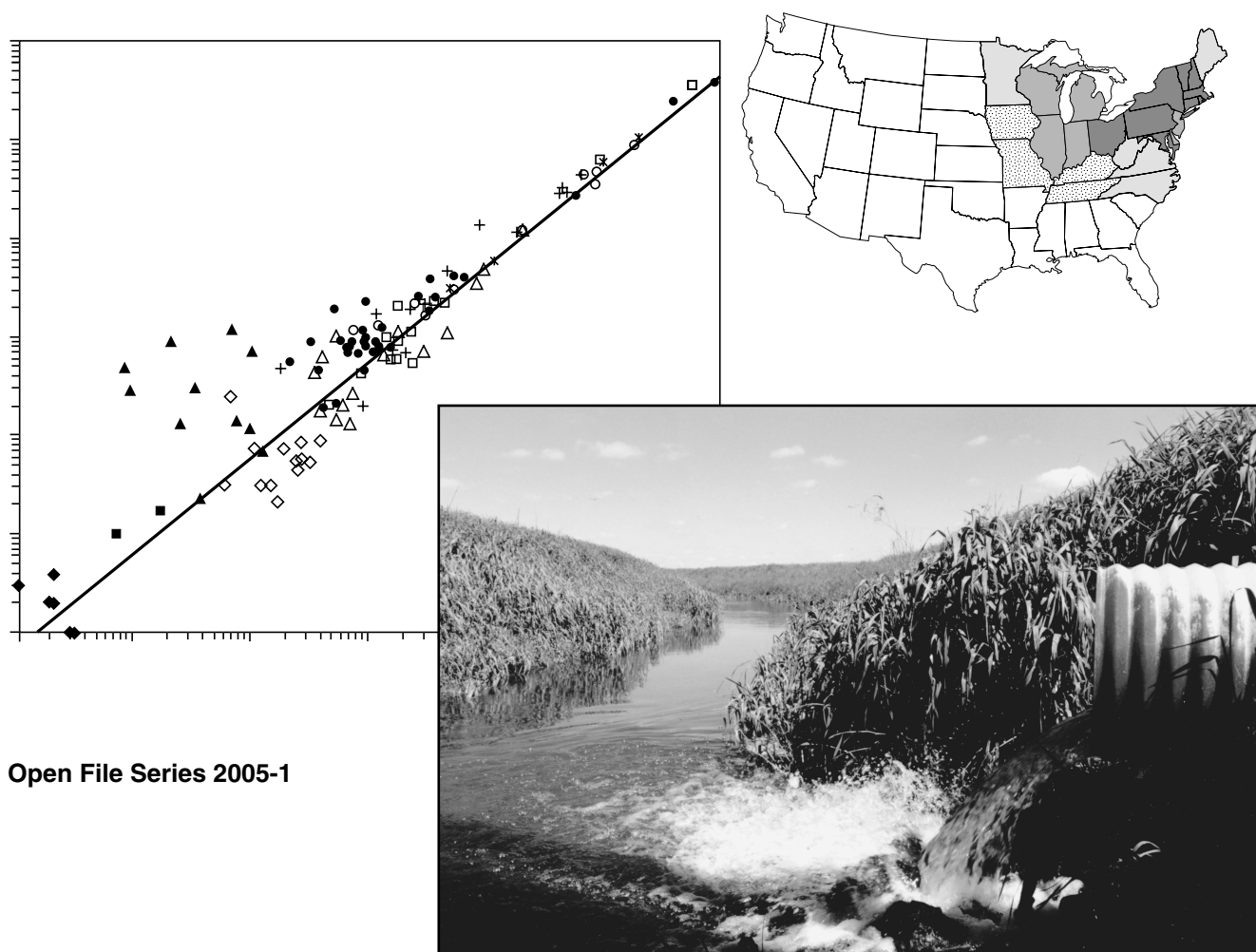




Database for the Characterization and Identification of the Sources of Sodium and Chloride in Natural Waters of Illinois

S.V. Panno, K.C. Hackley, H.H. Hwang, S. Greenberg, I.G. Krapac, S. Landsberger and D.J. O'Kelly



Open File Series 2005-1

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S.V. Panno, K.C. Hackley, H.H. Hwang, S. Greenberg, I.G. Krapac,
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Open File Series 2005-1

ILLINOIS STATE GEOLOGICAL SURVEY
William W. Shilts, Chief
615 E. Peabody Drive
Champaign, Illinois 61820
217-333-4747
<http://www.isgs.uiuc.edu>

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Introduction

Contamination of groundwater and surface water by Na^+ and Cl^- is a common occurrence in urban areas (Mason et al. 1999, Buttle and Labadia 1999, Naftz and Spangler 1994) and has adversely affected municipal and private water supplies in Illinois and other states (Moyland 1980, Cleary 1978, Kelly and Wilson 2002). The work by Kelly and Wilson suggests that Na^+ and Cl^- concentrations in shallow groundwater in northeastern Illinois have been increasing since about 1960. Nevertheless, elevated concentrations of these ions in groundwater and surface water can adversely affect vegetation in environmentally sensitive areas such as wetlands. Specifically, Na^+ and Cl^- contamination within a wetland's watershed and recharge areas can destroy rare and endangered plant species (Wilcox 1986a, b; Grootjans et al. 1988; Panno et al. 1998, 1999).

Natural sources of Na^+ and Cl^- in the midcontinent region of the U.S. include contributions of soil/rock-water interactions, basin brines, and minor atmospheric deposition (Panno et al., 2002). Sources of Na^+ and Cl^- originating from human-related activities that we investigated included agricultural chemicals, effluent from private and municipal septic systems, animal waste (e.g., from livestock operations), municipal landfills, and road deicing agents. We also examined seawater intrusion, another source of Na^+ and Cl^- contamination located in coastal areas far from the midcontinent region.

While the identification and quantification of Na^+ and Cl^- in water is a simple matter, identifying the source(s) of the Na^+ and Cl^- present in surface water and groundwater can be problematic. To solve groundwater and surface-water contamination problems, it is first necessary to identify the contamination source(s). Numerous approaches have been used to help identify the sources of Na^+ and Cl^- in natural waters (e.g., Whittemore 1995, Davis et al. 1998). However, no one has yet tried to discriminate among all of the sources listed above. The Cl/Br mass ratio has been used successfully to study the origin of saline ground-

water and brines from relatively deep geologic formations and to characterize atmospheric precipitation, shallow groundwater, and domestic sewage (Richter and Kreidler 1993, Davis et al. 1998). Under most circumstances, the conservative behavior of Br^- and Cl^- during transport makes these halides and their ratios especially useful in determining surface water and groundwater movement. However, because of the similarities of the ranges of Cl/Br ratios for different sources the technique is not always definitive. Other indicators used to explore the origin and evolution of surface water and groundwater include radioactive and stable isotopes (e.g., Back et al. 1993, Appelo and Postma 1994). For example, tritium, δD , $\delta^{18}\text{O}$, and $\delta^{13}\text{C}$, have been used as indicators of the evolution of groundwater and surface water and may also be used to fingerprint contaminants (Clark and Fritz 1997).

Objectives

The purpose of this investigation was twofold: (1) to further characterize the background (what naturally occurs in shallow groundwater) and the natural and anthropogenic sources of Na^+ and Cl^- contamination in the environment and, (2) to determine which geochemical and isotopic techniques, either alone or together, could be used to effectively identify the natural and anthropogenic source(s) of Na^+ and Cl^- contamination in surface water and groundwater impacted by the seven potential sources identified above.

The following is a description of the samples collected, the methods and analytical procedures used, and the chemical and isotopic results obtained for all the sample collected during this investigation. Characterization of the sources of Na^+ and Cl^- presented herein is limited. A more in-depth characterization of background and sources, interpretation of data, and development of techniques for identifying sources are presented in Panno et al. (in press).

Methods

A total of 128 water and waste samples were collected for this investigation. Samples included precipita-

tion, unsaturated zone water, and groundwater presumed to be uncontaminated and therefore having "background" levels of Na^+ and Cl^- ; source contaminants/waste water; and impacted or affected groundwater samples (Tables 1 and 2). Each of the background samples and the potential sources of Na^+ and Cl^- were chemically and isotopically characterized. Many samples of surface water and/or groundwater analyzed were known to be contaminated by a single Na^+ and Cl^- source. The sources of Na^+ and Cl^- in these samples were determined primarily on the basis of a sampling site's location in proximity to one of the potential sources, such as row-crop agriculture, roadways, private septic systems, animal-raising facilities, and landfills. There is a small degree of uncertainty because it is possible that something unusual may have occurred in the vicinity of the sample locations that could have affected our results.

Sample Collection

Precipitation Precipitation samples were collected in rural east-central Illinois over a period of 12 months using a plastic funnel 27 cm in diameter and a 10L glass container. Rainwater or snow was collected in a clean vessel after individual storm events during a single month in winter, spring, summer, and fall. Each sample was mixed in 4L bottles and stored in a refrigerator. At the end of each collecting month, the accumulated precipitation sample was measured for pH and specific conductance.

Unsaturated Zone Two water samples were collected from ceiling seeps in Mammoth Cave (Kentucky) at Edna's Dome and Cathedral Dome and are presumed to represent uncontaminated soil water from the unsaturated zone. The domes underlie a large, undeveloped area of Mammoth Cave National Park.

Pristine Aquifers Twelve groundwater samples were collected from sand and gravel aquifers. Five samples were from a buried bedrock valley aquifer in east-central Illinois, one was from smaller aquifers overlying the buried bedrock valley aquifer, and

six samples were from several small, but locally productive sand and gravel aquifers in northeastern Illinois. All of the samples were collected from wells screened from tens of meters to over 100 m below the land surface.

Agricultural Tile Drains Thirteen water samples were collected from agricultural tile drains in east central Illinois that were sampled at different times of the year, representing all seasons. The tile drains were located just south of Champaign, Illinois, and just west of Rantoul, Illinois. Four agricultural-related groundwater samples were collected in September, 2002 from an unconfined sand and gravel aquifer in southeastern Illinois (near Lawrenceville) in a cultivated area at depths of 3, 10, 15, and 25 m.

Road Deicer Thirteen groundwater samples presumed to be contaminated with road salt were collected from private wells tapping a shallow sand and gravel aquifer in northeastern Illinois. Because the sample locations were in residential areas within city limits with city sewer service, we assumed that road salt was probably the only major source of Na^+ and Cl^- . In addition, a sample of winter-time snowmelt drainage was collected from a bridge in the Chicago area that had received road salt.

Rock salt, made up predominantly of halite (NaCl) with trace amounts of sylvite (KCl) and other minor constituents, was first used on roads after World War II. Rock salt and, to a lesser extent, CaCl_2 , are the primary road deicers used by counties in northeastern Illinois. Historically, the use of relatively large amounts of NaCl occurred initially in about 1960 when road salt was first used in conjunction with snow plowing (Salt Institute, 2003). Now, road deicers and brine solutions (made from a 23% solution of rock salt) are used to pre-treat roadways and prevent bridges from developing icy surfaces. During very cold periods, NaCl brines are replaced in the Chicago area with a 32% solution of CaCl_2 (D. Johnson, Illinois Department of Transportation, personal communication, 2003). Current Illinois Department of Transportation (IDOT) guidelines suggest using between 45 and

160 kg of salt or 75 to 230 L of brine solution per lane mile per snow/ice event and reapplication is conducted "as needed" (IDOT 1999).

