep wells. In Will County, there were no obvious changes in concentrations for any parameters except Cl⁻, which increased in both shallow and deep wells, but to a lesser degree than the western counties. Chloride appeared to increase in both shallow and deep wells in Cook County, although there were few samples from shallow wells. In Lake County, it appeared that Cl⁻ concentrations actually decreased slightly with time in both shallow and deep wells.

Considered separately, the public supply well data generally showed trends identical to those of the full data set, although increases in Cl⁻ and Na were more rapid (Table 10). The percentage of samples from public supply wells with elevated Cl⁻ concentrations has been increasing with time (Table 11). Prior to 1970, about 80 percent of samples (70 percent for wells less than 100 feet) had Cl⁻ concentrations less than 15 mg/L, which Panno et al. (2006) determined to be the high end for background Cl⁻ concentrations in shallow groundwater in Illinois. Only about 3 percent and 1 percent had concentrations greater than 50 and 100 mg/L, respectively. Since then, the number of possible 'background' samples has decreased, and those with very high concentrations have been increasing. For the 1990-2005 data, 37 percent of samples had concentrations < 15 mg/L (16 percent for wells < 100 feet) and 38 percent and 14 percent had concentrations exceeding 50 and 100 mg/L, respectively. In shallower wells, the percentages of samples from public supply wells with Cl⁻ concentrations exceeding 50 and 100 mg/L were 66 and 34 percent, respectively.

Slope coefficients were calculated for the public supply data in each county to make a rough estimate of the trends; correlation coefficients were generally very low for these estimates

(Table 12). Slope coefficients were collected for data starting in 1960, when Cl⁻ concentrations began to increase. Positive values were calculated for Cl⁻ in all counties, with the highest value in DuPage County (3.0 mg/L/yr) and the lowest in Lake County (0.73 mg/L/yr). Positive values were also calculated for ∑Major ions for all counties except Will, which had a relatively large negative β_1 value (-4.3 mg/L/yr); DuPage had by far the largest positive value (8.5 mg/L/yr). Sodium had positive β_1 values in all counties, with DuPage again having the largest value. Negative β_1 values were calculated in Will County for all ions except Cl⁻ and Na, which had relatively large concentration increases.

Table 1. Median and IQR concentrations for the major ions and ∑Major ions as a function of time for the complete data set. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl⁻			*Na*	
<1950	762	6	11	435	24	58
1950-1960s	589	8	12	63	14	33
1970s	998	11	25	708	23	26
1980s	745	17	42	748	26	29
1990-2005	619	19	64	623	31	42
		Alkalinity (CaCO₃)			*Ca*	
<1950	757	308	127	508	72	44
1950-1960s	592	320	96	76	87	54
1970s	1000	311	81	694	87	38
1980s	743	320	84	730	87	38
1990-2005	615	330	80	623	89	43
		SO₄²⁻			*Mg*	
<1950	567	99	153	521	40	21
1950-1960s	122	129	183	73	46	18
1970s	722	110	138	695	48	17
1980s	715	104	122	729	49	18
1990-2005	620	77	109	623	48	16
		∑Major ions				
<1950	406	408	188			
1950-1960s	60	488	260			
1970s	672	477	228			
1980s	420	487	234			
1990-2005	611	487	265			
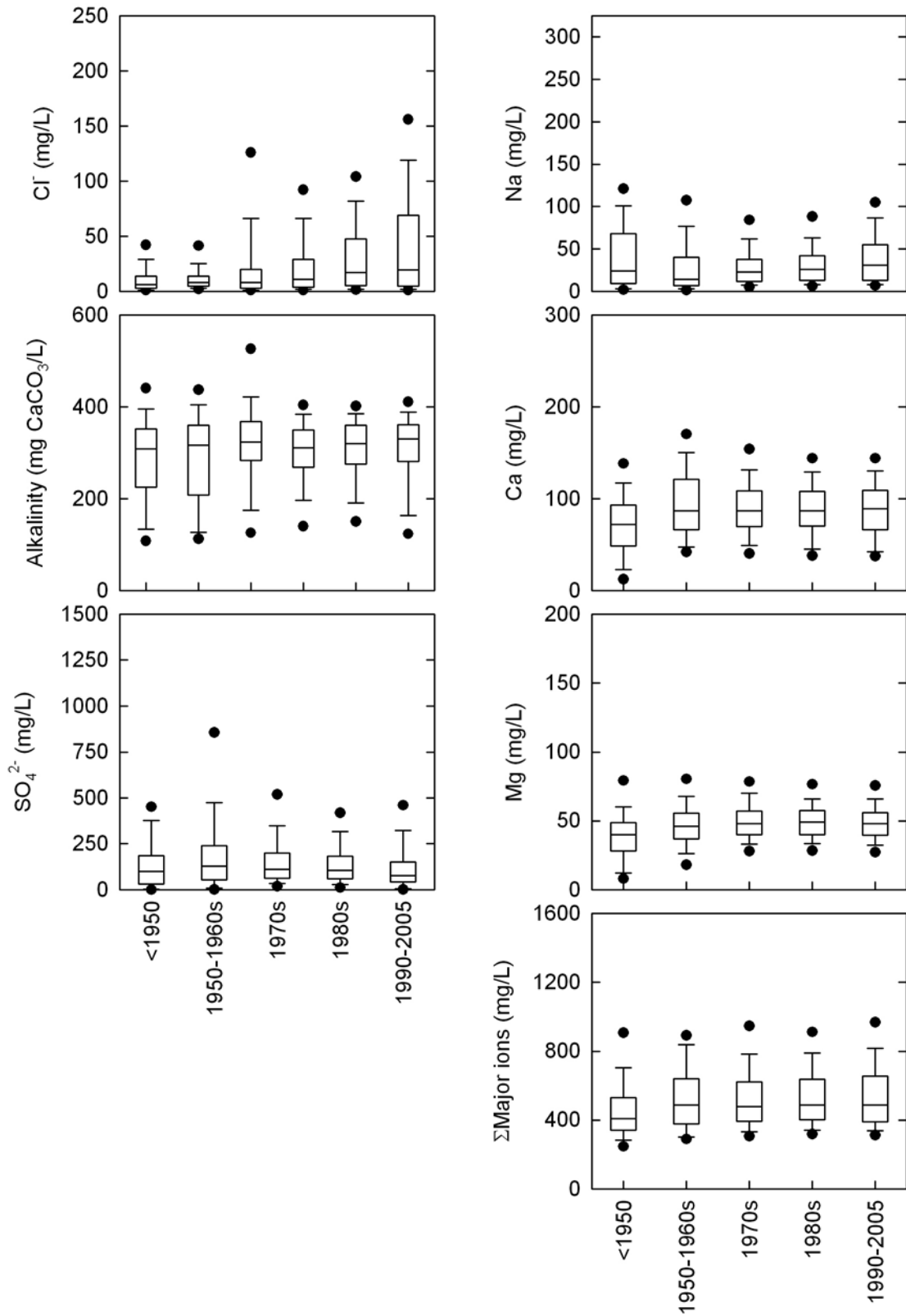
Figure 3. Box-and-whisker plots for major ions for the entire data set. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values.

Table 2. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for Cook County wells. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR		n	Median	IQR
		Cl⁻				*Na*	
<1950	210	8	14		78	47	71
1950-1960s	138	9	13		8	29	42
1970s	142	9	12		92	35	48
1980s	102	13	36		102	34	36
1990-2005	52	25	49		52	45	50
		Alkalinity ($CaCO_3$)				*Ca*	
<1950	211	308	206		81	70	43
1950-1960s	138	302	216		14	84	88
1970s	143	264	176		95	87	33
1980s	102	285	137		98	87	36
1990-2005	51	308	117		52	95	32
		SO_4^{2-}				*Mg*	
<1950	120	241	304		88	45	25
1950-1960s	22	178	243		13	52	31
1970s	101	270	295		95	56	17
1980s	99	174	184		98	53	16
1990-2005	52	145	179		52	57	16
		ΣMajor ions					
<1950	72	555	304				
1950-1960s	8	681	376				
1970s	89	610	255				
1980s	97	570	186				
1990-2005	51	571	229				
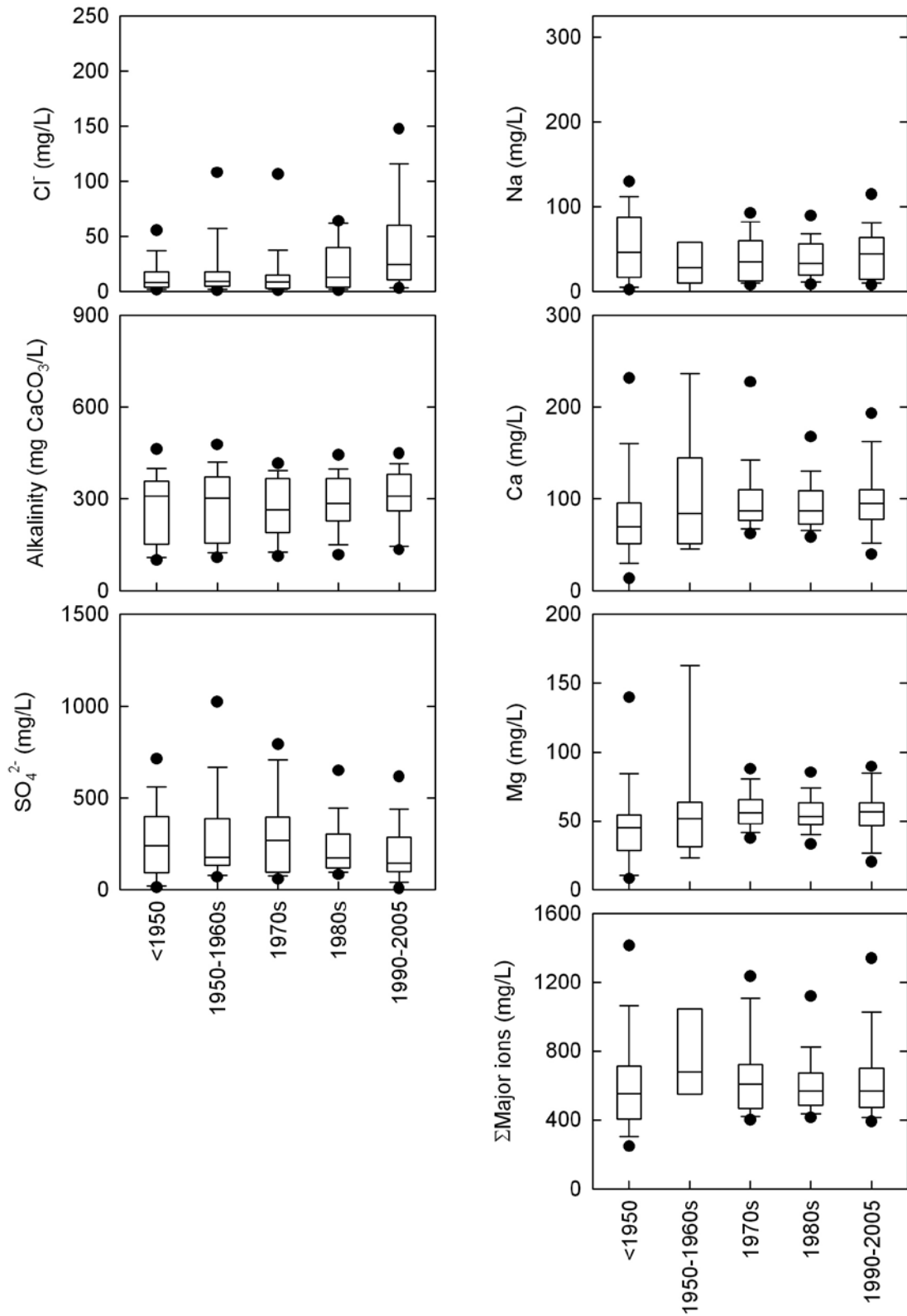
Figure 4. Box-and-whisker plots for major ions for Cook County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing whiskers or points indicate there are insufficient data to calculate those values.

Table 3. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for DuPage County wells. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl⁻			*Na*	
<1950	75	4	4	50	16	15
1950-1960s	129	10	20	15	25	54
1970s	206	26	42	176	25	18
1980s	126	59	64	127	33	18
1990-2005	59	101	67	59	57	21
		Alkalinity ($CaCO_3$)			*Ca*	
<1950	76	306	68	67	82	37
1950-1960s	131	320	60	15	98	47
1970s	207	310	60	168	100	55
1980s	126	321	49	122	112	43
1990-2005	59	332	63	59	126	30
		SO_4^{2-}			*Mg*	
<1950	64	103	91	70	43	12
1950-1960s	31	155	183	16	48	19
1970s	176	149	122	169	53	18
1980s	123	163	130	122	58	19
1990-2005	59	221	148	59	60	10
		ΣMajor ions				
<1950	50	449	123			
1950-1960s	13	583	223			
1970s	165	570	257			
1980s	119	670	265			
1990-2005	59	781	173			
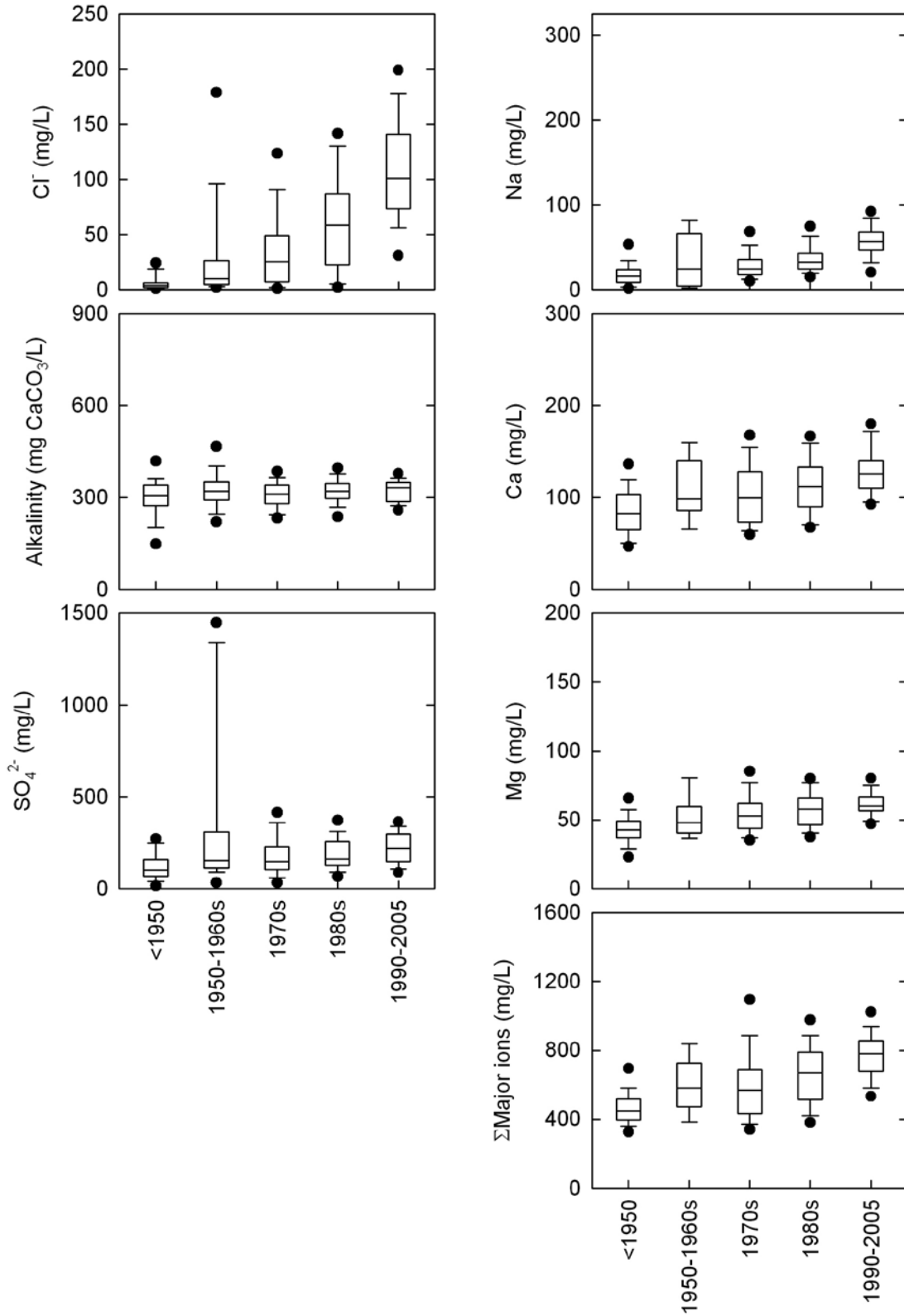
Figure 5. Box-and-whisker plots for major ions for DuPage County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing points indicate there are insufficient data to calculate those values.