In general, road salt represents a primary source of Na^+ and Cl^- that is widely available for stream and groundwater contamination where it is in use. For example, NaCl purchased as road salt in the contiguous U.S. has been used as a proxy for the mass of road salt applied in each state (e.g., Richter and Kreidler 1993). We normalized the amount of road salt sold in each state to the areas of each state (Figure 1). Based on this estimate, the states of the northeast received between 545 and 23,716 kg/km^2 of NaCl per year. The remaining states received less than 500 $\text{kg}/\text{km}^2/\text{yr}$. Road salt contamination of surface and groundwater is generally localized around roadways and is directly proportional to the mass of applied road salt (Foos 2003).

Private Septic Systems Twenty-nine samples of septic effluent were collected from the discharge points of private septic systems across Illinois. Septic system types sampled included standard leach fields, aeration systems, and sand filters. Effluent samples were collected from the discharge points for each type, with the exception of leach field systems,

where samples were collected from holding tanks. In addition, one surface water and two groundwater samples were collected just down-gradient from a private septic system in South Elgin, Illinois.

Animal Waste Three waste lagoon manure samples were collected from swine finishing facilities in central and southern Illinois (Panno et al. 1996, Krapac et al. 1998, 2000), one leachate sample was collected from a horse manure pile in northeastern Illinois (Hwang et al. 2003), and eleven affected groundwater samples were collected from monitoring wells in central and southern Illinois known to have been contaminated with hog manure (Larson et al. 1997, Krapac et al. 1998, Panno et al. 1996).

Municipal Landfills Ten landfill leachate samples from seven different landfills throughout Illinois were collected from their leachate-collection systems (two different cells were sampled at three of the landfills). In addition, five monitoring wells known to be contaminated with landfill leachate were sampled from three of the landfills. The names and locations of the ten landfills have been kept confidential at the request of the owners.

Seawater An average seawater composition, published by Krauskopf

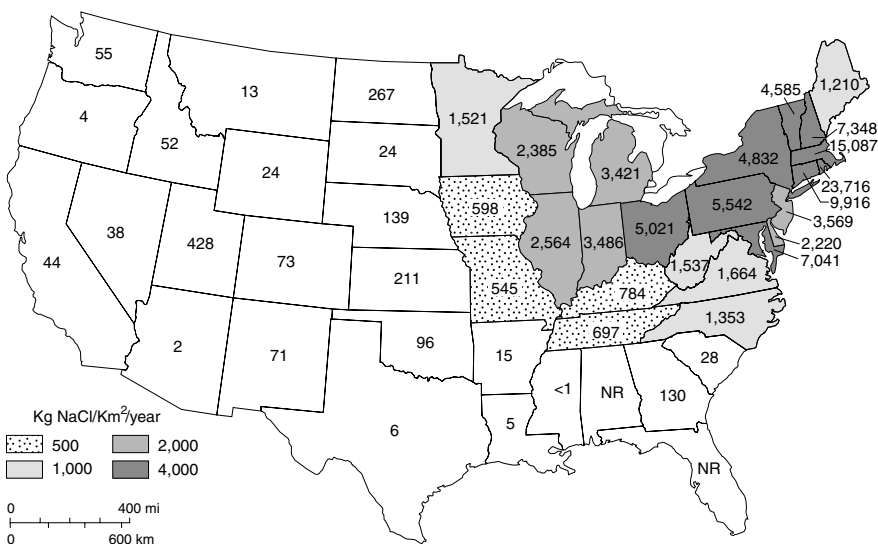


Figure 1 Map of the contiguous U.S. showing the average amount of road salt sold to each state annually averaged over a three-winter period, and normalized to the area of each state.

Table 1. Sources of samples.

Sample Id	Source of Samples
Precipitation	
P1	Champaign, IL rainwater composite for August, 2001
P2	Champaign, IL rainwater composite for November, 2001
P3	Champaign, IL rainwater composite for February, 2002
P4	Champaign, IL rainwater composite for May, 2002
Unsaturated Zone Water	
UZ1	Drip water from Edna's Dome, Mammoth Cave, KY
UZ2	Drip water from Cathedral Dome, Mammoth Cave, KY
Pristine Aquifer (Ground Water) Samples	
Aq1	Monitoring well CHM96B screened in Mahomet aquifer, Champaign County, IL
Aq2	Private well Staff 99 screened in Mahomet aquifer, Champaign County, IL
Aq3	Monitoring well CHM94B screened in Mahomet aquifer, Champaign County, IL
Aq4	Monitoring well CHM94A2 screened in Mahomet aquifer, Champaign County, IL
Aq5	Monitoring well IRO96A screened in Mahomet aquifer, Iroquois County, IL
Aq6	Private well screened in sand and gravel aquifer, Hampshire, IL
Aq7	Private well screened in Silurian dolomite, Hampshire, IL
Aq8	Private well screened in sand and gravel aquifer, Grays Lake, IL
Aq9	Private well screened in sand and gravel aquifer, Grays Lake, IL
Aq10	Monitoring well screened in sand and gravel aquifer, Canada
Aq11	Monitoring well screened in sand and gravel aquifer, Canada
Aq12	Private well screened in sand aquifer, central Illinois
Field Tile Water	
F1	Tile water from south of Champaign, IL collected 10/18/01
F2	Tile water from south of Champaign, IL collected 05/24/01
F3	Tile water from south of Champaign, IL collected 05/24/01
F4	Tile water from south of Champaign, IL collected 02/28/02
F5	Tile water from south of Champaign, IL collected 05/21/02
F6	Tile water from south of Champaign, IL collected 08/07/02
F7	Monitoring well screened at 25m in a sand aquifer, Lawrenceville, IL, 09/09/02
F8	Monitoring well screened at 15m in a sand aquifer, Lawrenceville, IL, 09/09/02
F9	Monitoring well screened at 10m in a sand aquifer, Lawrenceville, IL, 09/09/02
F10	Monitoring well screened at 3m in a sand aquifer, Lawrenceville, IL, 09/09/02
F11	Tile water from 2 km west of Rantoul, IL, 09/02/03
F12	Tile water from 2 km west of Rantoul, IL, 10/30/03
F13	Tile water from 2 km west of Rantoul, IL, 11/20/03
KCI	Concentrated saline solution made from potassium chloride for field application
Road Salt Affected Water	
S1	Contaminated private well in sand and gravel near, Hampshire, IL
S2	Contaminated private well in sand and gravel near, Hampshire, IL
S3	Contaminated private well in sand and gravel near, South Elgin, IL
S4	Contaminated private well in sand and gravel near, South Elgin, IL
S5	Contaminated private well in sand and gravel near, Marengo, IL
S6	Contaminated private well in sand and gravel near, Marengo, IL
S7	Contaminated private well in sand and gravel near, Union, IL
S8	Contaminated private well in sand and gravel near, Wonder Lake, IL
S9	Contaminated private well in sand and gravel near, rural area of McHenry County
S10	Contaminated private well in sand and gravel near, Johnsburg, IL
S11	Contaminated private well in sand and gravel near, Wonder Lake, IL
S12	Contaminated private well in sand and gravel near, Wonder Lake, IL
S13	Contaminated monitoring well in sand and gravel near, Paxton, IL
RS1	Concentrated saline solution made from Kane County, IL road salt
RS2	Concentrated saline solution collected from beneath a bridge, Western Springs, IL
Septic Effluent and Affected Waters	
E1	Private septic system, leach field type, septic tank sample collected during flushing of water softener
E2	Private septic system, leach field type, septic tank sample
E3	Private septic system, aeration type, discharge sample, Monroe County, IL
E4	Private septic system, aeration type, discharge sample, Monroe County, IL
E5	Private septic system, aeration type, discharge sample, Monroe County, IL
E6	Private septic system, sand mound type, discharge sample, Monroe County, IL
E7	Private septic system, aeration type, discharge sample, Monroe County, IL
E8	Private septic system, aeration type, discharge sample, Monroe County, IL

E9	Private septic system, aeration type, discharge sample, Monroe County, IL
E10	Private septic system, aeration type, discharge sample, Monroe County, IL
E11	Private septic system, aeration type, discharge sample, Monroe County, IL
E12	Private septic system, aeration type, discharge sample, Monroe County, IL
E13	Private septic system, aeration type, discharge sample, Monroe County, IL
E14	Private septic system, aeration type, discharge sample, Monroe County, IL
E15	Private septic system, aeration type, discharge sample, Monroe County, IL
E16	Private septic system, aeration type, discharge sample, Monroe County, IL
E17	Private septic system, aeration type, discharge sample, Monroe County, IL
E18	Private septic system, aeration type, discharge sample, Monroe County, IL
E19	Private septic system, aeration type, discharge sample, Monroe County, IL
E20	Private septic system, aeration type, discharge sample, Monroe County, IL
E21	Private septic system, aeration type, discharge sample, Monroe County, IL
E22	Private septic system, aeration type, discharge sample, Monroe County, IL
E23	Private septic system, aeration type, discharge sample, Monroe County, IL
E24	Private septic system, aeration type, discharge sample, Monroe County, IL
E25	Private septic system, aeration type, discharge sample, Monroe County, IL
E26	Private septic system, aeration type, discharge sample, Monroe County, IL
E27	Private septic system, aeration type, discharge sample, Monroe County, IL
E28	Private septic system, aeration type, discharge sample, Monroe County, IL
E29	Private septic system, aeration type, discharge sample, Monroe County, IL
Em1	Seep downgradient of South Elgin septic system
Em2	Seep downgradient of South Elgin septic system
Em3	Pond downgradient of South Elgin septic system
Cull	Concentrated saline solution made from Culligan brand water softener salt
MIS	Concentrated saline solution made from Morton System Saver Salt

Animal Waste and Affected Waters

A1	Hog waste from hog farm in Monroe County, IL
A2	Hog waste from hog farm in central IL
A3	Hog waste from hog farm in central IL
A4	Leachate from horse manure in McHenry County, IL
Am1	Hog waste contaminated private well, Monroe County, IL
Am2	Groundwater sample from private well immediately adjacent to livestock holding area and suspected of being contaminated with cattle waste, Monroe County, IL
Am3	Groundwater sample from private well immediately adjacent to livestock holding area and suspected of being contaminated with cattle waste, Monroe County, IL
Am4	Groundwater sample from private well immediately adjacent to livestock holding area and suspected of being contaminated with cattle waste, Monroe County, IL