Table 4. Median and IQR concentrations for the major ions and ∑Major ions as a function of time for Kane County wells. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl^-			*Na*	
<1950	105	7	10	62	11	30
1950-1960s	67	7	11	5	13	11
1970s	155	11	21	121	20	18
1980s	134	17	35	135	17	21
1990-2005	160	26	58	161	19	24
		Alkalinity ($CaCO_3$)			*Ca*	
<1950	104	330	65	64	79	36
1950-1960s	67	324	64	8	84	24
1970s	155	328	56	125	83	30
1980s	131	342	47	132	88	27
1990-2005	161	343	49	161	92	28
		SO_4^{2-}			*Mg*	
<1950	71	85	103	65	39	18
1950-1960s	12	65	82	6	41	21
1970s	122	68	53	125	45	14
1980s	129	75	49	132	47	14
1990-2005	161	62	78	161	48	12
		ΣMajor ions				
<1950	55	424	157			
1950-1960s	5	411	107			
1970s	116	415	138			
1980s	124	453	137			
1990-2005	160	465	181			
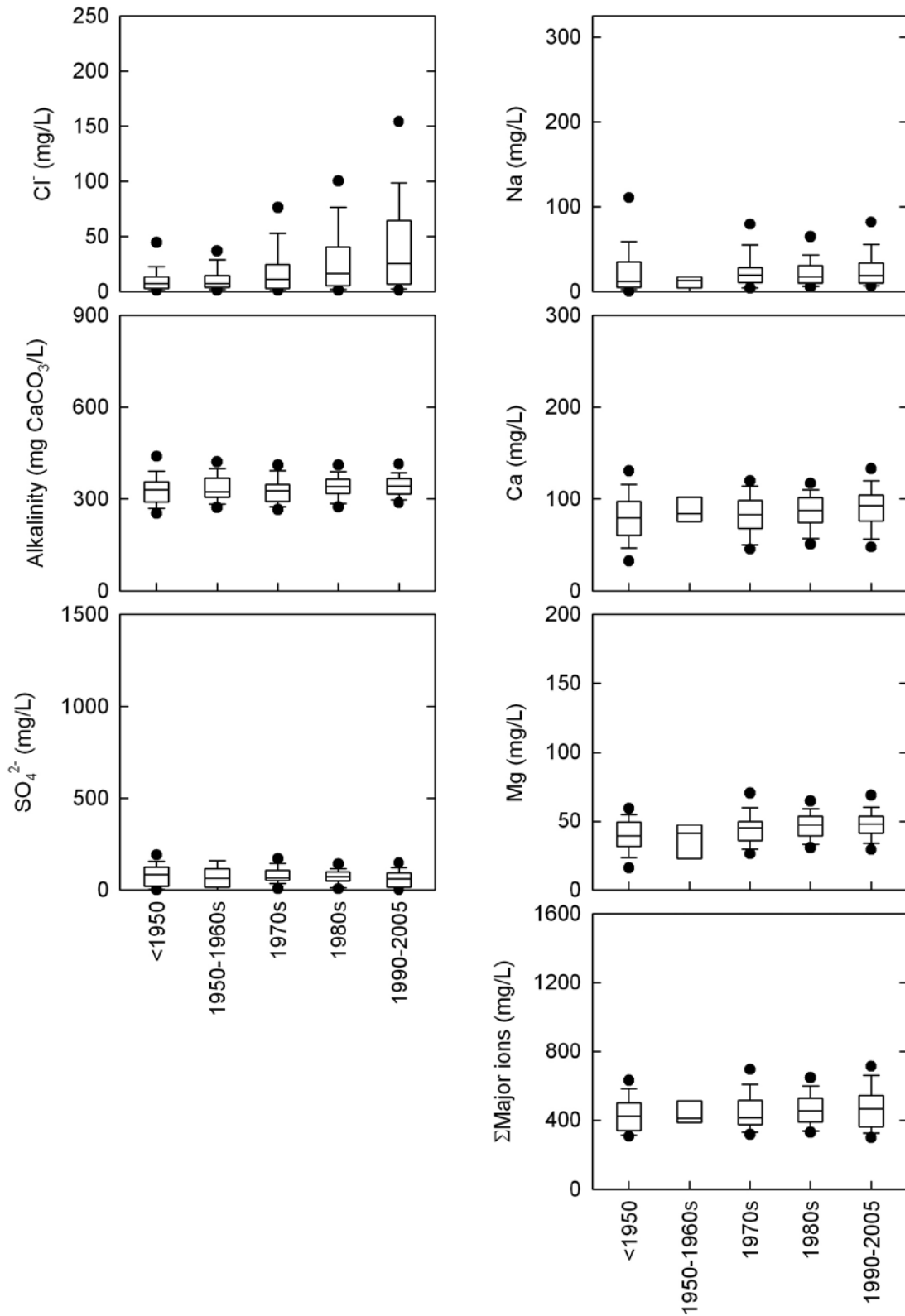
Figure 6. Box-and-whisker plots for major ions for Kane County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing whiskers or points indicate there are insufficient data to calculate those values.

Table 5. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for Lake County wells. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl⁻			*Na*	
<1950	147	9	15	125	72	67
1950-1960s	75	6	6	9	52	57
1970s	175	6	10	123	40	45
1980s	164	6	14	165	40	41
1990-2005	159	4	9	159	46	57
		Alkalinity (CaCO$_3$)			*Ca*	
<1950	146	188	176	132	39	52
1950-1960s	96	234	200	11	54	37
1970s	175	276	173	112	67	40
1980s	164	268	170	164	70	44
1990-2005	157	251	195	159	54	45
		SO$_4^{2-}$			*Mg*	
<1950	130	72	148	134	26	34
1950-1960s	9	64	289	11	37	21
1970s	126	74	117	112	44	19
1980s	158	77	152	163	45	20
1990-2005	157	97	272	159	46	18
		ΣMajor ions				
<1950	118	368	137			
1950-1960s	9	382	277			
1970s	111	398	164			
1980s	153	420	239			
1990-2005	156	432	303			
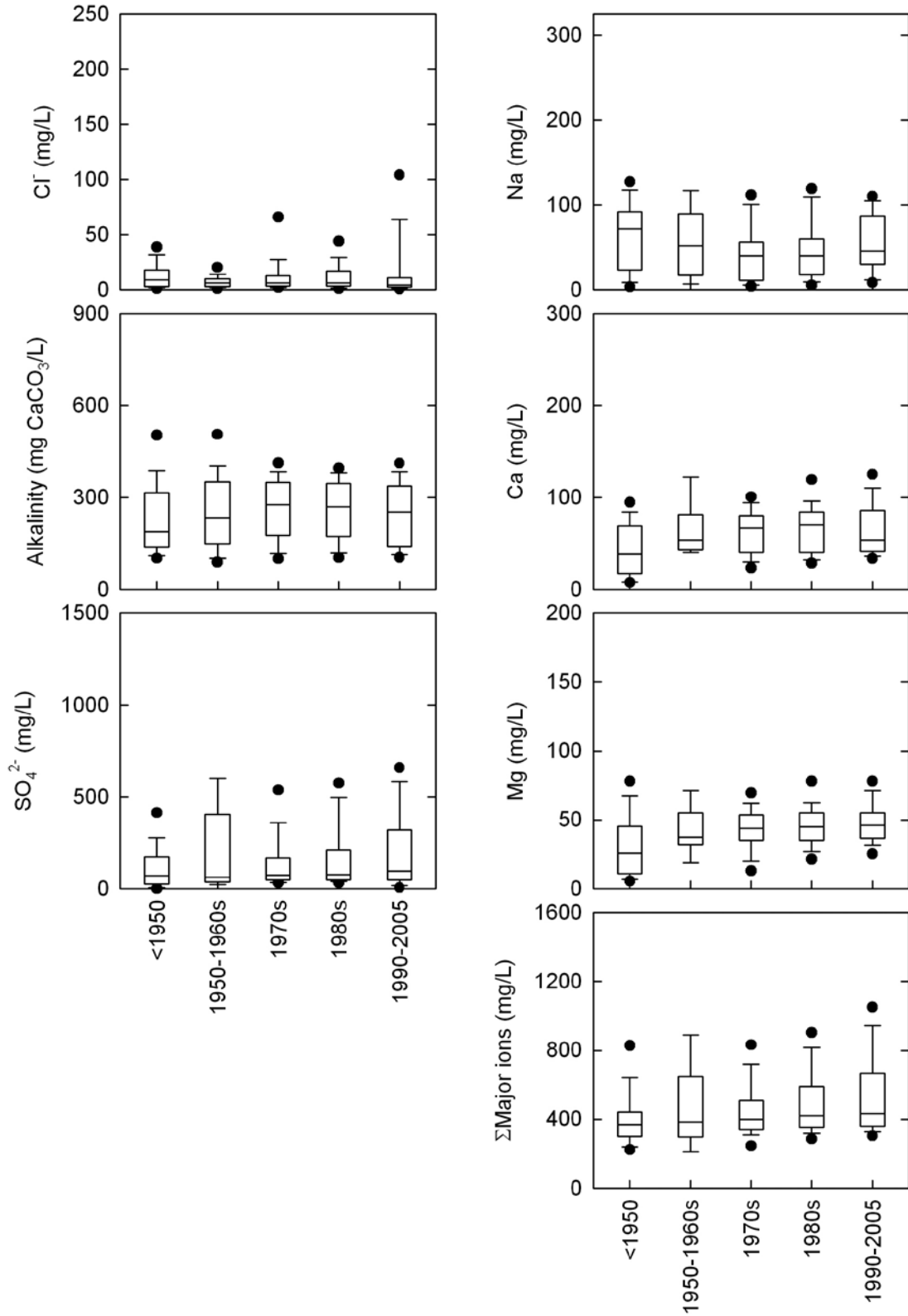
Figure 7. Box-and-whisker plots for major ions for Lake County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing points indicate there are insufficient data to calculate those values.

Table 6. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for McHenry County wells. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl^-			Na	
<1950	88	4	6	67	10	16
1950-1960s	74	7	9	13	9	9
1970s	202	16	30	104	12	16
1980s	149	21	34	149	15	17
1990-2005	124	25	56	127	15	23
		$Alkalinity\ (CaCO_3)$			Ca	
<1950	86	305	56	80	71	30
1950-1960s	74	332	66	13	74	19
1970s	202	316	74	104	85	29
1980s	150	338	54	145	85	32
1990-2005	122	346	44	127	86	27
		SO_4^{2-}			Mg	
<1950	74	11	52	81	38	11
1950-1960s	16	21	65	13	41	10
1970s	104	62	61	104	44	12
1980s	140	56	66	145	44	12
1990-2005	126	52	51	127	46	11
		$\sum Major\ ions$				
<1950	61	324	96			
1950-1960s	13	373	55			
1970s	102	408	139			
1980s	138	414	158			
1990-2005	120	435	156			
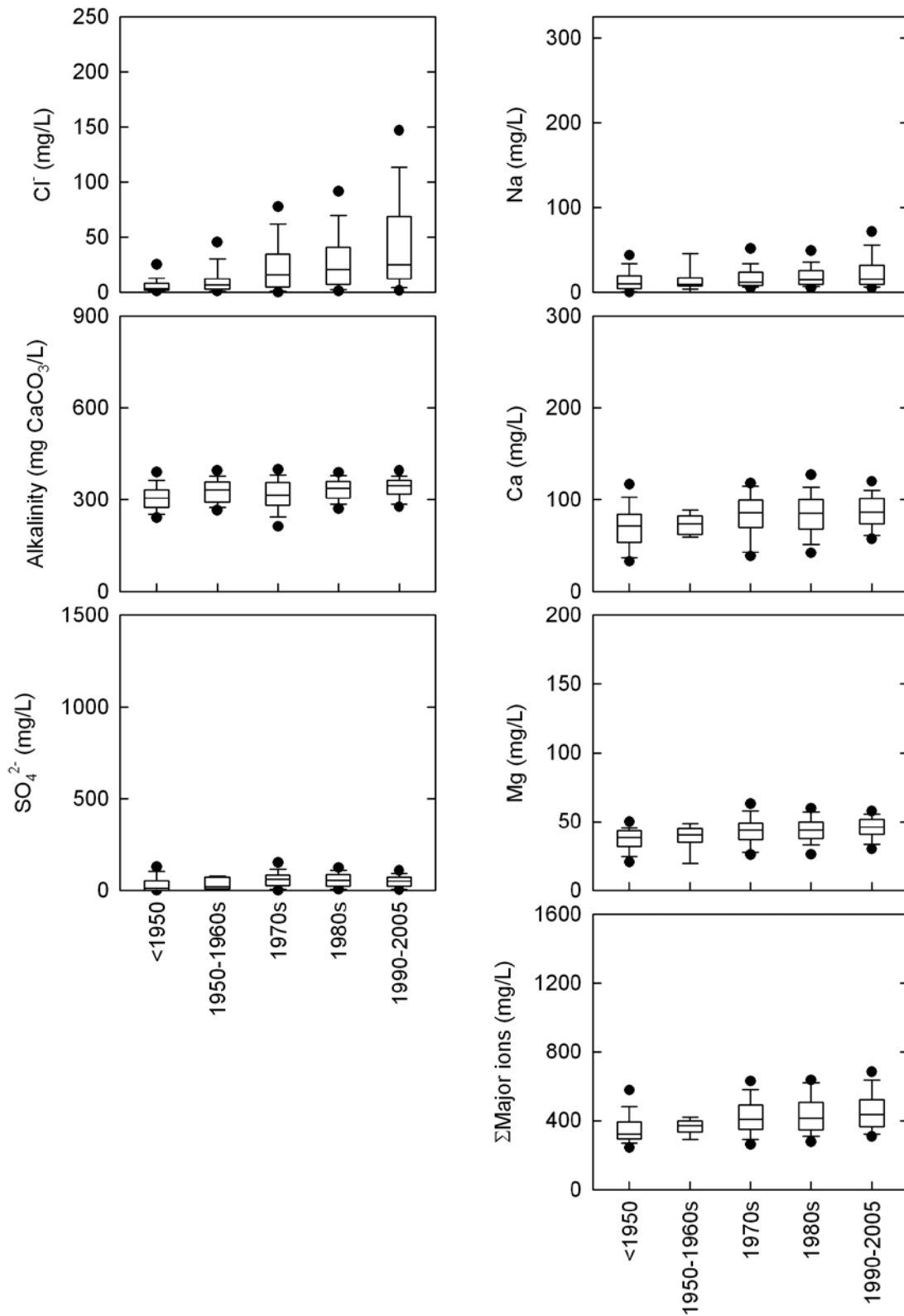
Figure 8. Box-and-whisker plots for major ions for McHenry County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing points indicate there are insufficient data to calculate those values.

Table 7. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for Will County wells. Concentrations in mg/L; n is the number of samples.

| Years	n	Median	IQR	n	Median	IQR
		Cl^-			Na	
<1950	137	5	11	53	19	29
1950-1960s	85	7	28	13	11	14
1970s	118	10	35	92	21	18
1980s	70	22	45	70	19	17
1990-2005	65	26	79	65	26	33
		$Alkalinity\ (CaCO_3)$			Ca	
<1950	134	337	88	84	90	42
1950-1960s	86	340	88	15	123	38
1970s	118	323	61	90	107	32
1980s	70	323	66	69	114	25
1990-2005	65	329	85	65	90	45
		SO_4^{2-}			Mg	
<1950	108	122	164	83	44	19
1950-1960s	28	158	200	14	54	11
1970s	93	142	126	90	51	14
1980s	66	171	130	69	52	11
1990-2005	65	95	101	65	44	16
		$\Sigma Major\ ions$				
<1950	50	445	190			
1950-1960s	12	607	189			
1970s	89	576	194			
1980s	66	589	148			
1990-2005	65	518	254			
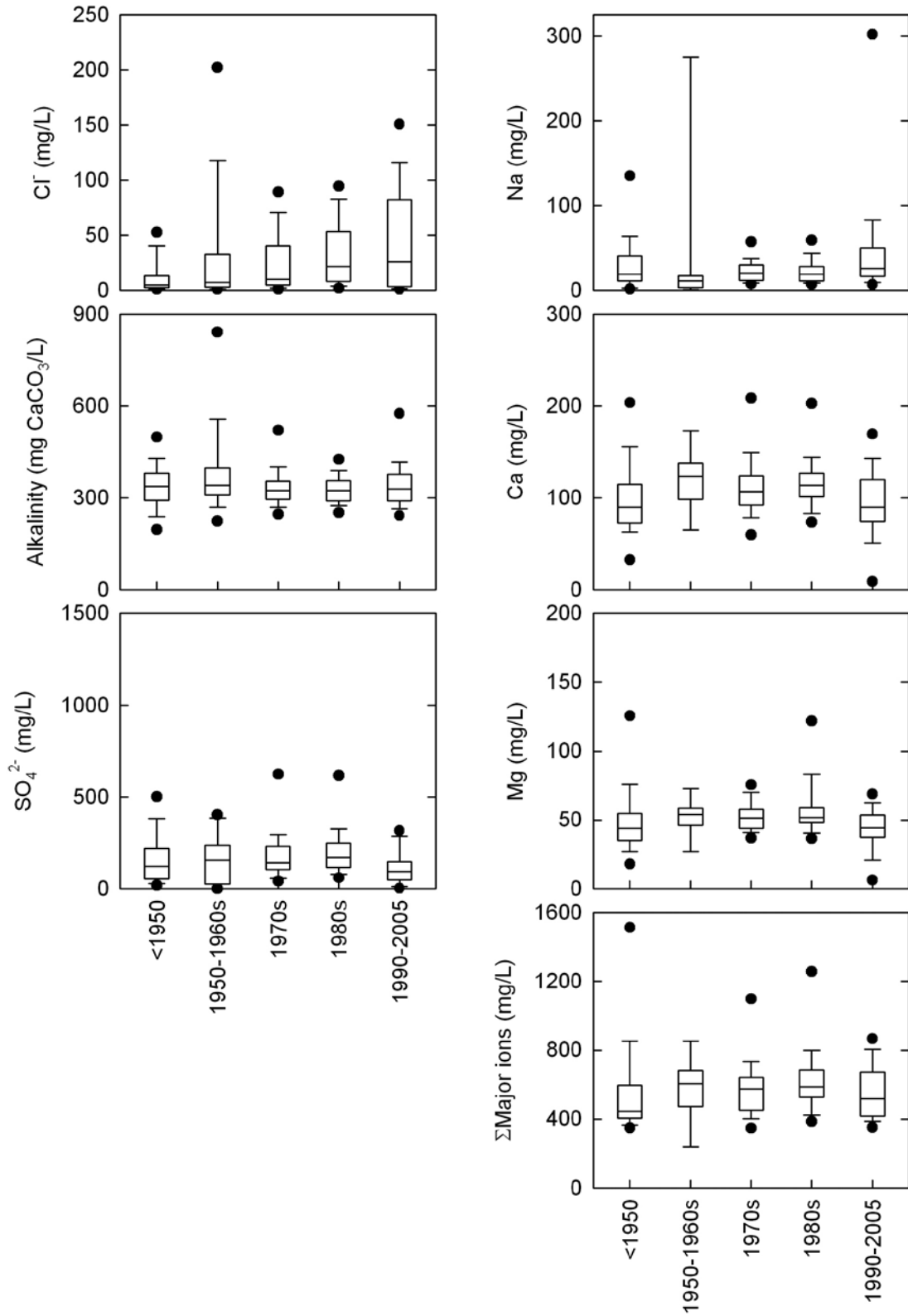
Figure 9. Box-and-whisker plots for major ions for Will County. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing points indicate there are insufficient data to calculate those values.

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Table 8. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for wells less than 100 ft in the six- county region. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR		n	Median	IQR
		Cl⁻				*Na*	
<1950	236	8	13		128	13	27
1950-1960s	152	9	14		13	7	12
1970s	223	22	37		117	18	18
1980s	127	35	46		127	19	22
1990-2005	110	36	95		111	26	36
		Alkalinity ($CaCO_3$)				*Ca*	
<1950	233	316	93		148	80	32
1950-1960s	153	332	83		16	93	69
1970s	223	326	92		111	100	31
1980s	124	341	88		121	102	34
1990-2005	111	352	59		111	95	37
		SO_4^{2-}				*Mg*	
<1950	170	99	115		153	42	16
1950-1960s	42	92	165		15	52	15
1970s	120	86	122		111	53	13
1980s	116	97	97		121	52	17
1990-2005	111	60	65		111	48	16
		ΣMajor ions					
<1950	119	423	182				
1950-1960s	13	452	247				
1970s	108	516	194				
1980s	112	552	192				
1990-2005	110	490	254				

Table 9. Median and IQR concentrations for the major ions and $\sum$Major ions as a function of time for wells between 100 and -200 ft in the six- county region. Concentrations in mg/L; n is the number of samples.

Years	n	Median	IQR	n	Median	IQR
		Cl^-			Na	
<1950	526	5	10	307	33	63
1950-1960s	451	7	12	50	17	43
1970s	773	9	19	589	24	28
1980s	603	12	36	606	27	30
1990-2005	509	17	56	512	32	43
		$Alkalinity\ (CaCO_3)$			Ca	
<1950	524	301	171	360	67	49
1950-1960s	453	316	104	60	84	46
1970s	775	305	80	581	84	38
1980s	604	315	82	594	85	36
1990-2005	504	325	83	512	86	46
		SO_4^{2-}			Mg	
<1950	397	100	173	368	39	24
1950-1960s	94	135	188	58	45	18
1970s	600	116	139	582	47	18
1980s	588	106	124	593	48	17
1990-2005	509	83	134	512	48	17
		$\Sigma Major\ ions$				
<1950	287	404	187			
1950-1960s	47	490	259			
1970s	562	461	231			
1980s	574	478	226			
1990-2005	501	486	267			
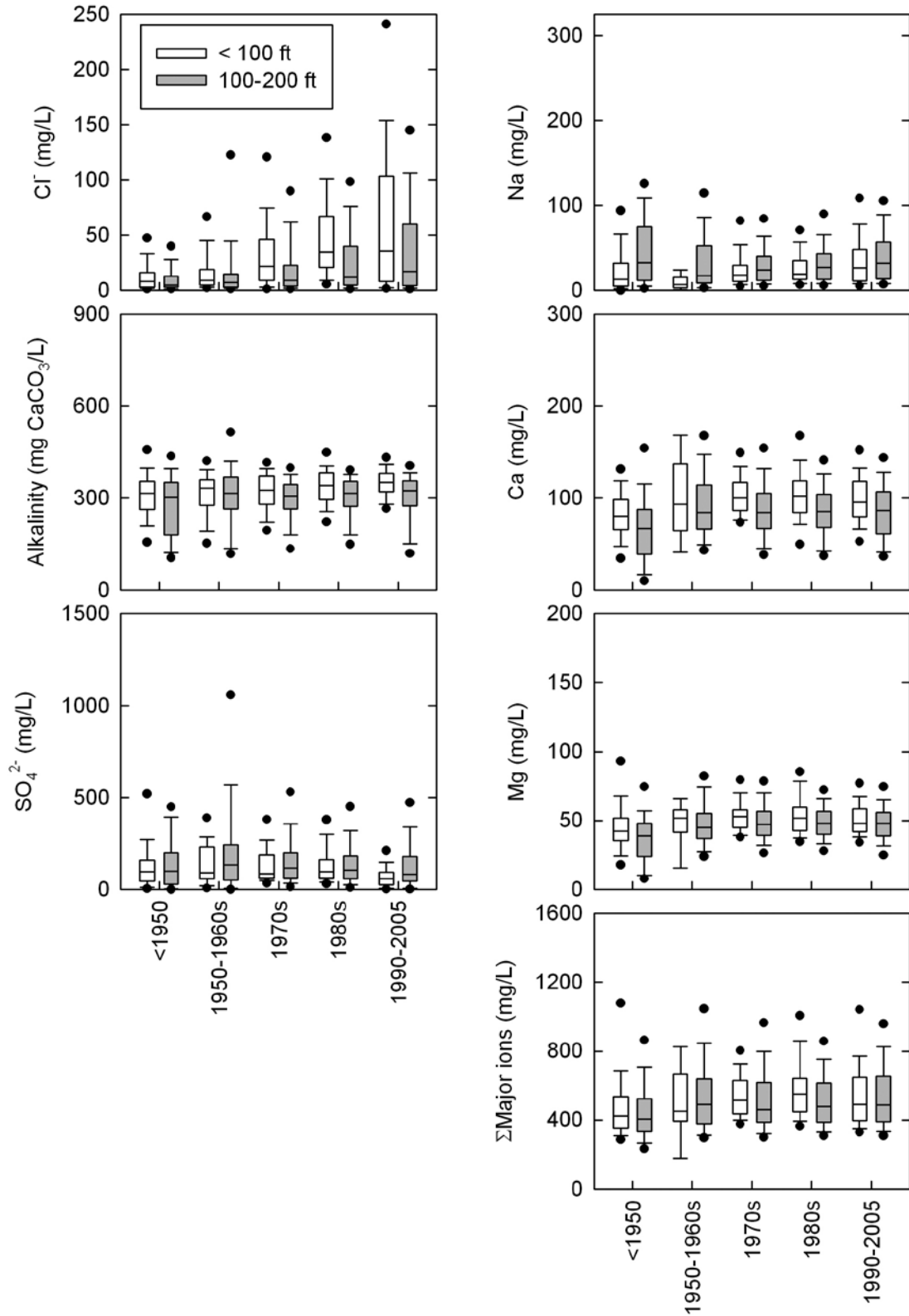
Figure 10. Box-and-whisker plots for major ions for the entire data set, based on well depth. The boxes show the median, 25th, and 75th percentile values; the whiskers show the 10th and 90th percentile values; and the points show the 5th and 95th percentile values. Missing points indicate there are insufficient data to calculate those values.

Table 10. Median and IQR concentrations for the major ions and ∑Major ions as a function of time for all public supply wells in the six- county region. Concentrations in mg/L; n is the number of samples.

Years	*n*	*Median*	*IQR*	*n*	*Median*	*IQR*
		Cl^-			*Na*	
<1950	168	5	7	139	15	27
1950-1960s	256	7	9	56	15	27
1970s	677	10	24	570	21	24
1980s	684	17	43	687	26	28
1990-2005	377	29	65	381	31	39
		Alkalinity ($CaCO_3$)			*Ca*	
<1950	157	312	89	144	82	33
1950-1960s	257	316	77	62	88	50
1970s	679	312	76	572	87	37
1980s	682	320	81	683	87	38
1990-2005	373	330	80	381	90	42
		SO_4^{2-}			*Mg*	
<1950	155	109	150	144	42	14
1950-1960s	72	123	170	62	45	15
1970s	576	100	122	573	48	16
1980s	669	102	112	682	49	17
1990-2005	378	79	93	381	48	14
		Σ*Major ions*				
<1950	126	432	191			
1950-1960s	58	464	240			
1970s	565	477	213			
1980s	664	488	218			
1990-2005	371	483	240			

Table 11. Chloride concentrations in public supply wells as a function of time showing median and IQR values (mg/L) and percentages of samples less than 15 mg/L and exceeding 50 or 100 mg/L.

	N	*Median*	*IQR*	*<15 mg/L*	*≥50 mg/L*	*≥100 mg/L*
<100 ft						
<1950	52	10	10	0.69	0.02	0.00
1950-1960s	68	10	13	0.71	0.03	0.00
1970s	139	24	37	0.36	0.19	0.04
1980s	127	39	47	0.16	0.39	0.11
1990-2005	44	87	94	0.16	0.66	0.34
100-200 ft						
<1950	116	4	5	0.95	0.00	0.00
1950-1960s	188	6	7	0.82	0.03	0.01
1970s	538	8	19	0.66	0.11	0.02
1980s	549	12	35	0.53	0.22	0.05
1990-2005	333	25	56	0.40	0.34	0.12
All						
<1950	168	5	7	0.87	0.01	0.00
1950-1960s	256	7	9	0.79	0.03	0.01
1970s	677	10	24	0.60	0.13	0.03
1980s	684	17	43	0.46	0.25	0.06
1990-2005	377	29	65	0.37	0.38	0.14

Table 12. Slope (β_1, in mg/L/yr) and r^2 values for major ions for all public supply well data per county. Values determined for data collected after 1960.

	Cl^-		*Alkalinity*		SO_4^{2-}	
County	β_1	r^2	β_1	r^2	β_1	r^2
Cook	1.34	0.02	0.42	0.00	-3.93	0.00
DuPage	3.00	0.28	0.76	0.02	2.08	0.03
Kane	1.21	0.10	0.81	0.04	0.33	0.01
Lake	0.73	0.00	-0.14	0.00	0.00	0.00
McHenry	1.12	0.10	0.72	0.03	-0.09	0.00
Will	1.88	0.20	-0.96	0.01	-4.45	0.06

	Ca		*Mg*		*Na*		*ΣMajor ions*	
	β_1	r^2	β_1	r^2	β_1	r^2	β_1	r^2
Cook	-0.72	0.01	-0.35	0.01	3.12	0.01	0.53	0.01
DuPage	0.95	0.05	0.31	0.03	1.16	0.20	8.47	0.14
Kane	0.58	0.06	0.29	0.06	0.24	0.01	2.76	0.05
Lake	0.02	0.00	0.04	0.00	0.55	0.00	0.85	0.00
McHenry	0.26	0.01	0.14	0.02	0.31	0.03	1.99	0.03
Will	-1.05	0.06	-0.53	0.04	0.58	0.08	-4.27	0.03

Individual Wells

Graphical representations of Cl⁻ concentrations as a function of time are presented in Figure 11 for some public supply wells having multiple samples. There were significant temporal increases in Cl⁻ concentrations for the majority of the wells (55 percent), based on the Kendall's tau statistic (Table 13). Lake County had the lowest percentage of wells with increasing Cl⁻ trends (39 percent) and Kane County had the highest (71 percent). Negative trends were found in 4 percent of the wells. Significant positive slope values were calculated for 57 percent of the
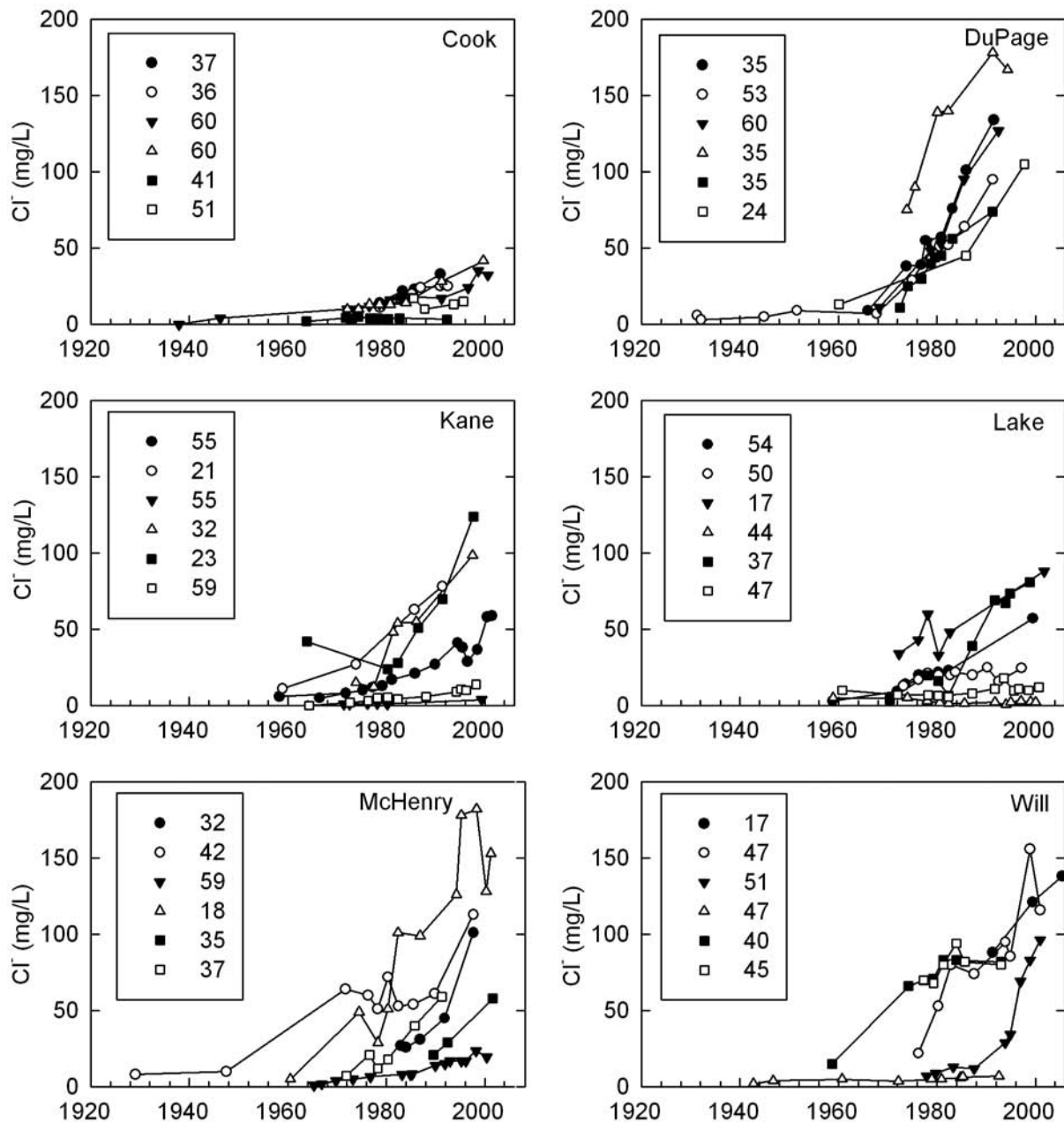
Figure 11. Chloride concentrations as a function of time for some public supply wells in the six counties in the Chicago area. Well depth (ft) given in legend.