Sample Id Source of Samples

Am5	Groundwater sample from a monitoring well immediately adjacent to livestock holding area and known to be contaminated with hog waste, McHenry County, IL
Am6	Groundwater sample from a monitoring well immediately adjacent to livestock holding area and known to be contaminated with hog waste, McHenry County, IL
Am7	Groundwater sample from a monitoring well suspected of being contaminated with cattle waste, Bloomington, IL
Am8	Groundwater sample from a monitoring well suspected of being contaminated with cattle waste, Bloomington, IL
Am9	Groundwater sample from a monitoring well immediately adjacent to livestock holding area and suspected of being contaminated with hog waste, McHenry County, IL
Am10	Groundwater sample from a monitoring well immediately adjacent to livestock holding area and suspected of being contaminated with hog waste, McHenry County, IL
Am11	Groundwater sample from a monitoring well immediately adjacent to livestock holding area and suspected of being contaminated with cattle waste, McHenry County, IL

Landfill Leachate and Affected Waters

L1	Leachate from municipal landfill in Kane County, IL
L2	Leachate from municipal landfill in Kane County, IL
L3	Leachate from municipal landfill in Lake County, IL
L4	Leachate from municipal landfill in Kane County, IL
L5	Leachate from municipal landfill in Kane County, IL
L6	Leachate from municipal landfill near Paxton, IL
L7	Leachate from municipal landfill near Paxton, IL
L8	Leachate from municipal landfill in Saline County, IL
L9	Leachate from municipal landfill in Saline County, IL
L10	Leachate from municipal landfill near Monticello, IL
Lm1	Leachate contaminated monitoring well from South Elgin, IL
Lm2	Leachate contaminated monitoring well from South Elgin, IL

Lm3	Leachate contaminated monitoring well from Canada
Lm4	Leachate contaminated monitoring well from Canada
Lm5	Leachate contaminated monitoring well from California

Seawater and Affected Water

SW	Seawater composition from Krauskopf, 1979
SWb	Seawater from Utsalady Bay off the coast of Camano Island, WA
SWm1	Seawater contaminated groundwater from Camano Island, WA
SWm2	Seawater contaminated groundwater from Camano Island, WA

Saline Springs and Basin Brines

B1	Saline groundwater from a exploratory well near Villa Grove, IL
B2	Saline groundwater from a private well in the Mahomet aquifer near Cisco, IL
B3	Saline groundwater from a private well in the Mahomet aquifer near Cisco, IL
B4	Saline groundwater from a spring near Columbia, IL
B5	Saline groundwater from a spring near Columbia, IL
B6	Saline surface water from Columbia, IL
B7	Saline groundwater from a spring near Equality, IL
B8	Saline groundwater from a private well in the Mahomet aquifer near Monticello, IL
B9	Saline groundwater from a spring near Ottawa, IL (Old Salt Well)
B10	Saline groundwater from a private well near Springfield, IL
B11	Saline groundwater from a private well near Springfield, IL
B12	Saline groundwater from a private well near Springfield, IL
B13	Saline groundwater from a monitoring well in the Mahomet aquifer near Allerton Park
B14	Na-Cl evaporite dissolution brine from the Permian-age Wellington aquifer, Kansas (from Banner et al., 1989)
B15	Illinois Basin brine from basal Pennsylvanian sandstone (sample 10 from Hwang, 1996)
B16	Illinois Basin brine from basal Pennsylvanian sandstone (sample 17 from Hwang, 1996)
B17	Illinois Basin brine from the Mississippian-age Aux Vases Formation, southern Illinois (sample EOR-B9 from Demir and Seyler, 1999)
B18	Illinois Basin brine from the Mississippian-age Aux Vases Formation, southern Illinois (sample EOR-B38 from Demir and Seyler, 1999)

(1979), was used as an end member (SW). In addition, three water samples were collected from Camano Island County in the state of Washington, a bay water (source) sample from Utsalady Bay and two groundwater samples affected by seawater intrusion from private wells on the island.

Saline Groundwater Three saline springs, one deep saline well, and five private wells affected by saline water seeping into a buried valley aquifer were sampled. The saline spring near Columbia, Illinois, located along the Waterloo-Dupo Anticline, is associated with oil and natural gas deposits; two samples of the seep (taken about one year apart) and one of seep water mixed with stream water were collected here. The saline spring sampled near Equality, IL is one of several saline springs associated with the Shawneetown Fault Zone. The third spring sampled, located within Starved Rock State Park and known as the Old Salt Well, is one of several in that area (Willman and Payne 1942).

A 110-m well drilled by the Illinois State Geological Survey (ISGS) in 1997 near Villa Grove, Illinois, intersected water- and methane-producing sand layers in coal-bearing, Pennsylvanian age bedrock. The well produced saline water under flowing artesian conditions and was sampled prior to its sealing (T. Young, ISGS, personal communication, 1997). Four private wells screened within the Mahomet aquifer near a saline seep coincident with a structure in bedrock associated with the LaSalle Anticlinorium that intersects the aquifer (Panno et al. 1994) were each sampled once. Finally, one shallow well near Springfield, Illinois, was sampled at three levels and showed profound stratification of Na⁺ and Cl⁻.

Prepared Brine Solutions Brine solutions were made from road salt collected at IDOT salt storage facilities (RS1), from Culligan-brand water softener salts (Cull), from potassium chloride salt used primarily for agricultural

purposes (KCl), and Morton-brand iodized table salt (MIS). Solutions of approximately 100,000 mg/L of total dissolved solids were made from each salt type using 100 grams of salt dissolved in one liter of deionized water (Table 1). These prepared brine solutions were analyzed for their halide concentrations to determine their ratios and help establish end member values for potential anthropogenic sources.

Analytical Procedures

Most water samples (sources, affected, and background) were analyzed in the field for temperature, pH, Eh and specific conductance using meters that allow temperature compensation in accordance with field techniques as described in Wood (1981). Water samples were analyzed for cations, anions, ammonium, total Kjeldhal nitrogen (TKN), dissolved organic carbon (DOC), and the stable isotopes $\delta^{18}\text{O}$, δD , and $\delta^{13}\text{C}$. Samples collected for cations and anions were passed through 0.45- μm high-capacity filters and stored in polyethylene bottles. Cation samples were acidified in the field with ultra-pure nitric acid to a pH of < 2. All samples were transported to the laboratory in ice-filled coolers and kept refrigerated at approximately 4°C until analyzed.

Concentrations of cations in the water samples were determined with a Thermo-Jarrell Ash Model ICAP 61e Inductively Coupled Argon Plasma Spectrophotometer. Instrument operation, inter-element interference correction, background correction, and data collection were controlled using ThermoSPEC/AE 6.20 software. Blanks, calibration check standards, and reference standards were analyzed with each sample set. Concentrations of anions were determined using a Dionex DX-120 ion chromatograph with Ionpac AG14 Guard Column, Ionpac AS14 Analytical Column, and Anion Self-Regenerating Suppressor-11 (4 mm) following U.S. EPA Method 300.0 (Pfaff 1993). Analytes were measured with a CDM-3 conductivity detector cell with a DS4 detection stabilizer. The eluent was treated with 3.5 mM sodium carbonate and 1.0 mM sodium bicarbonate. Instru-

Table 2. Database for the characterization and identification of sodium and chloride in natural waters of Illinois.

Sample ID	Temp. °C	pH pH units	Eh mV	Sp.Cond. S/cm	Alkalinity (CaCO ₃)	Na	K	Ca	Mg	Sr	Ba	B	SiO ₂	HCO ₃	SO ₄	Cl	Br
Precipitation																	
P1	ND	5.9	ND	16.0	3.3	0.3	<1	1.0	0.2	0.002	0.004	0.03	0.64	4	1.6	0.1	0.005
P2	ND	6.1	ND	18.0	3.9	0.2	<1	1.2	0.2	0.002	0.003	<0.02	0.09	5	1.7	0.2	0.004
P3	ND	5.7	ND	2.4	<1	0.4	3	0.6	0.1	0.002	0.003	0.01	<0.01	<1	1.3	0.2	0.003
P4	ND	6.5	ND	14.0	ND	0.1	<1	0.6	0.1	<0.001	0.002	<0.01	<0.01	ND	1.4	0.3	0.005
Mean	NC	6.0	NC	15.1	NC	0.2	NC	0.8	0.2	NC	0.003	NC	NC	NC	1.5	0.2	0.004
Median	NC	6.0	NC	15.0	3.3	0.2	<1	0.8	0.2	0.002	0.003	0.01	0.04	4	1.5	0.2	0.004
Unsaturated Zone Water																	
UZ1	12.7	7.7	490	218	103	1.7	1	38	5.5	0.114	0.068	<0.01	8.36	126	8.0	1.7	0.015
UZ2	12.8	7.7	539	200	99.7	1.0	1	39	3.3	0.088	0.022	<0.01	9.06	122	5.2	0.7	0.010
Pristine Aquifer (Ground Water) Samples																	
Aq1	13.9	7.3	92	676	ND	29	2	85	33	0.390	0.080	0.57	20.5	NC	43	0.9	0.020
Aq2	14.2	7.3	72	606	ND	14	<1	77	34	0.450	0.060	0.14	19.2	NC	25	7.2	0.014
Aq3	13.7	7.2	103	720	ND	45	<1	85	35	0.660	0.100	1.07	17.9	NC	51	6.7	0.027
Aq4	13.9	7.4	62	665	374	49	2	73	28	0.690	0.120	1.36	19.1	456	8.7	0.8	0.031
Aq5	12.1	7.3	76	1280	322	70	<1	163	61	1.110	0.020	1.07	16.9	393	406	9.8	0.075
Aq6	11.5	7.2	129	797	408	7.0	2	109	51	0.291	0.810	0.02	16.3	497	39	12	0.031
Aq7	16.3	7.1	472	537	307	13	10	67	29	2.500	1.760	0.18	7.44	374	2.8	2.4	0.029
Aq8	ND	ND	ND	515	135	90	3	17	8.8	0.526	0.023	0.71	9.06	165	119	2.0	0.036
Aq9	13.6	7.1	259	1000	410	31	<5	130	78	0.906	0.590	0.39	18.2	500	268	3.2	0.023
Aq10	ND	7.2	508	819	377	2.3	8	127	43	0.643	0.041	0.07	11.0	460	91	3.5	0.154
Aq11	ND	7.5	491	607	313	119	6	16	11	0.499	0.046	0.41	13.2	382	1.0	6.6	0.167
Aq12	10.9	6.6	-221	550	295	12	<1	73	29	0.141	0.064	0.07	22.1	360	0.1	9.3	0.054
Mean	10.0	6.6	170	731	245	40	3	85	37	0.734	0.310	0.50	15.9	398	88	5.4	0.055
Median	13.7	7.2	103	670	322	30	3	81	34	0.584	0.072	0.40	17.4	393	41	5.0	0.0309
Field Tile Water																	
F1	15.3	7.3	473	668	247	5.4	1	96	37	0.151	0.061	0.03	10.5	301	44	30	0.015
F2	9.80	7.3	411	551	180	5.7	<1	75	33	0.120	0.048	0.01	8.01	220	25	25	ND
F3	11.6	8.2	411	603	217	8.6	<1	89	33	0.158	0.064	<0.01	7.78	265	73	26	ND
F4	6.70	7.2	392	602	192	8.9	4	77	12	0.106	0.046	0.03	9.34	234	28	37	0.026
F5	11.5	7.0	474	531	169	5.6	<1	68	30	0.105	0.050	0.04	10.3	206	23	23	0.029
F6	20.2	7.9	512	619	248	4.5	1	89	35	0.139	0.054	0.02	9.47	302	30	24	0.024
F7	12.5	7.2	459	511	215	25	<1	66	16	0.184	0.091	<0.01	15.7	262	16	6.3	0.058
F8	14.6	7.5	165	425	136	3.3	3	66	15	0.071	0.033	0.02	7.35	166	58	5.7	0.024
F9	14.1	7.4	422	472	133	3.1	<1	69	17	0.075	0.026	0.01	10.3	162	22	12	0.020
F10	15.1	7.2	473	567	173	3.1	<1	85	22	0.094	0.019	0.02	11.7	211	15	14	0.022
F11	20.9	6.8	348	673	281	2.2	<1	104	30	0.156	0.024	0.03	10.3	343	12	16	0.016
F12	18.6	6.9	523	655	242	7.4	<4	90	39	0.130	0.054	0.09	13.7	295	62	10	0.017
F13	14.2	7.6	796	763	281	7.5	<2	104	44	0.143	0.054	<0.01	12.4	343	75	18	0.018
Mean	14.2	7.3	451	588	209	6.9	1	83	28	0.126	0.048	0.02	10.5	255	37	19	0.021
Median	14.2	7.3	459	602	215	5.6	2.0	85	30	0.130	0.050	0.02	10.3	262	28	18	0.022
KCl	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	60000	117.6
Road Salt Affected Samples																	
S1	11.5	7.1	260	1564	475	218	3	166	80	0.152	0.129	0.03	16.7	579	46	416	0.255
S2	11.7	6.9	402	1363	454	59	2	156	70	0.107	0.055	0.01	19.0	554	28	150	0.096
S3	12.5	7.1	380	1876	395	224	18	134	47	0.370	0.100	0.07	17.5	482	42	392	0.102
S4	12.0	7.1	336	1944	419	224	19	126	43	0.310	0.090	0.09	16.5	511	42	352	0.104
S5	15.9	7.1	456	1484	363	111	7	92	34	0.149	0.025	<0.01	12.4	443	30	219	0.056
S6	14.0	7.2	156	1356	296	54	4	100	44	0.115	0.023	0.03	10.1	361	35	229	0.054
S7	13.4	7.1	215	1170	358	99	4	101	42	0.184	0.029	0.16	14.0	437	14	135	0.061
S8	11.2	7.0	507	1330	427	92	4	122	60	0.127	0.081	0.14	20.9	521	26	169	0.127
S9	11.2	7.2	453	1215	353	59	8	121	63	0.102	0.055	<0.02	18.6	431	41	167	0.143
S10	13.5	7.0	413	1297	421	204	7	73	32	0.069	0.036	0.07	18.7	514	48	170	0.076
S11	12.4	7.0	462	1700	403	191	7	128	54	0.140	0.063	0.07	16.6	492	42	301	0.151
S12	12.3	7.2	477	969	370	42	<5	100	49	0.124	0.062	0.09	16.8	451	34	84	0.050
S13	12.6	7.0	461	847	275	20	<5	101	48	0.203	0.055	0.10	10.6	335	137	44	0.036
Mean	12.6	7.1	383	1393	385	123	6	117	51	0.166	0.062	0.07	16.0	470	44	217	0.101
Median	12.4	7.1	413	1356	395	99	7	121	48	0.140	0.055	0.07	16.7	482	41	170	0.096
RS1	ND	ND	ND	138000	ND	35496	ND	ND	ND	ND	ND	ND	ND	ND	ND	54015	4.002
RS2	15.0	ND	ND	17040	75.0	6270	26	241	29	1.270	0.192	0.04	3.21	91.4	248	8930	0.630