Table 13. Percentage of wells having significant positive trends and slope values for Cl⁻ for individual wells with multiple samples. Significant trends determined by Kendall tau statistic, significant slopes determined by t statistic.

County	n	% Significant positive trend	% Significant positive slope	% rate >1 mg/L/yr	% rate >4 mg/L/yr
Cook	29	0.45	0.48	0.31	0.07
DuPage	43	0.62	0.7	0.64	0.27
Kane	42	0.71	0.6	0.33	0.07
Lake	49	0.39	0.39	0.22	0.04
McHenry	53	0.54	0.61	0.37	0.13
Will	26	0.62	0.54	0.35	0.04
TOTAL	242	0.55	0.56	0.37	0.11

wells, with 37 percent having values greater than 1 mg/L/yr and 12 percent with values greater than 4 mg/L/yr. DuPage, Kane, and McHenry Counties had the highest percentages of wells with positive slope values (62–70 percent), and Lake County had the lowest (39 percent). DuPage County had by far the largest percentage of wells with slope values greater than 1 and 4 mg/L/yr, and Lake County had the lowest percentages. DuPage County had significantly greater slope values than Lake and Cook Counties, and McHenry had significantly greater values than Lake County. It should be noted that percentages reported in Table 13 apply only to the data set and cannot be used to draw conclusions for the entire population of wells in each county. Slope values and regression coefficients for Cl⁻ trends are reported in Appendix B for each public supply well having significant slope values. Wells that did not have significant slope values are also listed in Appendix B.

Almost half (113 of 242) of the wells had at least one sample collected in the 1990s or 2000s, with the latest data available in 2005. There was basically no difference between the wells with the most recent data compared to the entire group of wells for Cl⁻; 59 percent had significant positive slopes (vs. 57 percent), 40 percent had values greater than 1 mg/L/yr (vs. 37 percent), and 12 percent had values greater than 4 mg/L/yr (vs. 12 percent). This suggests that there has not been a leveling off in Cl⁻ concentrations in the 1990s or later.

For the other parameters (Table 14), positive trends for individual wells were most common for ΣMajor ions (38 percent) and Na (33 percent), and least common for alkalinity and SO_4^{2-} (26 percent each). Negative trends were most commonly observed for SO_4^{2-} (11 percent of wells). The same patterns were found for slope coefficients, with 44 percent of wells having significant positive values for ΣMajor ions, 38 percent for Na, and SO_4^{2-} having the smallest percentage (27 percent). Sulfate also had the largest percentage of negative slope values (13 percent).

Changes in Cl⁻ concentrations were plotted versus well depth (Figure 12a). The shallowest wells (< 100 feet) had significantly greater slope values (median 2.9 mg/L/yr) compared to deeper wells (median 1.2 mg/L/yr), but even some of the deepest wells (200 feet) had large increases in Cl⁻ concentrations. There were no significant differences based on source aquifer (shallow bedrock vs. unconsolidated), although shallow bedrock wells were significantly deeper (median depth 165 feet) than the unconsolidated wells (median depth 125 feet). Changes in Cl⁻ concentrations were also plotted versus overlying till thickness for 187 wells for which this information was available (Figure 12b). It was hypothesized that the greater the till thickness overlying and

protecting the source aquifer, the lower the slope values. There was a significant difference when comparing wells with relatively thin till deposits (< 100 feet), which had a median slope value of 0.98 mg/L/yr, with thick till deposits (> 100 feet; median 0.20 mg/L/yr).

Table 14. Percentage of wells having significant positive and negative trends and slope values for major ions (other than Cl⁻) and ∑Major ions for individual wells with multiple samples. Significant trends determined by Kendall tau statistic, significant slopes determined by t statistic.

Parameter	County	N	Positive trend	Negative trend	Positive slope	Negative slope
Alkalinity	Cook	29	0.14	0.10	0.24	0.14
	DuPage	43	0.40	0.07	0.42	0.07
	Kane	41	0.37	0.05	0.34	0.02
	Lake	49	0.14	0.04	0.18	0.06
	McHenry	51	0.27	0.06	0.31	0.04
	Will	26	0.15	0.15	0.12	0.12
	Total	239	0.26	0.07	0.28	0.07
Ca	Cook	29	0.38	0.07	0.31	0.07
	DuPage	42	0.45	0.00	0.52	0.00
	Kane	39	0.26	0.03	0.31	0.05
	Lake	48	0.17	0.10	0.25	0.13
	McHenry	48	0.21	0.06	0.25	0.06
	Will	24	0.25	0.00	0.25	0.13
	Total	230	0.28	0.05	0.32	0.07
Mg	Cook	29	0.38	0.14	0.38	0.17
	DuPage	42	0.33	0.10	0.40	0.10
	Kane	39	0.26	0.05	0.21	0.05
	Lake	48	0.23	0.08	0.25	0.08
	McHenry	48	0.25	0.06	0.33	0.08
	Will	24	0.21	0.04	0.25	0.17
	Total	230	0.27	0.08	0.30	0.10
Na	Cook	29	0.17	0.10	0.21	0.03
	DuPage	42	0.57	0.10	0.60	0.12
	Kane	39	0.31	0.03	0.33	0.08
	Lake	48	0.27	0.00	0.25	0.00
	McHenry	48	0.29	0.04	0.31	0.04
	Will	24	0.33	0.00	0.42	0.04
	Total	230	0.33	0.04	0.35	0.05
SO_4^{2-}	Cook	29	0.34	0.07	0.28	0.10
	DuPage	41	0.32	0.07	0.37	0.05
	Kane	39	0.31	0.10	0.31	0.13
	Lake	48	0.27	0.08	0.19	0.10
	McHenry	48	0.15	0.21	0.17	0.21
	Will	24	0.17	0.08	0.08	0.17
	Total	229	0.26	0.11	0.24	0.13
∑Major ions	Cook	29	0.31	0.10	0.34	0.03
	DuPage	41	0.46	0.05	0.54	0.05
	Kane	38	0.45	0.11	0.50	0.05
	Lake	48	0.35	0.02	0.33	0.04
	McHenry	47	0.36	0.06	0.34	0.04
	Will	24	0.33	0.17	0.29	0.21
	Total	227	0.38	0.07	0.40	0.06
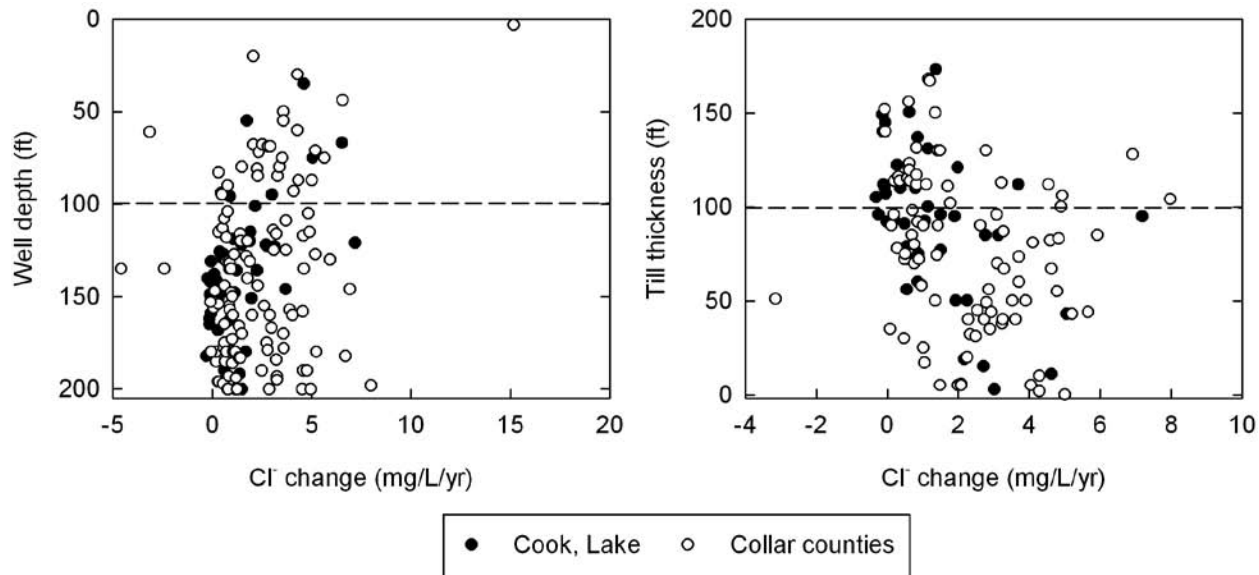
Figure 12. Change in Cl⁻ concentrations based on β_1 values as a function of (a) well depth and (b) overlying till thickness.

Sources of Chloride

Clearly, Cl⁻ concentrations have been increasing in shallow groundwater in the Chicago area starting around 1960. In terms of volume, road salt is the largest potential source of Cl⁻ in the Chicago region, and its large volume application began in 1960. Because of the large numbers of counties and municipalities, it is difficult to determine precisely the amount of road salt applied annually. In an average winter, the Illinois Department of Transportation uses about 143,000 tons of road salt in the six-county region, with counties and municipalities applying approximately the same amount (Keseley, 2006). There are more than 55,000 lane miles in the Chicago region, and most wells are located in the vicinity of major roads. Of the 242 individual wells examined, 209 were located within one mile of an interstate highway or major arterial road. There were no statistically significant differences in rates of change of Cl⁻ or for Cl⁻ concentrations in 1998-2004 between those wells close to (< 1 mile) versus far away (> 1 mile) from major roads. Median rate and concentration values, however, were considerably lower for wells far away from roads in Lake, McHenry, and Will Counties. For example, the median Cl⁻ concentration in five wells in Will County located far away from major roads was 25.0 mg/L, compared to 46.9 mg/L in 21 wells close to major roads. Median Cl⁻ concentrations were higher in wells far away from roads in Cook County, and approximately the same in Kane County. All wells in DuPage County were within one mile of major roads.

Septic systems are another potentially important source of Cl⁻ to shallow groundwater. Approximately 95 percent of households in the Chicago region were connected to public sewers in 1990, ranging from 57 percent in McHenry County to 99 percent in Cook County; Lake County had the largest number of septic systems (28,855), and Kane County had the fewest (17,505) (U.S. Census Bureau, 1993). Assuming each household with a septic system has a water softener and uses the typical manufacturer's recommended amount of rock salt (NaCl, 5 pounds/

day), a maximum of about 140,000 tons of rock salt are potentially available to enter the subsurface environment, less than half of the amount of road salt applied. In practice, water in shallow aquifers is often sufficiently soft so that softeners are not necessary.

Other potential Cl⁻ sources are probably minor, at least in a regional sense. Landfill leachates often have elevated levels of Cl⁻, but are point, or localized, sources covering relatively small areas. The largest concentration of landfills is found in heavily industrialized south Chicago. Fertilizer (KCl) does not appear to be a significant source of Cl⁻ to groundwater; concentrations in shallow groundwater in predominantly agricultural areas of Illinois rarely exceed 20 mg/L. Leakage from storm water and sewage pipes is a diminishing issue, as construction of new pipes and tunnels has been increasing. If leaky sewage pipes were a major source of Cl⁻ to groundwater, then one would expect to have seen elevated concentrations in Cook and Lake Counties in the past.

Additional evidence suggests that road salt is the major source of Cl⁻ to groundwater in the Chicago region. Roadcap and Kelly (1994) measured Cl⁻ concentrations in excess of 1000 mg/L in several shallow monitoring wells installed along the uncurbed Interstate-94 in south Chicago, including two exceeding 3500 mg/L. Using various diagnostic techniques, Panno et al. (2006) determined that elevated Cl⁻ concentrations in 13 shallow wells in McHenry County, the county with the highest percentage of septic systems, were due to road salt runoff. Chloride concentrations also have been increasing since the 1950s in the Illinois River waterway (which includes the Des Plaines River and Sanitary & Ship Canal in Chicago). The highest concentrations and most rapid increases have occurred in winter and early spring, suggesting that road salt runoff is the major source; septic discharge would not be expected to have seasonal variability (Panno et al., submitted).

Spatial Variability

The geographic location appears to somewhat influence Cl⁻ concentrations and rates of change, with the western and southern collar counties having the greatest increases. Chloride concentrations in Lake County tend to be very low, with a median of 4.2 mg/L and a 75th percentile value of 11 mg/L for samples collected since 1990. The median Cl⁻ value for these most recent samples in DuPage County was 101 mg/L and in the other four counties, the median was between 25 and 26 mg/L. Note that most of the sampled wells in Cook County were located in the extreme northwestern part of the county, so they may be more similar to DuPage County wells (Figure 13a). Cl⁻ trends may reflect the rapid changes in land use occurring in the western and southern collar counties. On the other hand, samples collected from wells in unincorporated areas or towns in the collar counties away from the Chicago megalopolis tended to have small or insignificant trends in Cl⁻ concentrations (Figure 13b). Cook and Lake Counties have been urban and residential areas for much longer than the western and southern collar counties, and many major roads are curbed. Curbing diverts runoff into storm water sewers, which limits the recharge of contaminated surface water to groundwater. Although we were unable to obtain complete curbing data for northeastern Illinois, there does appear to be less curbing in some collar counties. About 10 percent of roadways in Will County and 6.5 percent of county road miles in Kane County are curbed (P. Killinger, Will Co. Dept. of Highways, and P. Holcomb, Kane County Div. of Transportation, personal communication, 2007). In contrast, in DuPage County, which is more urbanized than Will or Kane Counties, more than 60 percent of roadways
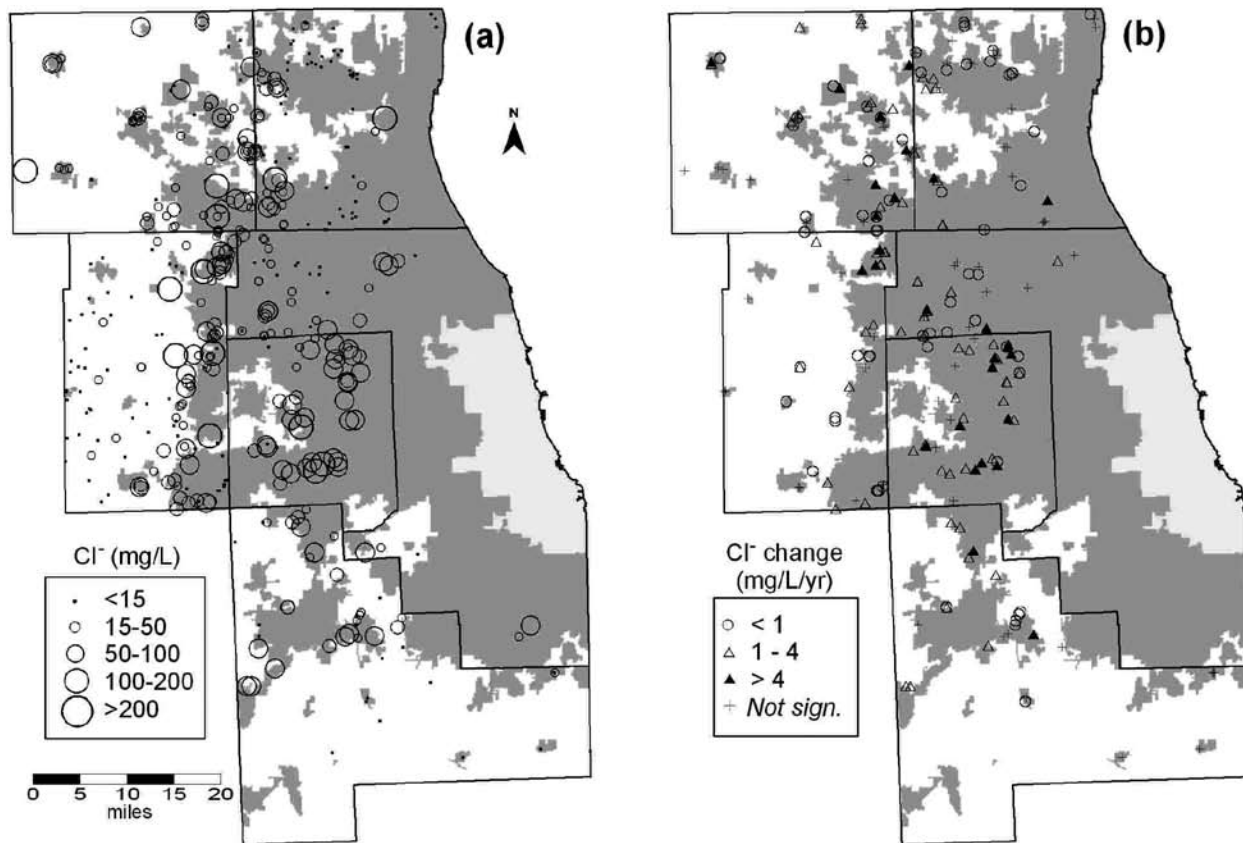
Figure 13. (a) Chloride concentrations for samples from 1998-2004 and (b) changes in Cl-concentrations for individual wells based on β_1 values. Gray areas show incorporated municipalities. For wells with no samples from 1998-2004, the concentration for the year 2000 was determined using the β_1 value. *Not sign.* refers to wells where the β_1 value was determined to be not significant.

are curbed (M. Cotten, DuPage County Div. of Transportation, personal communication, 2007). Since they developed earlier and are more urban, Cook and Lake Counties probably have higher curbing percentages than DuPage County. The lesser amount of curbing in the western and southern collar counties thus could allow more contaminated runoff to recharge the shallow aquifers. To further test this hypothesis, more detailed data on road curbing would be necessary; such data are not currently available in GIS-ready formats.

An alternative explanation for the greater increase in Cl- concentrations in the western and southern collar counties is that unconsolidated sand-and-gravel deposits are generally thicker and closer to the surface in these areas, especially in 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 Figure 14a. Wells with the greatest Cl- concentrations and rates of change are often found in areas where aquifers are within 50 feet of the surface, although there were no consistent statistically significant differences between data from areas with shallow aquifers versus those without. In fact, when data from all four collar counties are considered together, there were significantly *greater* Cl- concentrations and rates of change in areas where there was no aquifer material within 50 feet of the surface. This probably reflects the influences of samples from (1) a relatively small area in DuPage County with shallow aquifers
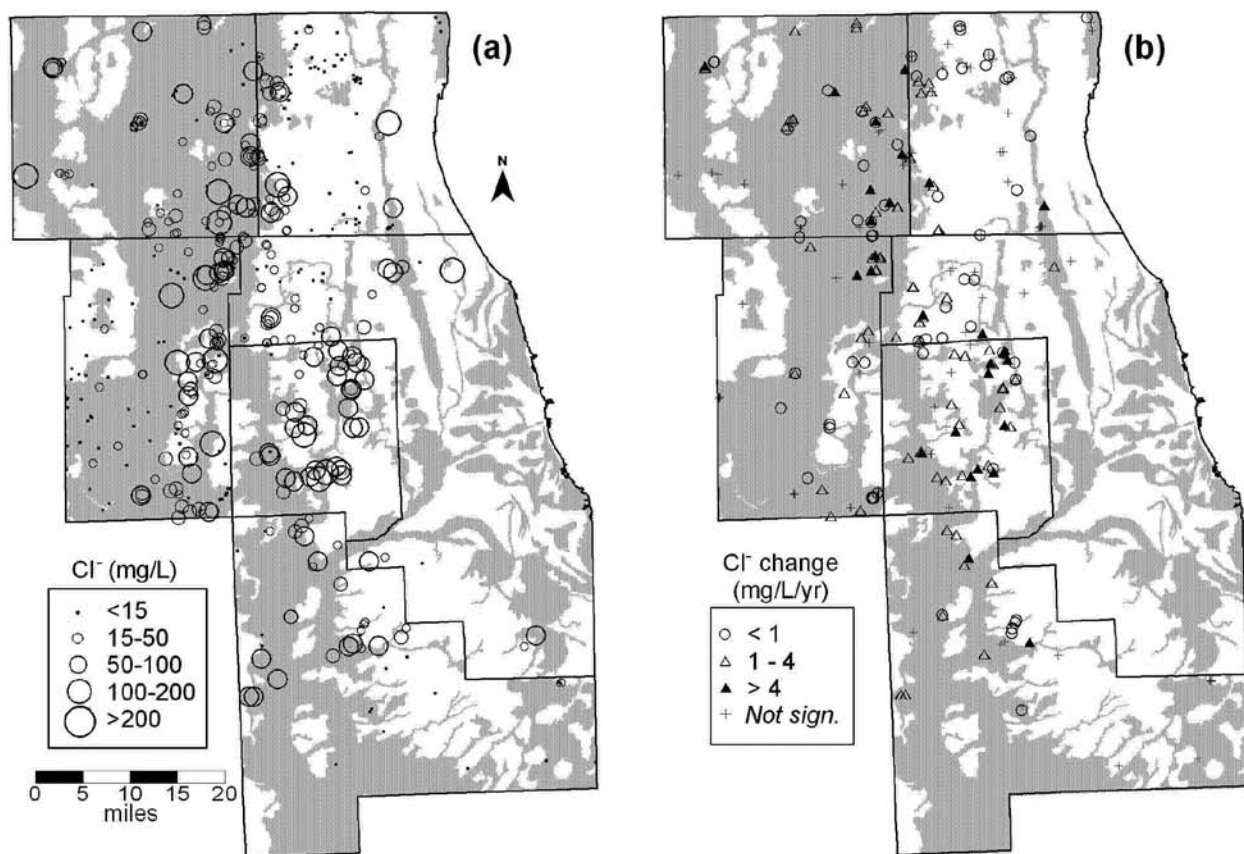
Figure 14. (a) Chloride concentrations for samples from 1998-2004, and (b) changes in Cl⁻ concentrations for individual wells based on β_1 values. Gray areas show where aquifer material is < 50 ft beneath land surface. For wells with no samples from 1998-2004, the concentration for the year 2000 was determined using the β_1 value. *Not sign.* refers to wells where the β_1 value was determined to be not significant.

and many wells with elevated Cl⁻ concentrations, and (2) Kane County, which has shallow aquifers throughout most of the county, but many sampled wells with low Cl⁻ concentrations. It thus appears that the presence or absence of shallow aquifer material is not the sole control on Cl⁻ concentrations. In Kane and Will Counties, most wells with low Cl⁻ concentrations are in the western and southern sections, respectively, where there is less urban and suburban development (Figure 14b).

Sampling in Kane County in 2003 (Kelly, 2005) clearly showed this spatial variability based on the amount of development. Concentrations of TDS, Cl⁻, and the other major ions were significantly greater in the eastern third of Kane County compared to both the western and central thirds (Figure 15). The median Cl⁻ concentration in the eastern third was 42.0 mg/L, compared to 3.8 and 6.6 mg/L in the western and central thirds, respectively. Figure 15 shows the location of municipalities, primarily found in the eastern third, and shallow aquifer material (< 50 feet). As residential and road development pushes westward in Kane County, shallow aquifers, which are generally within 50 feet of the surface, will become more vulnerable to surface contamination. Figure 15 also shows Cl⁻ concentrations in Kane County for previous periods (1945-1964 and 1980-1984), indicating considerably lower concentrations in the past. About 75 percent of samples
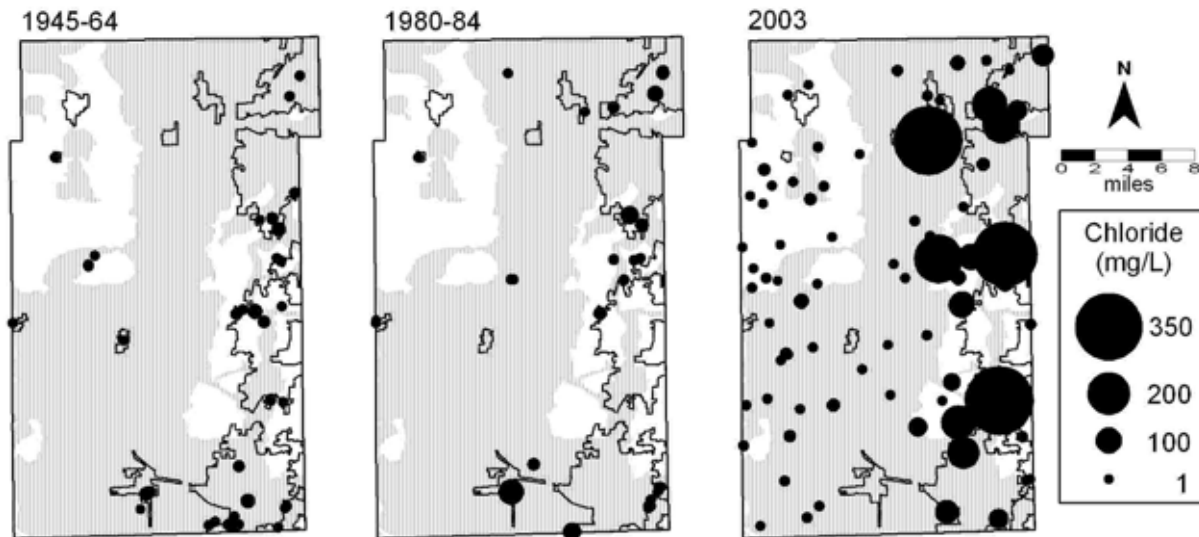
Figure 15. Chloride concentrations in Kane County from three different time periods. Gray areas show where aquifer material is < 50 ft beneath land surface, and municipal boundaries are outlined. Data for the first two periods are from the databases, the last is from Kelly (2005).

from 1945-1964 and 65 percent of samples from 1980-1984 collected in the eastern, developed third of Kane County were < 15 mg/L (maximum 34 and 69 mg/L, respectively).

Conclusions

Urbanization can seriously degrade groundwater quality of shallow aquifers, particularly in snowy climes where deicers are heavily used. Patterns and trends in Cl^- concentrations are useful indicators of shallow groundwater quality in such settings. Results of this study showed that shallow groundwater quality in the Chicago metropolitan area has degraded, as indicated by increasing levels of dissolved solids, primarily Cl^-. Shallow groundwater quality has degraded at least since the 1960s, especially in the collar counties (DuPage, Kane, McHenry, and Will), where Cl^- concentrations increased in the majority of public supply wells during that time. About 43 percent of sampled wells in these four counties have rate increases greater than 1 mg/L/yr and 15 percent have increases greater than 4 mg/L/yr. Chloride concentrations in approximately 24 percent of samples collected from public supply wells in the Chicago area in the 1990s were greater than 100 mg/L (35 percent in the collar counties). In comparison, median Cl^- concentrations were less than 10 mg/L prior to 1960. Although there is the potential for septic discharge to cause increases in Cl^- concentrations in some parts of the study area, road salt appears to be the dominant source of Cl^- to the shallow aquifers.

Increases in Na and ΣMajor ions over large parts of the Chicago region are also primarily the result of road salt runoff. Increases in Ca and Mg may be attributable indirectly to road salt runoff, as Na entering the subsurface would exchange with Ca and Mg in soils and sediments, releasing these cations into solution. Anion exchange is generally not an important process, however. Trends in alkalinity and SO_4^{2-} are more likely due to other urbanization activities, such as exposure of soils and sediments due to excavation. The exposure of chemically

reduced compounds such as organic matter and pyrite (FeS_2) to air can cause these compounds to be oxidized, resulting in increased concentrations of HCO_3^- and SO_4^{2-}. Decreasing SO_4^{2-} concentrations in some areas (primarily Cook and Will Counties) may be because plumes of high-SO_4^{2-} water introduced from earlier excavation activities have migrated through the shallow aquifers. Decreasing SO_4^{2-} concentrations also might have resulted from depletion of unoxidized pyrite in the exposed source materials. More detailed analysis would be necessary to determine why SO_4^{2-} appears to be decreasing in some areas.

Most areas in this region have probably not yet seen maximum concentrations of most major ions. With average groundwater travel times of about 0.6 to 3 ft/yr, the maximum distance traveled since 1960 for the bulk of recharge from the surface is less than 150 feet. Clearly there are areas where there have been significantly more rapid travel times, as evidenced by elevated concentrations in wells deeper than 150 feet. The pumping of large volumes of water from wells in the Chicago region accounts for some of the more rapid travel times. However, it seems likely that, even if all sources of pollution were stopped immediately, peak concentrations of surface-derived dissolved contaminants will be considerably higher in the future than they are now (e.g., Howard et al., 1993). A more detailed evaluation of the Cl^- data may help in estimating recharge rates to shallow aquifers.

Groundwater quality in the Chicago region reflects an interplay between natural hydro-geology and human activities. The greatest increases in Cl^- concentrations generally occur in the collar counties, where there are shallower and more significant sand-and-gravel deposits, but groundwater quality in shallow aquifers in rural parts of these counties is generally good (Kelly, 2005). It thus appears that land use, primarily in the form of road salting, is the major factor affecting Cl^- concentrations in the collar counties. In Cook and Lake Counties, however, lower Cl^- concentrations and rates of change cannot be attributed to lower rates of road salt application. The hydrogeological conditions (i.e., generally thicker till deposits and deeper aquifers) would be expected to offer better aquifer protection, but groundwater quality data suggest that similar hydrogeologic conditions in DuPage County have not protected shallow aquifers there. It appears that because most roadways in Cook and Lake Counties are curbed, saline runoff in these counties is channeled to storm water retention and is less important as a source of aquifer recharge than in the collar counties. Results from Roadcap and Kelly (1994) indicate that where curbing is absent in the city of Chicago, Cl^- concentrations in shallow groundwater can reach extremely high levels (> 3500 mg/L). This is an important point, as recently there has developed a consensus among water resource managers that a goal of storm water management should be to maximize infiltration and minimize runoff. If the quality of the recharge to groundwater is poor, then fixing one problem (storm water runoff) may produce another (decreasing groundwater quality).

Although water quality of shallow aquifers has degraded and likely will continue to degrade given the ongoing and projected development in the Chicago metropolitan area, these aquifers will still be critical to meeting future water needs. Measures that could be taken for long-term protection of shallow groundwater quality include delineation and protection of well capture zones and use of alternative road deicing procedures. While increased curbing could help protect groundwater quality, especially in vulnerable areas, this must be balanced against the need to provide continued or increased recharge to shallow aquifers. Thus there may be some trade-offs between measures taken to protect water quality versus those taken to increase the quantity of groundwater supplies.