I	F	NO ₃	NH ₄	TKN	Total N	PO ₄ -P	Fe	Mn	DOC	δ ¹⁸ O (‰)	δ D (‰)	δ ¹³ C DIC(‰)	Cl/Br Ratio	Cl/I Ratio	I/Na Ratio
0.0029	<0.1	0.43	0.41	0.65	1.08	<0.1	<0.01	<0.004	ND	-3.75	-21.2	ND	20	35	0.00953
0.0017	<0.1	0.49	0.29	1.01	1.50	<0.1	<0.01	<0.001	ND	-8.75	-61.5	-17.2	50	120	0.00835
0.0015	<0.1	0.44	0.43	1.08	1.52	<0.1	<0.01	0.008	1.0	-6.66	-34.7	ND	63	137	0.00365
0.0013	<0.1	0.42	0.44	0.32	0.74	<0.1	<0.01	0.004	ND	-3.41	-18.3	ND	56	228	0.01314
0.0018	NC	0.44	0.39	0.76	1.21	0.0	NC	NC	NC	-5.64	-33.9	NC	47	130	0.00867
0.0016	<0.1	0.44	0.42	0.83	1.29	<0.1	<0.01	0.003	NC	-5.20	-28.0	NC	53	129	0.00600
0.0019	<0.01	0.43	<0.01	0.08	0.51	<0.1	<0.01	<0.002	0.7	-5.78	-35.7	-12.2	112	858	0.00113
0.0019	0.1	0.21	<0.01	<0.01	0.21	<0.1	<0.01	<0.002	0.6	-5.88	-39.1	-13.2	68	372	0.00188
0.0039	ND	<1.6	ND	ND	NC	ND	0.84	0.130	1.4	-6.86	-43.8	-11.5	45	229	0.00013
0.0013	ND	<1.2	0.81	ND	NC	<1.4	7.20	0.090	2.4	-6.94	-46.3	-6.90	521	5393	0.00009
0.0091	ND	<1.7	ND	ND	NC	<1.0	1.37	0.210	1.8	-6.62	-41.0	-16.0	248	736	0.00020
0.0130	ND	<1.6	0.02	0.59	0.59	ND	1.43	0.070	2.1	-6.70	-44.6	-15.0	26	62	0.00027
0.0260	ND	<1.7	1.04	3.15	3.15	<1.0	2.16	0.220	1.9	-6.50	ND	-16.7	131	377	0.00037
0.0029	0.4	<0.02	<0.01	0.24	0.24	<0.1	1.10	0.055	<1.0	-8.32	-55.8	-11.9	389	4084	0.00042
0.0037	0.9	0.14	0.13	0.14	0.28	<0.1	<0.01	0.009	<1.0	-7.74	-53.8	-13.8	81	648	0.00028
0.0187	0.9	0.08	<0.01	0.05	0.13	ND	<0.01	0.003	ND	-7.11	-52.0	-10.8	56	107	0.00021
0.0047	0.4	0.13	0.28	0.28	0.41	<0.1	0.35	0.134	1.7	-7.25	-44.5	-9.60	141	677	0.00015
0.0006	0.3	<0.02	0.05	0.11	0.11	<0.1	0.02	<0.01	3.7	-13.6	-114.7	-10.8	23	5853	0.00026
0.0284	2.0	<0.02	0.37	1.97	1.97	<0.1	0.09	0.030	9.0	-15.8	-110.7	-13.7	39	232	0.00024
0.0033	0.2	<0.02	1.06	2.80	2.80	ND	3.00	0.094	6.8	-6.54	-43.5	-4.20	173	2789	0.00028
0.0096	0.4	NC	0.31	0.78	0.81	NC	1.46	0.087	2.6	-8.33	-54.2	-11.7	156	1766	0.00024
0.004327	0.4	0.13	0.325	0.28	0.41	<0.1	1.24	0.090	2.1	-7.02	-46.3	-11.7	106	663	0.00025
<0.0016	0.1	6.51	<0.01	0.23	6.74	<0.1	<0.01	<0.004	1.8	-6.36	-42.5	-8.33	1974	NC	NC
ND	0.1	12.6	0.01	1.49	14.1	<0.1	<0.01	0.002	ND	-6.70	-42.8	-7.59	NC	NC	NC
ND	0.09	0.51	0.04	0.35	0.86	<0.1	<0.01	0.026	ND	-6.67	-40.5	-6.44	NC	NC	NC
<0.0013	0.2	11.3	2.28	2.21	13.6	ND	<0.01	0.003	21	-6.68	-42.7	-8.36	1388	NC	NC
<0.0011	0.1	14.6	<0.01	2.83	17.4	ND	<0.01	0.004	11	-6.41	-39.4	-7.89	805	NC	NC
<0.0011	<0.2	7.25	<0.01	<0.01	7.25	ND	<0.01	<0.005	0.6	-5.96	-41.3	-6.09	995	NC	NC
0.0074	0.6	8.80	<0.01	0.02	8.82	ND	<0.01	<0.005	ND	-6.35	-39.6	-11.9	108	853	0.00030
0.0010	<0.1	2.07	<0.01	<0.01	2.07	ND	0.03	0.260	0.6	-6.44	-41.8	-9.50	235	5486	0.00032
<0.0010	<0.1	17.8	<0.01	0.46	18.3	ND	<0.01	0.281	0.6	-6.36	-40.2	-10.2	577	NC	NC
<0.0009	<0.1	23.1	<0.01	<0.01	23.1	ND	<0.01	<0.005	0.7	-6.04	-37.7	-10.6	628	NC	NC
0.0007	<0.1	12.0	0.02	0.77	12.8	ND	<0.01	<0.005	0.9	-5.66	-34.4	-11.5	974	23591	0.00031
ND	0.4	9.52	0.03	3.46	13.0	<0.1	<0.01	<0.010	2.9	-6.74	-43.4	-8.5	611	NC	NC
ND	<0.5	12.2	<0.01	1.18	13.4	<0.1	<0.01	<0.010	1.1	-6.49	-41.9	-7.44	1000	NC	NC
NC	NC	6.58	0.18	1.00	12.0	NC	NC	0.044	3.2	-6.37	-40.6	-8.80	715	2302	NC
<0.0011	0.1	11.3	<0.01	0.98	13.0	<0.1	<0.01	0.015	1.0	-6.41	-41.3	-8.36	805	5486	NC
<0.6327	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	510	NC	NC
0.0648	0.3	0.45	<0.01	0.19	0.64	<0.1	0.20	0.028	<1.0	-7.93	-53.6	-15.7	1631	6419	0.00030
<0.0049	0.1	3.89	<0.01	<0.01	3.89	<0.1	<0.01	<0.004	<1.0	-7.84	-51.7	-15.6	1560	NC	NC
<0.0070	<0.01	1.10	0.06	0.13	1.23	<0.1	<0.01	0.010	2.6	-6.29	-44.4	-16.0	3843	NC	NC
<0.0700	0.13	1.44	<0.01	ND	1.44	<0.1	0.01	<0.010	ND	-6.46	-43.8	-16.1	3385	NC	NC
0.0036	<0.1	7.25	0.01	0.01	7.26	<0.1	<0.01	<0.002	1.8	-8.35	-54.5	-12.3	3942	60380	0.00003
0.0023	<0.1	0.08	0.03	0.19	0.27	<0.1	0.22	0.003	0.8	-8.45	-55.9	-12.8	4225	100970	0.00004
0.0033	<0.1	4.55	<0.01	<0.01	4.55	<0.1	0.10	0.009	1.3	-8.17	-53.2	-14.0	2230	41096	0.00003
0.0042	0.2	7.53	<0.01	0.19	7.72	<0.1	<0.01	<0.001	0.7	-8.65	-55.9	-13.3	1331	39915	0.00005
<0.0040	<0.1	12.1	0.01	0.01	12.1	<0.1	<0.01	0.001	0.5	-8.86	-56.9	-10.4	1164	NC	NC
<0.0040	<0.1	6.27	<0.01	<0.01	6.27	<0.1	0.03	<0.001	0.9	-8.50	-57.6	-13.3	2232	NC	NC
0.0109	<0.1	14.2	<0.01	<0.01	14.2	<0.1	<0.01	<0.001	1.3	-8.33	-50.7	-13.1	1989	27562	0.00006
0.0017	<0.1	7.70	0.07	0.45	8.15	<0.1	<0.01	<0.001	0.8	-8.75	-55.9	-11.4	1687	50392	0.00004
0.0027	0.4	3.60	<0.01	<0.01	3.60	<0.1	0.16	0.114	7.6	-8.63	-55.9	-14.1	1199	16274	0.00013
NC	NC	6.66	0.01	0.09	5.89	NC	NC	NC	1.4	-8.09	-53.1	-13.7	2340	26385	NC
0.0023	0.2	4.55	0.03	0.19	4.55	<0.1	<0.01	<0.004	1.1	-8.35	-54.5	-13.3	1989	40505	0.00004
<0.3600	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	13497	NC	NC
<0.0376	<1	2.26	ND	ND	NC	<1	0.01	0.040	ND	-13.6	-102	ND	14175	NC	NC