Acknowledgments

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Appendix A

Table A-1. Summary statistics for Cook County wells < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	45	348	180	899	999	100	332	269	379	110
	1950-1960s	33	305	110	420	512	92	336	204	380	176
	1970s	16	316	114	322	430	108	377	252	406	154
	1980s	10	366	111	364	478	114	402	296	457	161
	1990-2005	5	364	94	240	506	266	335	298	428	131
Ca	<1950	16	104	65	227	257	30	90.1	66	116	50
	1950-1960s	3	91	49	98	140	42	90.4	54	128	74
	1970s	10	119	67	188	250	62	90.5	86	106	20
	1980s	9	144	63	179	241	62	113	98	201	104
	1990-2005	5	150	80	190	264	74	122	86	218	131
Cl^-	<1950	44	19	26	132	133	1.0	8.0	3.5	24	20
	1950-1960s	33	22	30	144	145	1.0	11	6.8	21	15
	1970s	16	10	6.8	23	25	2.0	7.5	5.3	16	11
	1980s	10	37	31	96	105	8.9	32	9.9	55	45
	1990-2005	5	45	70	165	169	4.3	15	7.3	62	55
Mg	<1950	16	92	90	263	284	21	50	45	92	47
	1950-1960s	3	45	22	42	63	21	52	29	60	32
	1970s	10	57	14	45	82	37	56	50	59	8.5
	1980s	9	72	23	70	107	37	63	58	91	34
	1990-2005	5	71	45	110	141	31	57	36	100	64
Na	<1950	15	32	26	90	93	3.0	24	13	48	35
	1950-1960s	1	7.0	--	--	7.0	7.0	7.0	--	--	--
	1970s	10	44	41	99	108	9.0	31	10	96	86
	1980s	10	37	27	89	98	9.6	35	11	42	31
	1990-2005	5	45	35	92	103	11	40	23	60	36
SO_4^{2-}	<1950	24	281	260	982	1010	28	166	112	370	258
	1950-1960s	7	143	102	287	356	69	94	79	165	86
	1970s	12	348	331	934	1000	66	250	92	439	347
	1980s	10	279	169	445	520	75	302	108	412	304
	1990-2005	5	302	314	675	681	6.3	146	60	620	560
ΣMajor ions	<1950	15	743	482	1756	2112	356	533	475	954	480
	1950-1960s	1	449	--	--	449	449	449	--	--	--
	1970s	10	725	414	1069	1510	441	530	488	659	171
	1980s	9	816	300	720	1244	524	652	537	1086	549
	1990-2005	5	831	523	1179	1579	400	544	438	1279	841

Table A-2. Summary statistics for Cook County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	166	259	117	505	560	55	279	150	350	200
	1950-60s	105	271	124	520	600	80	278	148	368	220
	1970s	127	263	95	370	456	86	260	189	351	163
	1980s	92	276	86	382	496	114	281	223	339	116
	1990-2005	46	295	97	370	478	108	305	224	367	143
Ca	<1950	65	77	50	239	244	5	68	48	84	36
	1950-60s	11	112	74	234	283	49	77	55	150	95
	1970s	85	102	46	289	340	51	86	76	111	35
	1980s	89	90	26	176	207	31	85	71	104	34
	1990-2005	47	96	33	153	188	35	94	78	110	33
Cl^-	<1950	166	16	31	330	330	0	8.0	4.0	17	13
	1950-60s	105	31	106	970	970	0	8.0	4.0	16	12
	1970s	126	26	92	963	963	0	9.0	3.0	15	12
	1980s	92	21	25	149	150	1.0	12	3.4	31	28
	1990-2005	47	56	134	921	922	0.6	25	11	60	49
Mg	<1950	72	42	26	166	169	2.9	44	23	53	30
	1950-60s	10	67	52	175	202	27	53	35	64	30
	1970s	85	58	15	79	103	24	56	48	67	19
	1980s	89	55	14	111	130	19	53	47	62	15
	1990-2005	47	54	17	74	91	17	57	48	61	13
Na	<1950	63	65	65	438	438	0	64	23	93	69
	1950-60s	7	39	30	81	90	9.0	41	14	59	45
	1970s	82	38	27	145	152	6.4	35	14	60	46
	1980s	92	39	24	134	140	6.3	33	20	57	37
	1990-2005	47	73	200	1393	1400	7.3	53	14	64	50
SO_4^{2-}	<1950	96	266	242	1601	1601	0	245	49	400	351
	1950-60s	15	359	263	954	1079	125	275	176	425	249
	1970s	89	297	224	895	900	5.0	280	101	383	283
	1980s	89	230	160	759	764	5.0	171	126	296	171
	1990-2005	47	199	137	637	642	5.0	144	106	269	163
ΣMajor ions	<1950	57	582	277	1293	1461	168	558	380	696	316
	1950-60s	7	899	486	1372	1907	535	684	620	1045	425
	1970s	79	656	253	1212	1534	322	611	466	722	256
	1980s	88	592	169	934	1317	383	563	472	664	192
	1990-2005	46	657	367	2461	2802	341	590	471	699	228

Table A-3. Summary statistics for DuPage County < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	14	311	39	134	352	218	324	294	340	46
	1950-1960s	20	330	44	180	404	224	334	314	358	44
	1970s	16	349	36	130	398	268	356	332	372	40
	1980-2005	14	391	23	86	430	344	392	374	403	29
Ca	<1950	10	97	27	81	140	59	92	78	119	41
	1950-1960s	1	164	--	--	164	164	164	--	--	--
	1970s	12	135	19	69	165	96	135	123	150	27
	1980-2005	14	144	29	91	195	104	149	110	167	57
Cl^-	<1950	14	11	11	37	38	1.0	5.5	3.0	18	15
	1950-1960s	19	18	19	59	62	3.0	13	5.3	20	14
	1970s	16	45	47	204	210	6.0	30	22	46	24
	1980-2005	14	60	33	113	134	21	59	26	77	51
Mg	<1950	12	40	15	49	59	10	42	30	50	21
	1950-1960s	1	58	--	--	58	58	58	--	--	--
	1970s	12	67	8.5	23	81	58	63	60	76	16
	1980-2005	14	71	12	36	94	58	69	61	79	18
Na	<1950	7	13	12	32	32	0	8.9	3.0	22	19
	1950-1960s	1	26	--	--	26	26	26	--	--	--
	1970s	13	24	25	98	104	5.8	18	17	20	3.8
	1980-2005	14	28	10	36	47	11	27	25	32	7.0
SO_4^{2-}	<1950	11	101	76	260	271	11	86	46	148	102
	1950-1960s	4	174	93	180	270	90	167	94	253	159
	1970s	13	211	73	231	310	79	207	177	278	102
	1980-2005	14	247	90	231	362	131	292	141	308	167
ΣMajor ions	<1950	7	467	123	354	685	331	418	382	536	153
	1950-1960s	1	776	--	--	775	775	775	--	--	--
	1970s	11	722	114	348	915	566	668	628	805	176
	1980-2005	14	783	163	453	1003	551	804	598	910	312

Table A-4. Summary statistics for DuPage County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	62	293	75	404	452	48	300	270	334	64
	1950-60s	111	325	89	656	692	36	316	292	350	58
	1970s	191	305	46	302	464	162	308	276	330	54
	1980s	114	312	47	387	387	0	320	294	337	43
	1990-2005	57	325	41	243	480	237	331	286	350	65
Ca	<1950	57	85	35	222	247	25	82	64	101	37
	1950-60s	14	102	29	90	156	66	98	86	116	31
	1970s	156	103	37	175	223	48	96	73	123	50
	1980s	110	110	30	159	212	53	111	88	128	40
	1990-2005	57	129	26	117	197	80	126	111	141	30
Cl^-	<1950	61	6.0	10	69	70	1.0	3.0	2.0	6.0	4.0
	1950-60s	110	34	59	314	315	1.0	10	5.0	29	24
	1970s	190	39	49	450	450	0	25	7.0	53	46
	1980s	114	64	53	331	331	0	58	21	89	68
	1990-2005	57	111	48	210	240	30	101	74	142	68
Mg	<1950	58	45	19	144	165	21	43	38	49	12
	1950-60s	15	51	14	46	81	35	48	40	58	18
	1970s	157	54	16	85	113	28	52	43	61	19
	1980s	110	56	12	71	99	28	57	45	64	19
	1990-2005	57	61	10	48	83	35	60	57	67	10
Na	<1950	43	21	22	132	132	0	17	9.0	24	15
	1950-60s	14	33	31	87	87	0	23	4.0	66	62
	1970s	163	31	21	198	202	4.1	27	19	37	18
	1980s	115	39	19	104	110	6.2	33	25	44	19
	1990-2005	57	59	19	93	111	18	57	49	68	20
SO_4^{2-}	<1950	53	146	196	1451	1457	6.0	109	72	160	89
	1950-60s	27	379	448	1450	1482	32	155	119	366	247
	1970s	163	179	126	715	716	1.4	142	104	223	119
	1980s	111	186	89	512	512	0	158	122	245	124
	1990-2005	57	224	90	378	446	68	227	149	298	150
ΣMajor ions	<1950	43	489	255	1720	2041	321	449	400	495	95
	1950-60s	12	581	150	520	868	348	557	473	659	187
	1970s	154	589	216	1127	1429	301	549	430	680	250
	1980s	107	643	176	1039	1151	112	651	499	758	260
	1990-2005	57	779	137	645	1141	496	782	686	860	174

Table A-5. Summary statistics for Kane County wells < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	53	322	49	228	440	212	319	284	360	76
	1950-1960s	16	336	39	148	420	272	332	316	360	44
	1970s	30	331	45	153	420	267	328	292	380	88
	1980s	29	343	28	128	410	282	342	330	357	27
	1990-2005	45	352	46	251	545	294	344	321	369	48
Ca	<1950	30	89	18	78	136	58	93	75	100	26
	1950-1960s	1	76	--	--	76	76	76	--	--	--
	1970s	24	98	17	55	125	70	97	83	116	33
	1980s	32	99	19	76	142	66	101	85	108	23
	1990-2005	45	102	29	132	178	46	98	83	121	38
Cl^-	<1950	54	12	13	71	71	0	8.0	3.0	15	12
	1950-1960s	16	14	13	40	42	2.0	10	5.0	17	12
	1970s	30	44	40	174	175	1.0	35	17	55	38
	1980s	32	59	45	212	218	6.1	54	29	80	51
	1990-2005	44	72	88	414	415	1.0	53	10	91	82
Mg	<1950	31	45	10	40	65	25	46	37	51	14
	1950-1960s	0	--	--	--	--	--	--	--	--	--
	1970s	24	47	6.3	26	62	36	46	44	51	7.3
	1980s	32	51	8.4	33	71	38	51	43	55	12
	1990-2005	45	51	11	50	79	30	49	44	60	16
Na	<1950	29	10	12	54	54	0	7.0	3.0	11	8.0
	1950-1960s	0	--	--	--	--	--	--	--	--	--
	1970s	24	23	19	78	80	2.0	19	12	30	18
	1980s	32	25	15	60	63	2.6	26	14	33	19
	1990-2005	45	35	31	144	148	4.5	31	12	40	28
SO_4^{2-}	<1950	34	96	51	226	229	3.0	92	62	133	71
	1950-1960s	0	--	--	--	--	--	--	--	--	--
	1970s	24	75	25	117	156	39	72	58	84	26
	1980s	30	83	36	158	178	20	76	61	99	38
	1990-2005	45	67	55	251	251	0.1	62	26	94	68
ΣMajor ions	<1950	26	441	92	369	681	312	436	354	501	147
	1950-1960s	0	--	--	--	--	--	--	--	--	--
	1970s	23	500	108	431	790	359	477	409	572	162
	1980s	27	517	93	340	670	330	500	451	590	139
	1990-2005	53	322	49	228	440	212	319	284	360	76

Table A-6. Summary statistics for Kane County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	51	339	68	420	666	246	332	299	351	52
	1950-60s	51	338	57	352	556	204	324	304	368	64
	1970s	125	327	43	218	470	252	326	292	348	56
	1980s	102	344	45	221	480	259	342	312	369	57
	1990-2005	116	342	43	331	595	264	341	315	365	51
Ca	<1950	34	73	33	160	175	15	65	56	88	31
	1950-60s	7	85	22	66	109	43	87	77	101	25
	1970s	101	79	24	148	148	0.3	81	64	94	31
	1980s	100	83	19	82	119	37	86	72	96	25
	1990-2005	116	87	24	170	170	0.3	91	75	100	25
Cl^-	<1950	51	11	16	90	91	1.0	5.0	2.0	11	9.0
	1950-60s	51	11	12	66	66	0	7.0	3.3	15	12
	1970s	125	15	26	200	200	0	8.0	3.0	16	13
	1980s	102	20	24	109	109	0.2	10	4.2	27	23
	1990-2005	116	37	53	358	359	0.9	19	6.1	55	49
Mg	<1950	34	36	13	49	58	8.6	35	27	48	21
	1950-60s	6	37	13	35	53	18	41	24	45	21
	1970s	101	44	14	82	82	0	45	35	49	14
	1980s	100	45	11	50	70	20	46	36	53	17
	1990-2005	116	47	12	92	92	0.1	48	40	52	13
Na	<1950	33	37	36	154	157	3.0	31	12	45	33
	1950-60s	5	11	6.5	15	18	3.0	13	5.3	17	11
	1970s	97	28	36	267	270	3.0	21	10	28	18
	1980s	103	22	21	158	162	4.0	17	9.0	28	19
	1990-2005	116	26	32	276	280	4.4	17	9.4	29	20
SO_4^{2-}	<1950	37	67	68	220	220	0	42	3.0	119	116
	1950-60s	12	72	56	160	160	0	65	29	110	82
	1970s	98	85	55	295	295	0	67	54	112	58
	1980s	99	70	39	181	183	2.1	75	47	100	53
	1990-2005	116	60	48	247	247	0.2	63	10	93	83
ΣMajor ions	<1950	29	411	108	379	644	264	379	330	454	123
	1950-60s	5	441	68	164	531	368	411	394	500	107
	1970s	93	444	117	592	853	261	411	363	510	147
	1980s	97	446	90	400	676	276	445	373	496	123
	1990-2005	116	462	132	867	1128	260	459	360	526	165

Table A-7. Summary statistics for Lake County wells < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	26	290	161	694	796	102	233	186	366	180
	1950-1960s	30	348	163	843	999	156	348	232	384	152
	1970s	33	331	88	362	452	90	364	301	384	83
	1980s	26	314	97	363	467	104	325	248	384	136
	1990-2005	19	349	78	367	466	99	368	326	383	57
Ca	<1950	24	56	28	90	98	7.7	61	35	80	45
	1950-1960s	1	49	--	--	49	49	49	--	--	--
	1970s	17	90	14	42	110	68	91	76	102	26
	1980s	26	86	42	218	255	37	80	71	98	27
	1990-2005	19	86	32	111	147	36	80	66	117	51
Cl⁻	<1950	26	15	11	48	49	1.0	15	6.0	18	12
	1950-1960s	30	27	25	77	79	2.0	16	6.0	49	43
	1970s	33	38	44	139	140	1.0	13	6.0	61	55
	1980s	26	298	1201	6147	6150	3.0	28	12	48	36
	1990-2005	19	61	94	329	330	1.4	4.1	2.2	106	104
Mg	<1950	25	44	31	100	106	5.6	41	18	75	57
	1950-1960s	1	18	--	--	18	18	18	--	--	--
	1970s	17	60	14	53	91	38	54	53	64	11
	1980s	26	52	19	65	85	20	53	37	60	23
	1990-2005	19	56	18	75	112	37	48	46	63	17
Na	<1950	23	64	45	150	153	3.0	61	20	94	73
	1950-1960s	1	7.0	--	--	7.0	7.0	7.0	--	--	--
	1970s	21	34	29	115	117	2.1	27	8.0	52	44
	1980s	26	201	735	3784	3788	4.1	50	14	70	57
	1990-2005	19	39	42	158	162	4.1	34	8.2	48	40
SO₄²⁻	<1950	23	141	169	700	700	0	113	26	173	147
	1950-1960s	16	738	624	2014	2050	36	517	254	1148	895
	1970s	20	118	123	512	543	31	69	45	161	116
	1980s	22	155	188	757	760	2.7	84	41	160	119
	1990-2005	19	82	179	795	797	1.6	41	6.8	57	50
ΣMajor ions	<1950	22	483	206	896	1146	251	419	356	537	181
	1950-1960s	1	213	--	--	213	213	213	--	--	--
	1970s	17	541	149	441	787	346	488	410	676	266
	1980s	22	1022	2265	10759	11141	382	484	426	608	182
	1990-2005	19	533	270	830	1159	329	378	357	609	252