(Continued)

Table 2. (Continued). Database for the characterization and identification of sodium and chloride in natural waters of Illinois.

Sample ID	Temp. ° C	pH pH units	Eh mV	Sp.Cond. S/cm	Alkalinity (CaCO ₃)	Na	K	Ca	Mg	Sr	Ba	B	SiO ₂	HCO ₃	SO4	Cl	Br
Septic Effluent and Water Affected by Effluent																	
E1	ND	ND	ND	15400	459	2740	26	495	300	5.650	0.380	0.23	16.4	560	19	5620	1.04
E2	4.40	7.1	ND	1753	443	184	9	84	53	0.770	0.040	0.48	18.6	540	38	308	0.18
E3	10.0	7.5	321	1840	402	416	11	84	19	0.220	0.100	0.97	20.4	490	52	504	0.28
E4	12.8	7.5	355	1246	513	224	12	33	10	0.070	0.030	0.05	23.5	626	38	91	0.20
E5	9.20	7.5	51	1699	501	262	22	64	23	0.140	0.030	0.77	13.2	611	73	253	0.11
E6	12.0	8.6	365	1723	385	80	345	59	6.5	0.140	0.040	0.13	29.5	469	59	92	0.71
E7	ND	ND	ND	ND	598	46	17	60	41	0.660	0.130	0.08	13.6	729	22	35.5	0.09
E8	ND	ND	ND	ND	504	191	15	49	6	2.209	0.040	0.47	16.9	614	51	49.3	0.09
E9	ND	ND	ND	ND	139	98	23	46	22	0.170	0.030	0.15	30.2	169	92	91.7	0.14
E10	ND	ND	ND	ND	306	55	6	70	39	0.530	0.150	0.21	23.4	373	24	20.8	0.05
E11	25.6	6.8	253	1031	327	89	17	67	26	0.280	0.060	1.15	12.9	399	95	69.1	0.10
E12	23.0	7.4	341	816	202	94	14	61	23	0.210	0.020	0.19	14.1	246	94	55.5	0.06
E13	20.0	7.3	324	1225	346	115	17	69	24	0.210	0.020	0.70	16.6	422	130	84.3	0.08
E14	22.8	7.1	334	913	210	89	12	71	24	0.260	0.060	1.29	9.62	256	112	86.7	0.15
E15	26.5	6.8	370	837	130	79	18	68	26	0.260	0.050	0.17	17.5	158	107	61.5	0.08
E16	24.6	6.9	349	819	117	70	16	68	26	0.250	0.050	0.18	14.9	143	77	63.2	0.06
E17	26.0	6.9	614	805	150	69	9	73	24	0.280	0.070	0.29	6.66	183	97	79.0	<0.05
E18	23.7	6.6	602	1148	118	77	28	118	24	0.280	0.050	0.39	9.60	144	84	147	ND
E19	24.9	6.9	348	833	203	82	18	70	27	0.300	0.050	1.73	9.26	248	109	66.5	0.22
E20	22.8	7.1	377	1101	264	82	16	120	27	0.350	0.030	0.30	20.7	322	94	118	ND
E21	26.4	7.1	332	951	261	88	16	67	24	0.280	0.040	1.00	9.51	318	109	67.5	0.12
E22	25.3	6.8	587	978	196	90	25	89	26	0.300	0.400	0.78	12.1	239	97	110	<0.05
E23	24.2	7.1	332	1386	ND	46	257	27	2.3	0.110	0.020	0.90	10.8	NC	84	88.9	0.07
E24	28.0	6.5	-11	1983	368	255	33	66	24	0.290	0.100	0.33	7.89	449	92	312	ND
E25	21.7	5.8	-10	1198	ND	88	23	107	26	0.340	0.080	0.60	18.7	NC	26	30.8	0.07
E26	3.70	7.3	-31	2894	608	399	12	112	25	0.240	0.060	0.79	18.0	741	12	618	0.36
E27	7.90	7.6	281	1721	416	124	281	34	7.0	0.150	0.050	0.05	31.0	507	82	123	0.05
E28	10.3	7.5	-15	1238	487	70	8	142	21	0.260	0.100	0.80	31.0	594	8.4	105	0.09
E29	ND	7.4	179	ND	472	393	6	17	7.5	ND	ND	ND	21.6	575	48	324	<0.05
Mean	18.8	5.9	229	1570	315	231	45	86	32	0.520	0.079	0.52	17.2	384	70	334	0.15
Median	22.8	7.1	332	1212	346	89	17	68	24	0.270	0.050	0.43	16.6	422	83	91	0.10
Em1	11.1	7.3	331	749	341	21	3	105	45	0.120	0.030	0.08	13.8	416	54	50.6	0.10
Em2	7.40	7.2	253	798	333	19	4	101	43	0.100	0.030	0.05	13.1	406	56	39.7	0.08
Em3	0.50	7.5	ND	1185	387	75	13	111	47	0.240	0.080	0.15	11.6	472	77	116	0.29
Cull	ND	ND	ND	130195	3.04	38200	544	48	1.1	0.700	0.010	0.06	0.64	ND	8.2	83548	24.3
MIS	ND	ND	ND	ND	ND	24653	ND	ND	ND	ND	ND	ND	ND	ND	ND	37514	6.632
Animal Waste and Affected Water																	
A1	ND	6.8	ND	29130	8210	493	2760	343	70	0.820	0.040	ND	68.5	10010	797	900	0.544
A2	ND	8.0	ND	11400	4300	348	2010	34	3.1	0.087	0.023	2.43	33.4	5243	1.9	794	0.823
A3	ND	7.8	ND	38200	18.3	1190	4950	26	0.9	0.073	0.031	5.11	50.1	22.3	47	1980	1.413
A4	ND	7.3	344	5230	1620	110	1030	87	95	0.220	0.060	4.80	45.0	1975	2.1	440	0.739
Mean	NC	7.5	NC	20990	3537	535	2688	123	42	0.300	0.038	3.08	49.2	4313	212	1028	0.880
Median	NC	7.6	NC	20265	2960	420	2385	61	37	0.154	0.036	4.80	48	3609	25	847	0.781
Am1	15.8	6.9	432	1718	410	66	2	205	64	0.530	0.300	<0.02	22.5	500	59	127	0.515
Am2	14.5	6.8	ND	929	412	45	2	127	32	0.200	0.090	<0.02	18.2	502	15	33	0.118
Am3	15.2	6.8	417	894	304	65	2	107	20	0.190	0.110	<0.02	16.5	371	21	38	0.132
Am4	15.6	6.9	396	1232	410	102	2	113	44	0.260	0.100	<0.02	17.9	500	36	51	0.149
Am5	10.1	6.6	-242	2240	574	70	2	275	117	0.349	0.199	0.03	11.1	700	52	280	0.368
Am6	11.1	7.1	-228	1616	697	113	23	116	84	0.471	0.417	0.15	21.2	850	22	171	0.216
Am7	17.5	7.0	ND	1316	269.6	15	<1	173	70	0.241	0.128	<0.01	10.4	329	75	50	0.098
Am8	19.0	7.1	ND	1181	322.5	13	3	156	68	0.177	0.050	<0.01	7.78	393	151	65	0.107
Am9	14.7	7.1	568	1440	526	27	6	192	100	0.200	0.103	<0.01	ND	641	236	69	0.152
Am10	18.6	6.9	488	1406	634	20	67	147	71	0.142	0.161	<0.01	ND	773	68	56	0.201
Am11	15.2	6.9	542	1175	444	18	87	125	49	0.151	0.048	<0.01	ND	541	38	37	0.084
Landfill Leachate and Affected Water																	
L1	ND	ND	ND	ND	6560	4420	1460	53	216	11.3	0.399	11.7	73.9	7998	28	6170	22.92
L2	ND	ND	ND	ND	3120	1370	161	423	373	17.2	0.754	11.2	36.8	3804	0.5	838	7.852
L3	ND	ND	ND	ND	3120	2960	1070	35	119	12.1	0.468	9.60	25.9	3804	10	4550	42.76
L4	ND	ND	ND	ND	673	69	<5	146	104	0.916	0.643	0.31	63.0	821	0.4	198	2.000
L5	ND	6.9	ND	4340	1720	471	94	225	121	2.660	0.804	1.52	41.1	2097	85	444	1.480
L6	ND	8.1	ND	22000	6205	2860	1080	50	154	0.890	0.348	12.4	60.9	7565	9.0	3920	19.50
L7	15.9	6.4	154	2550	1129	189	28	226	143	0.881	0.343	0.95	25.9	1376	103	216	1.175
L8	13.6	6.5	153	2911	1301	218	46	185	163	0.841	0.299	1.23	25.3	1586	22	286	3.349