Table A-8. Summary statistics for Lake County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	120	221	117	614	626	12	170	134	311	177
	1950-60s	80	249	135	553	625	72	222	134	344	210
	1970s	142	254	104	644	720	76	260	170	316	146
	1980s	138	249	93	402	472	70	258	170	327	157
	1990-2005	138	227	101	365	441	76	214	136	315	179
Ca	<1950	108	42	29	114	117	2.8	34	17	65	48
	1950-60s	10	70	31	84	123	40	62	43	81	38
	1970s	95	57	23	84	96	12	61	39	77	38
	1980s	138	63	27	155	174	19	66	39	79	40
	1990-2005	140	63	32	184	204	20	51	41	85	44
Cl^-	<1950	121	14	31	326	326	0	8.0	3.0	17	14
	1950-60s	80	7.3	6.1	35	36	1.0	5.5	3.0	10	6.5
	1970s	142	8.6	11	94	95	1.0	5.0	3.0	10	7.0
	1980s	138	8.4	8.5	41	41	0.5	5.7	2.2	10	7.8
	1990-2005	140	13	26	176	176	0.5	4.3	2.2	10	7.7
Mg	<1950	109	29	21	89	90	1.9	23	11	44	33
	1950-60s	10	45	15	48	74	26	41	35	55	20
	1970s	95	41	14	67	76	9.2	40	33	52	19
	1980s	137	44	15	105	117	12	43	34	53	19
	1990-2005	140	46	16	97	110	13	44	36	54	19
Na	<1950	102	67	56	475	475	0	72	24	90	66
	1950-60s	8	59	39	109	117	8.0	54	28	90	62
	1970s	102	45	34	133	135	2.5	42	16	64	48
	1980s	139	46	36	185	189	4.0	40	18	56	38
	1990-2005	140	61	55	544	550	5.8	46	31	89	58
SO_4^{2-}	<1950	107	118	140	785	785	0	67	26	173	148
	1950-60s	11	240	231	599	618	20	201	36	451	415
	1970s	106	148	163	817	818	1.2	74	50	167	117
	1980s	136	172	183	783	794	11	76	51	226	175
	1990-2005	138	223	231	1155	1155	0.5	133	53	346	293
ΣMajor ions	<1950	96	401	187	1027	1223	197	363	294	425	130
	1950-60s	8	493	228	594	891	298	413	315	648	333
	1970s	94	433	167	738	952	214	392	332	455	123
	1980s	131	476	194	951	1184	233	409	345	574	229
	1990-2005	137	544	258	1421	1658	237	436	361	672	311

Table A-9. Summary statistics for McHenry County wells < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	41	300	37	172	410	238	302	269	325	56
	1950-1960s	32	323	40	150	402	252	332	292	354	62
	1970s	113	311	63	312	454	142	316	268	361	93
	1980s	48	339	47	228	450	222	339	313	378	65
	1990-2005	22	356	23	85	396	311	363	346	373	27
Ca	<1950	36	98	130	810	848	38	78	64	91	27
	1950-1960s	3	74	14	26	90	63	70	65	85	20
	1970s	37	98	15	68	140	72	97	88	111	24
	1980s	44	100	21	99	135	36	100	86	116	30
	1990-2005	22	103	13	52	130	78	101	95	110	15
Cl⁻	<1950	43	10	12	63	64	1.0	6.0	3.0	10	6.8
	1950-1960s	32	20	27	114	115	1.0	11	5.5	28	23
	1970s	113	35	40	250	250	0	24	11	47	36
	1980s	48	48	33	132	133	1.3	40	25	69	44
	1990-2005	22	74	54	167	182	15	56	26	121	95
Mg	<1950	37	40	6.3	29	57	28	40	36	43	7.6
	1950-1960s	3	47	3.1	6.0	51	45	46	45	50	4.5
	1970s	37	48	7.4	27	64	37	46	42	54	12
	1980s	44	48	10	45	65	20	47	41	58	17
	1990-2005	22	50	6.0	24	65	41	49	45	52	7.3
Na	<1950	33	10	9.1	32	32	0	6.0	3.7	19	15
	1950-1960s	3	10	4.7	9	15	6.0	8.0	6.5	13	6.8
	1970s	37	16	7.9	30	34	4.0	14	11	21	10
	1980s	48	22	14	49	55	5.1	17	13	31	18
	1990-2005	22	32	26	73	79	5.9	21	10	59	49
SO_4^{2-}	<1950	35	50	45	142	142	0	52	7.8	74	66
	1950-1960s	5	56	31	62	82	20	76	23	78	55
	1970s	38	82	36	235	244	9.0	74	62	100	38
	1980s	41	83	34	146	151	5.0	81	59	109	51
	1990-2005	22	72	30	132	137	5.0	69	52	91	39
ΣMajor ions	<1950	29	396	167	872	1150	278	345	301	417	116
	1950-1960s	3	402	31	55	421	366	418	379	420	42
	1970s	36	485	82	358	712	354	482	430	540	111
	1980s	41	511	111	409	696	287	515	412	625	212
	1990-2005	22	545	118	403	770	367	510	467	657	189

Table A-10. Summary statistics for McHenry County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	45	313	60	362	460	98	308	284	358	74
	1950-60s	42	334	45	226	492	266	332	296	364	68
	1970s	89	320	43	258	426	168	316	292	352	61
	1980s	102	333	54	522	765	243	333	305	356	51
	1990-2005	100	337	35	151	409	258	341	318	361	43
Ca	<1950	44	78	107	738	758	20	67	45	77	32
	1950-60s	10	73	10	28	87	59	76	62	82	21
	1970s	67	75	25	120	149	29	77	58	88	30
	1980s	101	77	20	96	133	37	76	66	91	25
	1990-2005	105	84	20	108	131	23	83	70	99	29
Cl⁻	<1950	45	3.5	3.6	16	16	0	2.0	1.0	4.0	3.0
	1950-60s	42	6.7	8.4	41	41	0	4.0	1.0	8.0	7.0
	1970s	89	17	35	305	305	0	8.0	2.5	18	16
	1980s	101	20	21	109	109	0.5	10	4.6	27	22
	1990-2005	102	38	40	207	208	0.8	20	11	56	45
Mg	<1950	44	36	13	81	97	17	37	28	43	15
	1950-60s	10	37	10	33	45	12	40	34	43	9.3
	1970s	67	41	12	57	77	20	42	33	46	13
	1980s	101	42	8.1	36	58	23	43	36	48	12
	1990-2005	105	44	8.4	44	60	16	45	39	50	11
Na	<1950	34	23	32	178	178	0	13	6.0	32	26
	1950-60s	10	16	17	58	60	2.0	10	8.0	20	12
	1970s	67	18	15	55	59	3.6	12	7.5	25	17
	1980s	101	17	11	54	58	4.0	12	9.0	24	15
	1990-2005	105	22	20	121	124	3.3	15	9.1	29	19
SO_4^{2-}	<1950	39	37	142	887	887	0	4.0	0	16	16
	1950-60s	11	24	27	75	75	0.4	10	8.1	30	22
	1970s	66	54	56	258	258	0	42	15	75	60
	1980s	99	47	36	168	170	2.5	34	19	73	54
	1990-2005	104	48	31	126	126	0.5	50	21	71	51
ΣMajor ions	<1950	32	354	189	1117	1343	226	320	284	366	82
	1950-60s	10	355	40	111	398	288	371	317	379	62
	1970s	66	393	117	554	800	246	383	304	426	122
	1980s	97	402	89	416	683	267	382	328	463	135
	1990-2005	98	437	102	439	702	264	419	358	497	139

Table A-11. Summary statistics for Will County wells < 100 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	50	311	88	412	512	100	314	256	352	96
	1950-1960s	21	305	101	478	550	72	320	274	340	66
	1970s	15	310	59	248	364	116	330	298	339	41
	1980s	14	282	32	104	330	226	280	251	304	53
	1990-2005	18	337	71	209	438	229	351	264	401	137
Ca	<1950	31	93	44	252	291	39	87	68	110	42
	1950-1960s	7	119	43	140	180	40	128	102	137	35
	1970s	11	120	13	48	140	92	118	116	128	12
	1980s	13	107	22	67	137	70	115	94	121	27
	1990-2005	18	89	21	82	143	61	85	78	95	17
Cl⁻	<1950	50	14	15	48	49	1.0	8.0	3.0	20	17
	1950-1960s	21	25	46	204	205	1.0	5.0	3.0	29	26
	1970s	15	15	13	44	48	4.0	10	5.0	20	15
	1980s	14	20	12	42	50	7.6	18	9.2	28	19
	1990-2005	18	57	65	248	249	0.8	35	7.8	88	80
Mg	<1950	31	49	28	159	179	20	42	33	61	27
	1950-1960s	7	49	18	58	70	13	55	44	57	13
	1970s	11	56	6.5	24	62	38	58	54	60	5.5
	1980s	13	50	8.7	27	61	35	51	45	55	10
	1990-2005	18	44	13	58	76	19	42	39	45	5.6
Na	<1950	20	24	17	54	56	2.0	18	12	38	27
	1950-1960s	7	8.2	8.3	21	21	0	3.5	1.4	15	14
	1970s	12	19	14	51	57	6.0	14	11	23	12
	1980s	14	12	4.8	18	26	7.8	10	8.7	14	5.3
	1990-2005	18	37	37	159	163	4.1	21	17	50	33
SO_4^{2-}	<1950	40	188	241	1308	1317	9.0	121	73	233	160
	1950-1960s	9	193	129	416	418	2.0	219	121	253	133
	1970s	13	200	68	217	290	73	225	159	241	82
	1980s	12	194	63	208	262	54	207	193	234	42
	1990-2005	18	68	68	282	296	14	57	32	67	35
ΣMajor ions	<1950	20	546	309	1396	1736	340	422	387	588	201
	1950-1960s	7	572	222	707	858	151	604	489	683	193
	1970s	11	626	45	136	711	575	627	592	644	52
	1980s	12	558	91	313	673	360	565	541	615	74
	1990-2005	18	497	117	415	803	389	463	406	565	160

Table A-12. Summary statistics for Will County wells 100-200 ft.

Parameter	Years	N	Mean	StdDev	Range	Max	Min	Med	25%	75%	IQR
Alkalinity	<1950	84	351	98	770	862	92	348	296	386	90
	1950-60s	65	409	164	791	999	208	362	315	424	109
	1970s	103	346	110	776	916	140	323	295	360	66
	1980s	56	337	45	197	468	271	332	300	370	70
	1990-2005	47	347	99	528	694	166	329	298	369	72
Ca	<1950	53	104	62	414	420	6.3	93	76	116	40
	1950-60s	8	122	28	86	168	82	123	100	138	38
	1970s	79	111	38	199	244	45	103	91	123	32
	1980s	56	120	34	183	232	49	114	103	130	27
	1990-2005	47	99	52	281	283	2.3	100	68	122	54
Cl⁻	<1950	87	17	37	204	204	0	4.0	2.0	9.0	7.0
	1950-60s	64	46	111	740	740	0	7.0	3.0	33	30
	1970s	103	28	36	190	190	0	10	5.0	43	38
	1980s	56	51	110	819	820	1.0	24	7.3	64	57
	1990-2005	47	41	45	176	177	0.6	21	3.1	82	78
Mg	<1950	52	49	29	148	150	1.9	45	37	51	14
	1950-60s	7	55	11	30	75	45	53	47	60	13
	1970s	79	55	22	131	156	25	50	44	58	14
	1980s	56	60	25	122	155	33	53	48	59	11
	1990-2005	47	44	19	102	107	4.6	45	34	55	21
Na	<1950	33	42	69	373	373	0	21	11	42	30
	1950-60s	6	83	177	441	444	3.0	12	6.0	20	14
	1970s	80	26	28	240	245	5.0	22	12	31	19
	1980s	56	32	54	408	411	3.2	22	13	35	22
	1990-2005	47	56	83	333	339	6.2	28	15	48	33
SO_4^{2-}	<1950	68	181	213	1481	1481	0	128	52	208	157
	1950-60s	19	139	123	385	385	0	121	26	230	205
	1970s	80	184	162	837	850	13	133	103	223	120
	1980s	54	204	155	719	750	31	140	117	260	143
	1990-2005	47	153	195	1237	1238	1.0	113	68	156	89
ΣMajor ions	<1950	30	596	364	1815	2165	349	461	411	611	200
	1950-60s	5	607	149	375	842	467	611	484	679	195
	1970s	78	588	228	1238	1544	306	556	436	644	208
	1980s	54	646	225	1106	1437	332	601	526	723	197
	1990-2005	47	601	247	1515	1811	296	568	431	692	261

Table B-1. Public supply wells with significant slope values in Cook County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl⁻ is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl⁻ (mg/L)
Barrington Woods	2	00125	140	-0.243	0.972	4	1958	1982	3.9
Bartlett	1	20609	200	0.790	0.884	15	1937	2000	32.3
Bartlett	2	20610	200	1.153	0.913	8	1972	1999	41.6
Elk Grove Village	13	00503	75	5.057	0.931	4	1979	1985	55
Hanover Park	6	00504	128	0.559	0.833	6	1978	1985	6.7
Hoffmann Estates	18	00507	182	-0.305	0.654	6	1977	1985	1.4
Hoffmann Estates	20	00508	192	1.372	0.863	4	1979	1985	20
Hoffmann Estates	21	21178	122	1.501	0.978	4	1978	1990	33
Hoffmann Estates	22	21179	119	1.058	0.921	8	1978	1992	25
Lake Run Apartments	1	20670	200	1.500	0.965	3	1984	1990	60
Palatine	6B		162	-0.129	0.767	6	1967	1985	2.4
Schaumburg	7	00522	96	0.882	0.810	4	1968	1985	18
Schaumburg	14	00516	163	0.862	0.980	6	1970	1985	16
Streamwood	1	00524	120	1.899	0.784	8	1957	1986	72
Streamwood	2	00525	121	7.191	0.990	4	1979	1986	76
Streamwood	4	00527	115	0.556	0.925	7	1968	1985	13
Streamwood	5	00528	136	2.252	0.573	7	1971	1985	41
Streamwood	7	00530	146	3.696	0.925	8	1972	1985	62

Table B-2. Public supply wells with significant slope values in DuPage County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl⁻ is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl⁻ (mg/L)
Addison	1	20734	155	2.625	0.646	10	1934	1985	62
Addison	2		115	0.305	1.000	3	1950	1983	10
Addison	7	20737	85	3.290	0.935	7	1965	1987	77
Addison	8	20738	75	3.527	0.960	9	1967	1985	78
Addison	9	20739	185	5.925	0.977	4	1977	1987	83
Addison	6A	20736	160	2.894	0.918	7	1973	1987	60
Bartlett	6	20614	61	-3.139	0.537	6	1977	1991	24
Belmont-Highwood PWD	1	20518	148	0.955	0.484	7	1947	1995	141
Gary Ave. Gardens	1		200	1.258	0.981	4	1958	1982	30
Highland Hills Sanit Dist	2	20508	200	4.936	0.962	5	1968	1992	127
IL Amer Dupage Util Dvn	1	20716	200	4.535	0.708	10	1957	1992	182
IL Amer Dupage Util Dvn	3	20718	180	5.243	0.609	10	1969	1992	199
Itasca	3	20756	200	0.763	0.800	8	1947	1991	31
Itasca	5	20757	190	4.592	0.807	11	1958	1991	108
Itasca	8	20758	115	4.898	0.937	9	1965	1991	134
Lisle	3	20730	193	3.249	0.509	6	1974	1991	133
Lombard	3		175	2.731	0.980	8	1948	1980	70
Maple Hill Improv Assn	1	20472	117	4.586	0.859	6	1973	1994	167
Maple Hill Improv Assn	2	20473	158	4.551	0.907	8	1960	1994	162
N Regional Water Facility	1	20480	200	4.538	0.952	4	1975	1985	47
N Regional Water Facility	3	20482	180	1.072	0.857	5	1975	1985	14
Naperville	4	21110	178	3.608	0.975	11	1931	1991	95
Naperville	5	21111	190	2.489	0.656	18	1931	1991	124
NW Belmont	2	20487	167	2.981	0.573	5	1970	1992	123
Roselle	4	20567	195	3.272	0.637	6	1972	1985	53
Roselle	6	20569	127	1.097	0.965	5	1977	1985	10
Steeple Run Sbdv	2	20506	116	3.230	0.961	8	1972	1991	74
Tee & Green	1		198	7.979	0.914	6	1972	1982	92
Vietzen MHP	1	20493	135	-2.418	0.901	5	1988	2000	59.2
Vietzen MHP	2	20494	135	-4.573	0.623	5	1990	1999	57.4
Warrenville	5		200	2.866	0.858	4	1977	1983	23
Warrenville (Albright)	1		135	4.629	0.659	5	1972	1982	67
Warrenville (Ray St)	2	20797	125	3.703	0.587	8	1969	1992	137
Wheaton	2	20548	184	3.216	0.986	17	1930	1992	94
Wood Dale	6	20525	190	4.777	0.974	7	1977	1990	74
York Center	2	20478	81	2.251	0.860	3	1960	1997	105