I	F	NO ₃	NH ₄	TKN	Total N	PO ₄ -P	Fe	Mn	DOC	δ ¹⁸ O (‰)	δ D (‰)	δ ¹³ C DIC(‰)	Cl/Br Ratio	Cl/I Ratio	I/Na Ratio
<0.0070	ND	0.11	32.7	ND	32.8	ND	0.22	0.130	ND	-7.56	-54.2	-8.73	5404	NC	NC
0.0130	0.4	0.07	18.1	ND	18.2	ND	0.10	0.030	ND	-7.01	-50.5	-10.6	1711	23692	0.00007
0.0386	0.4	<0.10	16.9	19.2	16.9	11.5	0.11	0.030	13	-4.64	-33.3	-13.7	1821	13070	0.00009
0.0342	0.3	<0.02	34.8	1.06	34.8	15.4	0.17	0.040	7.9	-4.22	-31.3	-10.8	448	2657	0.00015
0.0073	1.0	0.26	45.6	10.2	45.9	48.0	0.45	0.530	20	-7.38	-54.2	-8.60	2255	34473	0.00003
0.0110	0.2	70.1	0.03	0.03	70.1	ND	0.01	<0.010	1.5	ND	ND	ND	130	8336	0.00014
ND	ND	0.38	66.5	ND	66.9	8.98	0.07	0.070	ND	ND	ND	ND	394	NC	NC
ND	ND	14.8	19.4	ND	34.2	3.27	0.03	0.100	ND	ND	ND	ND	548	NC	NC
ND	ND	7.75	1.48	ND	9.2	16.5	0.09	0.040	ND	ND	ND	ND	655	NC	NC
ND	ND	14.3	0.69	ND	15.0	6.62	0.03	0.010	ND	ND	ND	ND	416	NC	NC
ND	ND	1.66	34.6	ND	36.3	5.03	<0.01	<0.01	ND	ND	ND	ND	691	NC	NC
ND	ND	10.2	0.09	ND	10.3	3.63	<0.01	<0.01	ND	ND	ND	ND	925	NC	NC
ND	ND	0.53	36.5	ND	37.0	5.35	<0.01	<0.01	ND	ND	ND	ND	1054	NC	NC
ND	ND	0.70	8.21	ND	8.91	3.33	<0.01	<0.01	ND	ND	ND	ND	578	NC	NC
ND	ND	8.59	0.23	ND	8.82	8.99	<0.01	<0.01	ND	ND	ND	ND	769	NC	NC
ND	ND	25.9	0.14	ND	26.0	7.27	<0.01	<0.01	ND	ND	ND	ND	1053	NC	NC
ND	ND	7.65	0.10	ND	7.75	1.77	<0.01	<0.01	ND	ND	ND	ND	NC	NC	NC
ND	ND	25.4	0.09	ND	25.5	6.10	<0.01	<0.01	ND	ND	ND	ND	NC	NC	NC
ND	ND	0.56	2.29	ND	2.85	4.02	<0.01	<0.01	ND	ND	ND	ND	302	NC	NC
ND	ND	<0.10	4.84	ND	4.84	1.38	<0.01	<0.01	ND	ND	ND	ND	NC	NC	NC
ND	ND	0.07	17.4	ND	17.5	5.04	<0.01	<0.01	ND	ND	ND	ND	562	NC	NC
ND	ND	4.38	0.29	ND	4.67	8.78	<0.01	0.010	ND	ND	ND	ND	NC	NC	NC
ND	ND	0.20	40.8	ND	41.0	5.44	<0.01	<0.01	ND	ND	ND	ND	1270	NC	NC
ND	ND	0.83	43.0	ND	43.8	8.40	1.12	0.100	ND	ND	ND	ND	NC	NC	NC
ND	ND	2.14	21.2	ND	23.3	5.62	2.93	0.290	ND	ND	ND	ND	440	NC	NC
ND	ND	0.10	42.7	ND	42.8	5.67	0.90	0.260	ND	ND	ND	ND	1717	NC	NC
ND	ND	29.3	14.7	ND	44.0	8.55	0.20	0.130	ND	ND	ND	ND	2460	NC	NC
ND	ND	0.05	25.0	ND	25.0	3.00	0.80	0.100	ND	ND	ND	ND	1167	NC	NC
ND	ND	130	ND	ND	130	34.5	0.42	0.780	ND	ND	ND	ND	NC	NC	NC
NC	NC	6.18	18.2	NC	30.5	8.35	NC	NC	NC	NC	NC	NC	923	NC	NC
0.0130	0.4	1.90	17.2	5.63	25.5	5.88	0.18	0.100	10	-7.01	-50.5	-10.6	769	13070	0.00009
0.0090	0.04	0.56	0.05	ND	0.61	ND	<0.01	0.010	ND	-7.33	-52.3	-13.2	533	5622	0.00042
0.0070	0.12	0.63	<0.01	ND	0.63	ND	<0.01	<0.010	ND	-7.03	-49.1	-12.9	509	5671	0.00037
0.0360	0.11	0.45	0.22	ND	0.67	ND	0.04	0.190	ND	-6.36	-46.0	-9.57	403	3222	0.00048
<0.4140	ND	ND	ND	ND	NC	ND	0.05	0.040	0.001	ND	ND	ND	3438	NC	NC
1.0557	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	5656	35536	0.00004
0.1877	<1.2	<0.25	3670	ND	3670	1050	5.70	1.100	ND	-2.90	ND	7.90	1654	4794	0.00038
0.3284	<0.5	<0.1	323	677	677	213	0.30	0.036	557	1.10	-5.30	25.8	965	2418	0.00094
0.2631	<1	<0.2	1806	4352	4352	1300	2.06	0.011	3150	-0.07	-2.20	37.1	1401	7526	0.00022
0.1824	<0.2	0.19	143	182	182	111	3.76	0.485	220	-1.99	-28.3	-2.00	595	2412	0.00166
0.2404	NC	NC	1486	1303	2220	669	2.96	0.408	982	-0.97	-8.95	17.2	1154	4288	0.00080
0.2254	<0.8	<0.22	1065	677	2174	632	2.91	0.261	557	-1.03	-5.30	16.9	1183	3606	0.00066
0.0210	0.19	80.9	0.05	4.48	85.4	<0.1	<0.01	0.010	1.3	-6.50	-42.4	-13.2	247	6048	0.00032
0.0388	0.20	15.4	0.01	0.48	15.9	<0.1	<0.01	<0.010	5.7	-2.87	-25.6	-12.3	276	840	0.00087
0.0174	0.18	21.4	0.02	0.02	21.4	<0.1	<0.01	<0.010	2.9	-5.99	-42.7	-13.5	291	2205	0.00027
0.0168	0.31	36.0	0.02	0.62	36.6	<0.1	<0.01	<0.010	2.9	-6.32	-40.2	-13.2	345	3045	0.00017
0.0433	0.1	12.7	<0.01	0.54	13.2	ND	0.01	0.537	15	-4.96	-36.2	6.96	761	6472	0.00062
0.0778	0.2	0.05	13.4	47.0	47.0	ND	0.48	0.062	35	-5.78	-38.5	11.4	791	2199	0.00069
0.0016	0.2	82.8	0.06	5.52	88.3	ND	<0.01	<0.005	2.2	-6.71	-45.5	-10.9	513	31879	NC
<0.0017	0.2	19.0	<0.01	15.8	34.8	ND	<0.01	0.671	1.4	-7.08	-44.0	-9.08	613	NC	NC
0.0126	<0.4	5.59	0.05	13.8	19.4	<0.2	<0.01	0.610	26	-7.06	-45.6	-11.6	456	5474	0.00047
0.0351	<0.4	0.02	21.8	30.0	30.0	<0.2	8.30	0.410	38	-7.17	-47.6	-11.5	280	1611	0.00171
0.0219	<0.4	18.7	0.02	5.11	23.8	<0.2	<0.01	0.080	4.8	-6.74	-42.6	-16.1	436	1669	0.00122
5.4130	<5	<0.01	ND	ND	NC	<1	5.43	60.00	ND	-8.09	-13.3	22.0	269	1140	0.00122
0.9913	0.3	0.30	ND	ND	NC	1.5	28.2	3.310	ND	-6.73	-40.9	1.68	107	845	0.00072
1.1181	<0.1	0.10	ND	ND	NC	<0.1	1.11	28.00	ND	-7.60	-14.0	20.2	106	4069	0.00038
ND	0.4	<0.02	ND	ND	NC	<0.1	<0.01	5.960	ND	-7.90	-53.1	-11.7	99	NC	NC
0.2556	0.8	<0.02	43.7	115	115	ND	0.18	1.230	111	-6.08	-39.1	14.3	300	1737	0.00054
2.6371	<0.1	<0.5	533	1487	1487	ND	3.76	0.042	1070	-8.91	10.8	17.9	201	1486	0.00092
0.5191	0.6	0.26	17.8	17.8	18.0	<0.1	15.9	0.564	25	-7.79	-47.9	13.6	184	416	0.00275
0.4301	<0.1	0.30	46.5	46.5	46.8	<0.1	6.25	0.234	49	-7.72	-38.8	16.7	85	665	0.00197

Continued

Table 2. (Continued). Database for the characterization and identification of sodium and chloride in natural waters of Illinois.

Sample ID	Temp. °C	pH pH units	Eh mV	Sp.Cond. S/cm	Alkalinity (CaCO ₃)	Na	K	Ca	Mg	Sr	Ba	B	SiO ₂	HCO ₃	SO ₄	Cl	Br
Landfill Leachate and Affected Water																	
L9	ND	7.9	398	22409	6910	3310	920	28	128	0.480	0.700	17.8	58.7	8425	8.0	4230	11.80
L10	ND	7.1	412	9310	2570	1180	280	21	64	0.500	1.380	9.44	39.6	3133	16	1730	7.774
Mean	NC	4.3	112	6352	3331	1705	514	139	158	4.777	0.614	7.62	45.1	4061	28	2258	12.06
Median	NC	7.0	276	6825	2845	1275	280	99	136	0.904	0.556	9.52	40.4	3469	13	1284	7.813
Lm1	10.4	7.0	170	1684	646	75	7	167	86	0.980	0.340	0.40	21.0	788	80	152	1.404
Lm2	11.0	7.3	241	1158	486	20	2	133	66	0.960	0.150	0.06	18.0	593	45	87	0.617
Lm3	ND	6.9	506	2583	851	242	114	218	147	1.460	0.060	1.5	15.0	1038	468	254	2.712
Lm4	ND	7.3	491	1187	268	48	13	99	98	6.090	0.055	0.18	8.21	327	401	17	0.215
Lm5	ND	ND	ND	ND	1290	171	<5	250	224	1.220	0.023	0.14	36.6	1573	390	112	1.300
Seawater and Affected Water																	
SW	ND	ND	ND	ND	ND	10770	380	412	1290	8.000	0.002	4.40	ND	140	2649	18800	67.00
SWb	ND	7.3	ND	28650	88	6000	328	281	729	3.480	0.009	1.94	5.07	107	1090	9480	25.64
SWm1	ND	7.8	ND	4000	335	591	20	69	121	0.887	0.349	0.32	34.7	409	9.4	1120	4.105
SWm2	ND	7.7	ND	1970	189	315	14	34	46	0.275	0.026	0.13	31.9	231	46	472	1.658
Saline Springs and Basin Brines																	
B1	ND	7.3	ND	19490	1145	4520	23	55	34	3.040	7.090	2.91	8.16	1396	<0.01	6517	5.807
B2	14.5	7.4	-142	2200	387	308	<1	96	38	0.660	0.490	0.23	14.3	472	<0.1	474	1.075
B3	13.3	7.6	36	1297	354	220	2	59	25	0.637	0.275	0.49	11.7	432	<0.01	237	0.560
B4	14.5	6.8	ND	23750	312	3510	91	661	309	25.70	0.150	2.59	10.6	380	531	8080	39.10
B5	14.4	6.7	-102	22363	245	3510	91	661	309	25.70	0.150	2.59	10.6	299	608	7058	33.50
B6	18.0	8.2	30	1732	248	167	5	135	24	1.280	0.090	0.13	22.7	302	87	292	1.350
B7	13.1	7.1	-198	23518	252	4820	34	590	175	1.270	0.280	0.45	9.56	307	783	8360	16.10
B8	13.3	7.3	51	1032	468	117	<1	74	37	0.760	0.560	0.39	14.9	570	<0.6	72	0.265
B9	11.2	7.0	241	7705	363	1220	40	433	141	14.20	0.049	0.85	7.31	442	215	1940	11.06
B10	14.0	7.1	465	1044	401	73	<1	127	58	0.307	0.081	0.02	12.4	489	129	109	0.300
B11	13.3	6.9	412	1230	417	72	<1	129	59	0.298	0.082	<0.01	12.4	508	134	113	0.445
B12	13.1	6.5	322	55300	262	8920	60	1410	560	43.20	6.260	1.10	10.1	319	21	17900	59.77
B13	14.1	7.4	87	987	342	127	<6.3	44	30	0.818	0.361	0.37	14.0	417	8.7	118	0.167
B14	ND	ND	ND	ND	2.0	100000	63	750	73	ND	ND	ND	ND	ND	1900.0	150000	17.00
B15	23.1	7.1	-185.0	ND	102.0	34500	88	2540	924	122	38.80	ND	9.6	124	ND	101500	197
B16	30.4	6.4	-175.0	ND	44.0	44400	86	4700	1290	200	0.320	ND	6.5	54	ND	89600	334
B17	ND	6.8	-287.0	ND	98.4	48540	280	4710	1720	199	0.750	3.40	9.4	120	720	85000	180
B18	ND	7.0	-140.0	ND	57.4	50280	282	5650	1640	242	0.550	4.00	11.4	70	590	89000	190
Mean	12.2	6.7	23.1	8980	306	16961	64	1268	414	48.9	3.130	1.08	10.9	372	318	31465	60.4
Median	14.1	7.1	30.0	2200	287	3510	63	512	107	3.04	0.320	0.67	10.6	380	373	6788	13.6