Table B-3. Public supply wells with significant slope values in Kane County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl$^-$ is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl$^-$ (mg/L)
Aurora	101	00344	116	1.407	0.758	4	1970	1999	50.1
Batavia	6	00732	157	0.893	0.989	3	1988	1999	20.4
Batavia	7	00733	118	0.709	0.967	3	1991	1999	13.4
Carpentersville	3	20028	72	2.334	0.756	8	1971	1986	44
Carpentersville	5	20029	183	1.42	0.860	14	1966	2001	58.7
Carpentersville	6	20030	179	2.785	0.819	15	1973	2000	58.1
East Dundee	0		0	2.086	0.973	5	1923	1984	67
East Dundee	2	20033	69	2.925	0.999	4	1958	1991	78
East Dundee	3	20034	128	1.717	0.83	10	1968	1991	64
Elburn	2	20036	153	-0.074	0.916	6	1937	1989	0.5
Fox River WRD - Skyline	1	20106	131	0.701	0.486	8	1960	1991	31
Fox River WRD - Skyline	2	20107	135	0.96	0.57	7	1969	1991	31
IL Amer-R. Grange Dvn	1	20092	180	0.698	0.779	6	1972	1986	13
IL Amer-Valley Arena	1	20123	187	2.064	0.913	3	1983	1992	51
Montgomery	6		160	2.001	0.695	7	1959	1981	54
Ogden Gardens Sbdv	1	20081	185	0.188	0.866	6	1973	1986	3.5
Patterson MHP	1	20085	80	3.365	0.873	6	1986	2000	103
Powers Water Co	1	20087	80	1.496	0.997	3	1977	1986	17
Subdivision Water Trust	1	20064	147	0.122	0.562	7	1964	1988	5.8
Subdivision Water Trust	2	20065	180	0.200	0.676	8	1964	1988	9.2
Subdivision Water Trust	1-3	20066	196	0.356	0.915	11	1964	1998	13.7
Sleepy Hollow	2		44	6.562	0.973	3	1968	1980	100
South Elgin	4	20097	109	3.705	0.927	6	1973	1997	98.4
South Elgin	5	20098	68	2.079	0.662	5	1959	1997	92
St. Charles	7	20103	173	1.006	0.928	9	1963	1989	29
Sugar Grove	5	20088	200	0.813	0.594	8	1967	1985	19
Utl Inc Ferson Creek	2	20039	186	1.019	0.981	6	1975	1990	18
Utl Inc Ferson Creek	3	20040	175	0.611	0.979	6	1974	1990	11
Utl Inc Lk Marian Water	3	20054	75	5.653	0.967	6	1963	1997	124
West Dundee	2	20114	87	5.006	0.901	6	1969	1985	106

Table B-4. Public supply wells with significant slope values in Lake County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl$^-$ is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl$^-$ (mg/L)
Antioch	3	20311	141	0.200	0.583	12	1953	1997	11.9
Antioch	5	20313	129	0.492	0.972	5	1978	1997	14.1
Barrington	3	20238	148	1.143	0.896	12	1964	1992	37
Barrington	4	20238	148	1.991	0.854	6	1978	1992	33
Countryside Manor Sbdv	1	20284	168	0.286	0.343	10	1973	1997	24.5
D L Well Owners Assn	1	20001	55	1.746	0.767	6	1972	2001	88.1
Fox Lake	2	20006	135	0.857	0.817	11	1941	1985	21
Fox Lake	3	20007	95	3.023	0.918	5	1975	1985	38
Fox Lake	4	00220	101	2.163	0.856	3	1986	1997	53
Fox Lake Hills Sbdv	2	20009	126	0.375	0.884	8	1973	1992	9.9
Fox Lake Plant	2-1	20010	146	0.499	0.695	8	1972	1986	13
Grandwood Park Sbdv	2	20015	159	-0.063	0.416	6	1963	1991	2.5
Grandwood Park Sbdv	3	20016	142	-0.074	0.432	13	1963	1998	1.5
Island Lake	3	20282	122	2.708	0.904	6	1971	1991	59
Island Lake	102	20280	115	1.927	0.738	7	1971	1983	26
Lk Barrington Shor Sbdv	1	21020	127	0.609	0.989	5	1973	1985	9
Lake Villa	6	00190	149	-0.112	0.999	3	1986	1999	2.2
Lincolnshire	2		35	4.622	0.810	6	1961	1980	86
Lindenhurst	1	20268	165	-0.140	0.639	9	1962	1992	1.4
Lindenhurst	4	20271	131	-0.038	0.702	4	1980	1992	1.2
Tower Lakes	1	20278	180	1.677	0.977	8	1958	1999	57.2
Tower Lakes	2	20279	67	6.523	0.925	6	1971	1993	247
Utl Inc Hilldale Manor	1	20305	123	3.142	0.885	9	1970	1998	80.7
Utl Inc Hilldale Manor	2	20306	123	2.763	0.829	6	1971	1992	64
Vernon Hills	4		190	0.625	0.790	4	1961	1980	21
Winthrop Harbor	4	20291	138	0.109	0.621	7	1971	1985	7

Table B-5. Public supply wells with significant slope values in McHenry County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl⁻ is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl⁻ (mg/L)
Algonquin	0	20212	0	1.519	0.899	7	1922	1987	46
Algonquin	1	20213	165	0.618	0.992	8	1978	1992	12
Algonquin	5	20217	131	0.835	0.696	5	1976	1986	13
Algonquin	6	00186	152	0.824	0.453	7	1984	2000	19.6
Cary	3	20138	155	0.860	0.776	9	1956	1991	39
Cary	8	20142	105	4.827	0.870	5	1982	1997	101
Cary	10	20144	194	1.200	0.870	3	1981	1991	56
Deering Oaks Sbdv	2	20164	178	0.576	0.493	8	1966	1989	31
Eastwood Manor	1	20171	180	1.161	0.950	5	1958	1985	21
Fox River Grove	1	20154	140	1.782	0.322	10	1929	1997	113
Fox River Grove	2	20155	120	1.427	0.394	11	1956	1997	105
Harvard	3	20199	71	5.208	0.669	8	1938	1985	101
Harvard	4	20200	69	2.790	0.673	7	1963	1985	57
Harvard	5	20201	68	2.543	0.826	9	1958	1985	54
Harvard	6	20202	197	0.564	0.919	15	1965	2000	19.4
Harvard	7	00335	144	0.632	0.985	3	1986	1999	14.5
Hebron	4	20187	125	3.094	0.658	9	1983	2000	120
Huntley	5	20204	95	0.496	0.378	9	1969	1989	32
Huntley	6	20205	154	0.327	0.977	4	1979	1989	1.4
Island Lake	4-6	00625	146	6.913	0.996	3	1989	1999	72.2
Lake in the Hills	4	20198	114	0.762	0.623	6	1957	1991	32
Private well: Marengo			30	4.296	0.719	6	1971	1980	67
McHenry	2	20207	60	4.294	0.830	11	1960	2001	153
McHenry	3	20208	185	0.648	0.917	6	1971	1985	10
McHenry	5	20210	95	0.489	0.859	7	1978	2001	20
McHenry	6	20211	131	1.890	0.973	8	1978	1998	43.6
McHenry (Lakeland Park)	2		85	2.300	0.694	7	1958	1982	34
Northern Illinois Utl Inc	1		87	4.328	1.000	3	1958	1981	70
Oakbrook Estates MHP	1	20165	182	6.714	0.722	6	1986	2001	208
Richmond	1	20188	170	1.491	0.405	8	1938	1985	30
Richmond	2	20189	144	2.283	0.901	6	1956	1982	30
Utl Inc Holiday Hills	2	20176	108	0.608	0.855	7	1958	1986	24
Utl Inc Whispering Hills	4	20182	93	4.106	0.869	5	1964	1989	90
Wonder Lake Water Co	1	20149	180	-0.058	0.394	7	1973	1991	1.6
Woodstock	1	22149	196	0.287	0.897	6	1922	1985	9.4
Woodstock	6	22153	193	0.829	0.557	7	1960	1985	27
Woodstock	8	00607	166	1.357	0.997	3	1989	2001	23.8
Woodstock	101	00630	114	3.086	0.999	3	1989	2001	57.8

Table B-6. Public supply wells with significant slope values in Will County. Slope (β_1) and r^2 values determined by linear regression for post-1960 samples only. Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl^- is concentration at final available sample date.

Public Supply	Well #	EPAID	Depth (ft)	β_1 (mg/L/yr)	r^2	N	initial date	final date	Latest Cl^- (mg/L)
Channahon	2,5	00384	55	3.575	0.991	3	1991	2005	138
Greenfield Comm Well	1	20365	120	1.756	0.753	7	1972	1987	74
Hillview Sbdv	1		127	5.190	0.955	5	1972	1982	95
IL American West Suburb	12	21154	157	3.904	0.783	8	1976	2000	116
IL American West Suburb	19	20362	170	3.578	0.784	9	1977	2000	96.3
Joliet	202	22108	90	0.769	0.674	7	1962	1987	28
Joliet	203	22109	83	0.314	0.951	8	1962	1987	9.2
Joliet	204	22110	113	0.540	0.792	9	1950	1987	18
Joliet	205	22111	94	0.480	0.577	8	1962	1985	15
Manhattan	2	20382	156	0.078	0.508	9	1942	1992	6.9
Romeoville	1	22124	160	4.051	0.955	6	1958	1982	50
Romeoville	3		160	1.047	0.981	3	1964	1981	27
ShawnitaTrace Water	1	20343	183	1.346	0.945	6	1972	1987	34
Sunnyland Sbdv	1	20355	132	0.905	0.593	7	1958	1992	82
Sunnyland Sbdv	3	20356	150	1.008	0.425	7	1972	1992	80

Table B-7. Public supply wells that did not have a significant slope (β_1). Well # is local well number, and EPAID is Illinois EPA well code. N is number of samples and latest Cl⁻ is concentration at final available sample date. Wells in bold type had significant trend (S) values; if in italics, the trend was negative.

County	Public Supply	Well #	EPAID	Depth (ft)	initial date	final date	N	Latest Cl⁻ (mg/L)
Cook	**Bartlett**	**3**	20611	97	1960	1985	11	9.9
Cook	Hoffmann Estates	8		180	1973	1980	4	1.5
Cook	Hoffmann Estates	16	00505	200	1978	1985	3	1
Cook	Mission Brook Sanitary Dist	4	20647	170	1985	1995	4	14.4
Cook	Mount Prospect	9		19	1955	1983	6	15
Cook	Palatine	5		136	1964	1984	5	2.2
Cook	Schaumburg	10	00514	116	1969	1985	5	5.9
Cook	Schaumburg	12	21156	154	1970	1983	5	5.8
Cook	**Spring Lakes MHP**	**2**	20617	136	1988	1999	3	18.4
Cook	Streamwood	6	00529	145	1977	1986	5	40
Cook	Utl Inc Co Line Water Co	1	20596	138	1963	1992	9	3.3
DuPage	Bloomingdale	9	20723	136	1982	1986	3	23
DuPage	Naperville	22	21126	200	1984	1991	3	141
DuPage	Polo Dr. & Saddle Rd Sbdv	2	20497	200	1981	1999	6	129
DuPage	Roselle	1	20564	182	1926	1988	11	14
DuPage	Roselle	2	20565	183	1953	1985	10	19
DuPage	Warrenville	1		125	1958	1982	8	44
DuPage	Warrenville	6	20483	178	1961	1983	8	5.3
Kane	Burlington	1	20025	108	1941	1989	5	2.5
Kane	Gilberts	1	20051	187	1978	1986	5	3.4
Kane	Highland Sbdv	1	20050	152	1975	1989	5	10
Kane	Maple Park	2	20055	134	1946	1989	7	1.9
Kane	Maple Park	3		185	1971	1980	6	1
Kane	Montgomery	10	00405	82	1986	2001	3	88.1
Kane	Ogden Gardens Sbdv	2	20082	176	1973	1986	6	2
Kane	Ogden Gardens Sbdv	3	20083	185	1972	1986	6	1
Kane	**South Elgin**	**3**	20096	112	1962	1985	10	27
Kane	St Charles	9	20105	86	1979	1989	5	34
Kane	Sugar Grove	2	20108	107	1961	1992	11	64
Kane	**Sugar Grove**	**3**	20109	110	1961	1986	3	76
Lake	**Antioch**	**4**	20312	129	1965	1997	11	9.6
Lake	D L Well Owners Assn	2	20002	71	1981	2001	4	104
Lake	Fox Lake Hills Sbdv	1	20008	130	1974	1991	5	2.5
Lake	Fox Lake Plant	2-2	20011	133	1976	1986	6	7.3
Lake	Grandwood Park Sbdv	1	20014	145	1958	2000	12	2.2
Lake	*Grandwood Park Sbdv*	*4*	00324	122	1989	1999	3	2.1
Lake	Holly Hock Hill MHP	1	20228	126	1987	1996	4	6.3
Lake	Island Lake	103	20281	95	1971	1986	7	28
Lake	Lake Villa	2	20262	156	1961	1985	6	1.4
Lake	Lake Villa	4	20264	153	1971	2001	8	2.7
Lake	Lake Villa	5	00546	150	1982	2001	7	3.3
Lake	Lindenhurst	2	20269	151	1967	1992	7	1.7
Lake	Lindenhurst	3	20270	132	1980	1992	4	3.8
Lake	Lindenhurst	5	20272	133	1976	1992	5	2
Lake	Mundelein	5	21005	140	1959	1986	8	4.5
Lake	Mundelein	7	21007	165	1972	1986	6	6.1

Lake	**Pekara Sbdv**	**2**	20294	155	1960	2000	12	11.9
Lake	Pekara Sbdv	3	20295	141	1978	1987	3	7.1
Lake	Pekara Sbdv	4	20296	150	1978	2001	8	8.9
Lake	Towners Sbdv	2	20243	180	1959	1987	8	5.2
Lake	Utl Inc Harbor Ridge	1	20247	123	1978	1992	5	2.1
Lake	Wildwood Sbdv	3	21046	173	1958	1991	6	3.3
Lake	Winthrop Harbor	5	20292	130	1959	1982	6	6.3
McHenry	Algonquin	3		189	1968	1980	6	2
McHenry	Huntley	4	20203	63	1953	1989	5	40
McHenry	**Island Lake**	**4-10**	00614	146	1989	1999	4	45.7
McHenry	Private well: Marengo			22	1971	1980	8	130
McHenry	Marengo	4	20191	100	1962	1985	5	21
McHenry	Marengo	5	20192	85	1962	1986	7	35
McHenry	Marengo	6	20193	87	1976	1986	6	28
McHenry	McHenry Shores Water Co	1	20150	180	1958	1986	6	5.1
McHenry	McHenry Shores Water Co	2	20151	135	1970	1985	7	0.5
McHenry	Nunda Utl Co	1	20161	189	1971	1987	6	3.5
McHenry	Union	2	20173	192	1938	1985	9	1.5
McHenry	Woodstock	3	22150	198	1939	1983	4	5
McHenry	Woodstock	5	22152	189	1960	1985	7	7.3
McHenry	Woodstock	7	22154	114	1961	1985	8	40
McHenry	Woodstock	10	00609	107	1991	2001	3	76.3
Will	**Beckwith Community Assn**	**1**	20380	187	1977	1987	3	9.7
Will	***Beckwith Community Assn***	***2***	20381	187	1978	1987	4	3.5
Will	Beecher	1	20370	164	1917	1983	5	1.2
Will	East Lawn Sbdv	1		110	1972	1983	5	81
Will	Huntley Community Sbdv	1		155	1972	1983	3	4.3
Will	Joliet	201	22107	103	1950	1983	9	9
Will	Manhattan	4		115	1977	1984	5	1
Will	Peotone	1		135	1906	1985	5	6
Will	Private well: New Lenox			90	1991	2003	4	1.2
Will	***Shorewood***	***3***	20352	151	1973	1985	3	2.1
Will	Utl Inc Cherry Hill Water Co	1	20331	145	1951	1990	5	47

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