I	F	NO ³	NH ⁴	TKN	Total N	PO ⁴ -P	Fe	Mn	DOC	δ ¹⁸ O (‰)	δD (‰)	δ ¹³ C DIC(‰)	Cl/Br Ratio	Cl/I Ratio	I/Na Ratio
4.3750	2.0	1.40	1193	1456	1457	5.0	12.8	0.040	1500	-6.73	9.20	23.9	358	967	0.00132
1.7219	<1	1.10	418	429	430	1.0	3.05	<0.050	340	-7.82	-9.50	25.5	223	1005	0.00146
1.7461	NC	0.35	225	355	355	NC	7.67	9.938	310	-7.54	-23.7	14.4	193	1233	0.00113
1.1181	0.6	0.30	232	272	273	1.5	5.43	1.230	226	-7.755	-26.4	17.28	192	1005	0.00122
0.1670	0.24	0.07	3.33	ND	3.40	ND	5.89	0.130	ND	-7.46	-50.1	-4.20	108	910	0.00222
0.0880	0.22	0.06	0.64	ND	0.70	ND	0.88	0.030	ND	-7.38	-52.3	-13.5	140	983	0.00438
0.2349	0.2	2.90	10.1	12.5	15.4	<0.1	<0.01	0.460	18	-13.3	-90.1	-11.2	94	1081	0.00097
<0.0015	0.9	<0.02	0.23	0.25	0.25	<0.1	<0.01	0.030	3.7	-13.2		-6.80	80	NC	NC
ND	1.4	<0.02	ND	ND	NC	<0.1	<0.01	2.670	ND	-7.69	-56.0	-15.0	86	NC	NC
0.0600	1.3	ND	ND	ND	NC	ND	0.002	0.0002	0.85	ND	ND	ND	281	313333	0.00001
0.0462	<0.1	0.05	0.10	0.09	0.14	ND	<0.01	0.110	8.5	-6.43	-47.4	-4.37	370	205168	0.00001
0.1498	0.3	<0.02	2.60	2.68	2.68	ND	<0.01	0.238	21	-9.88	-68.9	-19.2	273	7474	0.00025
0.0321	0.3	0.44	0.19	0.22	0.66	ND	<0.01	0.353	12	-9.90	-70.6	-19.2	285	14693	0.00001
0.1630	<0.1	<0.02	2.28	3.15	3.15	ND	<0.01	<0.010	ND	ND	ND	25.6	1122	39982	0.00004
0.0866	0.1	<0.02	3.08	ND	3.08	ND	3.52	0.078	6.8	-7.46	-51.3	-4.10	441	5470	0.00028
0.1120	0.6	<0.02	1.10	1.73	1.73	<0.1	2.00	0.029	8.0	-7.10	-47.0	-8.20	423	2117	0.00051
0.1486	1.1	<0.02	ND	ND	NC	<1.0	<0.01	0.490	ND	-7.70	-56.1	-9.40	207	54366	0.00004
ND	ND	0.49	4.04	ND	4.53	ND	<0.01	0.490	ND	ND	ND	ND	211	NC	NC
ND	ND	3.99	0.14	ND	4.13	ND	<0.01	0.090	ND	ND	ND	ND	216	NC	NC
0.1507	<0.1	<0.02	0.01	1.94	1.94	ND	0.02	0.092	ND	-5.69	-37.5	-9.74	519	55458	0.00003
0.1260	ND	2.00	3.81	ND	5.81	ND	2.04	0.040	8.7	-7.40	-51.3	-3.60	272	573	0.00108
0.0497	0.3	<0.02	1.79	1.75	1.79	ND	0.21	0.024	13	-8.20	-56.4	-11.8	175	39055	0.00004
ND	0.3	<0.02	0.06	0.14	0.06	ND	<0.01	0.705	2.8	-6.35	-48.2	-12.5	363	NC	NC
0.0078	0.3	<0.02	0.08	0.14	0.08	ND	<0.01	0.789	3.2	-6.43	-48.4	-12.7	254	14513	0.00011
0.5395	<2.5	<0.5	9.32	9.32	9.32	ND	1.1	9.950	0.2	-5.96	-36.7	-11.5	299	33181	0.00006
0.0103	0.396	<0.06	2.20	ND	2.20	<0.2	0.82	0.058	2.2	-6.77	-43.3	-15.6	706	11450	0.00006
ND	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	8824	NC	NC
ND	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	515	NC	NC
ND	ND	ND	ND	ND	NC	ND	ND	ND	ND	ND	ND	ND	268	NC	NC
3.9	ND	0.1	120	ND	NC	ND	<0.06	0.600	ND	ND	ND	ND	472	21795	0.00008
8.6	ND	<0.04	70	ND	NC	ND	5.50	0.600	ND	ND	ND	ND	468	10349	0.00017
0.7719	0.2	0.36	12.1	1.01	2.10	NC	NC	0.776	2.5	-3.84	-26.5	-4.08	875	16017	0.00014
0.1373	0.3	1.25	2.24	1.75	2.64	NC	1.55	0.291	5.0	-6.9	-48.3	-9.74	393	18154	0.00007

P = precipitation

UZ = unsaturated zone

Aq = pristine groundwater

F = field tile water

KCl = potassium chloride ("potash")

S = groundwater contaminated with road salt

E = septic effluent

Em = groundwater contaminated with effluent

Cull = Culligan-brand water softener salt

MIS = Morton iodized salt

A = animal waste

Am = groundwater contaminated with animal waste

L = landfill leachate

Lm = groundwater contaminated with landfill leachate

SW = seawater (Krauskopf 1979)

SWb = Utsalady Bay water

SWm = groundwater contaminated with seawater

RS = brine made from road salt

B = saline water

ND = no data or not determined

NC = not calculated

ment operations and data collection were controlled using PeakNet 5.01 software. As with the cations, calibration check standard and a blank were analyzed with each sample set.

Ammonium was determined using the Berthelot Reaction, which involves the formation of a blue-colored indophenol compound in a solution of ammonia salt, sodium phenoxide, and sodium hypochloride. Following enhancement of the color using sodium nitroprusside, the color intensity was measured with a Bran and Luebbe TRAACS 2000 colorimeter at 660 nm. Total Kjeldhal Nitrogen (TKN) was determined by difference. Organic material was first oxidized in water, followed by digestion by NaOH to convert all organic nitrogen compounds to NH_3 . The NH_3 was then analyzed as above. Because this technique yields total nitrogen, a separate analysis of NO_2 and NO_3 yielded TKN by difference (Raveh and Avnemelech 1979).

Bromide and I^- were analyzed using the Neutron Activation Analysis (NAA) techniques described in Strellis et al. (1996) and Landsberger et al. (2003). Briefly, all samples were irradiated between 2 and 10 minutes in a TRIGA reactor with an epithermal flux of 1.1×10^{11} neutrons/cm/second² at 500 kw. Irradiated samples were counted for 15 minutes using a 30% germanium detector with a frequency width at half maximum of 1.95 keV (Landsberger et al. 2003).

Dissolved organic carbon in water samples was determined in accordance with Greenberg et al. (1987). Total dissolved carbon was measured by injecting a filtered water sample into a heated coil (950 °C), completely combusting the sample. The mass of the CO_2 driven off was determined using standard techniques.

The $\delta^{18}\text{O}$ of the water samples was determined using a modified version of the CO_2 - H_2O equilibration method originally described by Epstein and Mayeda (1953), with modifications described in Hackley et al. (1999). The δD of water was determined using Zn-reduction methods (Coleman et al. 1982, Vennemann and O'Neil 1993), with modifications described in Hack-

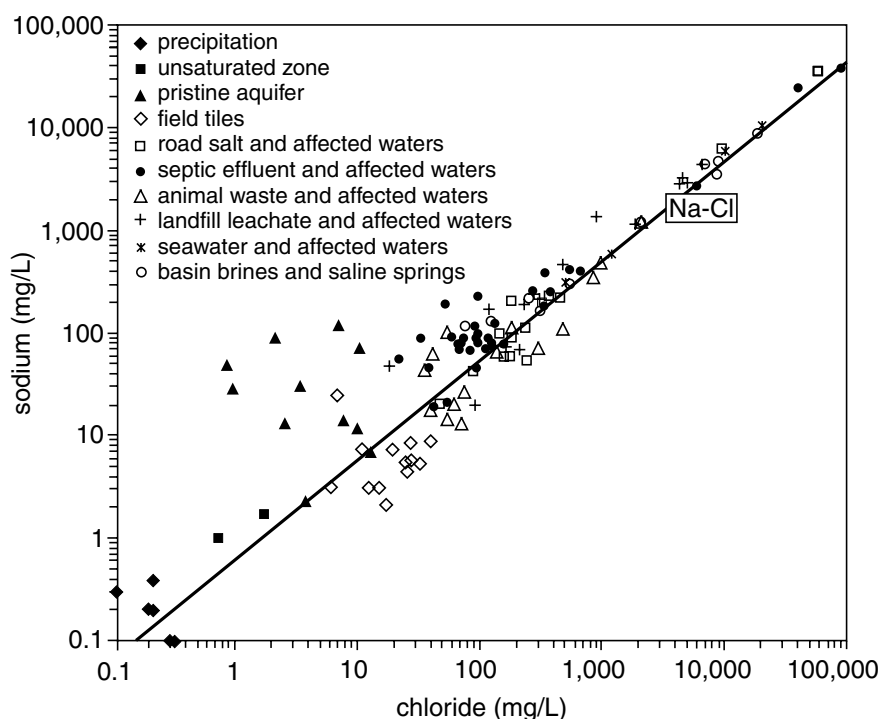


Figure 2 Scatter plot of the Na^+ and Cl^- concentrations showing an almost 1:1 relationship for all water samples.

ley et al. (1999). The $\delta^{13}\text{C}$ of dissolved inorganic carbon was determined by the gas evolution technique similar to that described by Atekwana and Krishnamurthy (1998).

Chemical and Isotopic Data

Data Tables

All sample location descriptions are presented in Table 1. All analytical data including field parameters, chemical compositions, isotopic compositions, and pertinent ion ratios for end member and affected water samples are presented in Table 2. A complete analysis of all of the data is presented in Panno et al. (in press).

Sodium and Chloride

Most of the water samples contained Na^+ and Cl^- concentrations that plotted along a line defined by the dissolution of NaCl (figure 2). Exceptions included samples of precipitation, soil water from an uninhabited area, and groundwater from apparently uncontaminated aquifers. These water

samples tended to be enriched in Na^+ relative to Cl^- ; the source of the additional Na^+ in the atmosphere is not known. We speculate that the sources of the additional Na^+ in the soil water and groundwater may be rock-water interactions with Na-clays and/or feldspars present as silt- and sand-size fragments in the soil zone and aquifer.

Background and sources samples were collected to characterize their chemical and isotopic compositions and ionic ratios. The Na^+ and Cl^- concentrations were smallest in precipitation and the largest in saturated road salt solutions (figure 3). Background concentrations of Na^+ and Cl^- in uncontaminated sand and gravel aquifers of northeastern Illinois were both 0–15 mg/L, with the threshold between background and anomalous at 15 mg/L (Panno et al. in press).

Stable Isotopes

Variations in δD and $\delta^{18}\text{O}$ revealed the effects of evaporation that typically occurs in animal waste lagoons or other surface water environments (Figure 4). Animal waste (stored in

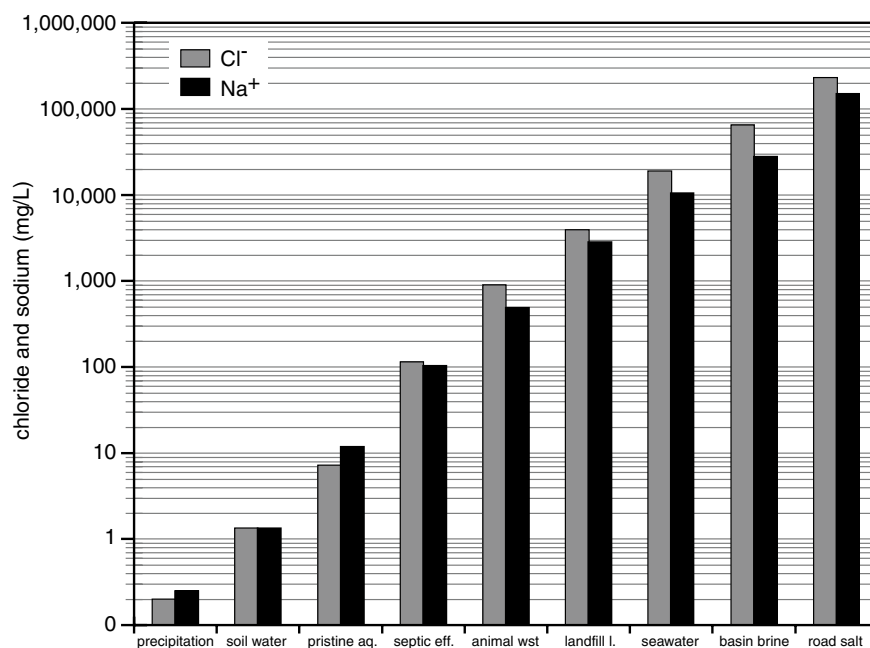


Figure 3 Bar graphs of the maximum Na^+ and Cl^- concentrations in all background waters, source waters, and sources examined in this investigation.

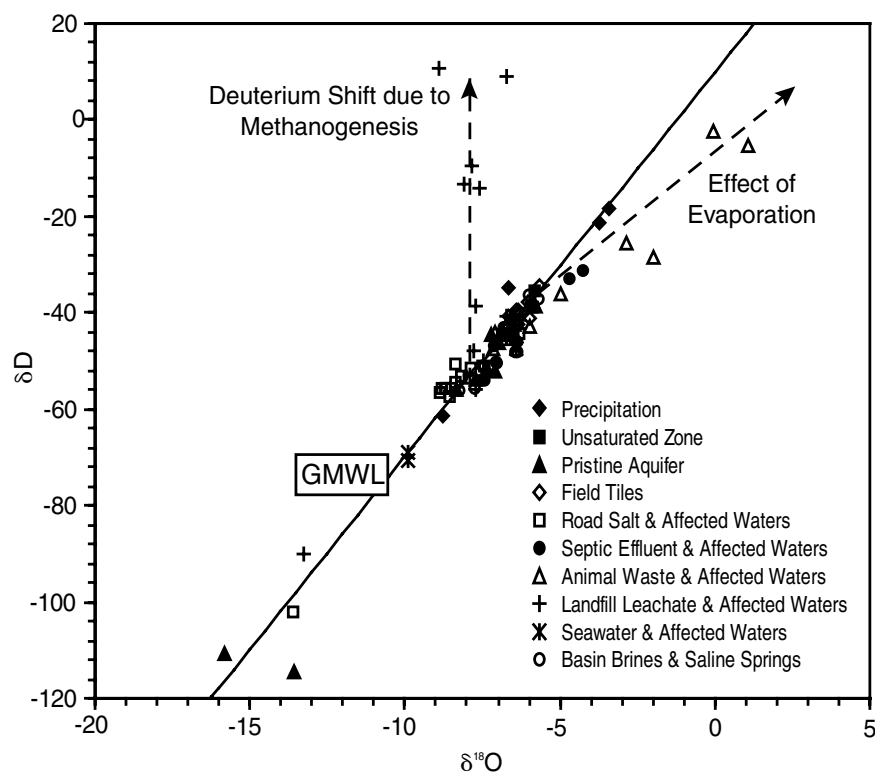


Figure 4 Stable isotopes δD vs. $\delta^{18}\text{O}$ showing that most water samples fall along the meteoric water line. The exceptions are deuterium-enriched landfill leachates (due to methanogenesis) and evaporation trends of the animal waste and septic effluent samples.

open lagoons), and septic effluent followed divergent linear trends below the meteoric water line indicative of evaporation. Samples of landfill leachate and waters affected by such leachate typically plotted well above the meteoric water line because of partitioning of hydrogen isotopes during biodegradation of the organic waste and microbial methane formation (methanogenesis) within the landfill (Hackley et al. 1996).

References

- Appelo, C.A.J., and D. Postma, 1994, *Geochemistry, groundwater and pollution*: Rotterdam, A.A. Balkema, 536 p.
- Atekwana, E.A., and R.V. Krishnamurthy, 1998, Seasonal variation of dissolved inorganic carbon and $\delta^{13}\text{C}$ of surface waters: Application of a modified gas evolution techniques: *Journal of Hydrology*, v. 205, p. 265–278.
- Back, W., M.J. Baedeker, and W.W. Wood, 1993, Scales in chemical hydrology: A historical perspective, in *Regional Ground-Water Quality*, W.W. Aley, ed.: New York, van Nostrand Reinhold, pp. 111–129.
- Banner, J.L., G.J. Wasserburg, P.F. Dobson, A.B. Carpenter, and C.H. Moore, 1989, Isotopic and trace element constraints on the origin and evolution of saline groundwater from central Missouri: *Geochimica et Cosmochimica Acta*, v. 53, pp. 383–398.
- Buttle, J.M., and C.F. Labadia, 1999, Deicing salt accumulation and loss in highway snowbanks: *Journal of Environmental Quality*, v. 28, pp. 155–164.
- Clark, I.D., and P. Fritz, 1997, *Environmental isotopes in hydrogeology*: New York, Lewis Press, 328 p.
- Cleary, R.W., 1978, Pollution of groundwater, in *Water problems of urbanizing areas*, Proceedings of the Research Conference, New England College, Henniker, New Hampshire, July 16–21, 1978: New York, The American Society of Civil Engineers, pp. 134–142.

- Coleman, M.L., T.J. Shepard, J.J. Rouse, and G.R. Moore, 1982, Reduction of water with zinc for hydrogen isotope analysis: *Analytical Chemistry*, v. 54, pp. 993–995.
- Davis, S.N., D.O. Whitemore, and J. Fabryka-Martin, 1998, Uses of chloride/bromide ratios in studies of potable water: *Ground Water*, v. 36, no. 2, pp. 338–350.
- Epstein, S., and T. Mayeda, 1953, Variation of ^{18}O content of waters from natural sources: *Geochemica et Cosmochemica Acta*, v. 4, pp. 213–224.
- Foos, A., 2003, Spatial distribution of road salt contamination of natural springs and seeps, Cuyahoga Falls, Ohio, USA: *Environmental Geology*, v. 44, pp. 14–19.
- Grootjans, A.P., R. van Diggelen, M.J. Wassen, and W.A. Wiesinga, 1988, The effects of drainage on groundwater quality and plant species distribution in stream valley meadows: *Vegetation*, v. 75, pp. 37–48.
- Hackley, K.C., C.L. Liu and D.D. Coleman, 1996, Environmental isotope characteristics of landfill leachates and gases: *Ground Water*, v. 34, pp. 827–836.
- Hackley, K.C., C.L. Liu, and D. Trainor, 1999, Isotopic identification of the source of methane in subsurface sediments of an area surrounded by waste disposal facilities: *Applied Geochemistry*, v. 14, pp. 119–131.
- Hwang, H.H., 1996, Source of saline groundwater in basal Pennsylvanian sandstones, southwestern Illinois: Implications for fluid mixing and water-rock interactions: Ph.D. thesis, University of Illinois, 139 p.
- Hwang, H.H., S.V. Panno, and K.C. Hackley, 2003, Effect of land usage on groundwater quality in McHenry County based on chemical and isotopic assessment: Preliminary results, in *Proceedings of the 13th Annual Research Conference of the Illinois Groundwater Consortium, Research on Agrichemicals in Illinois, Groundwater Status and Future Directions XIII*, Carbondale, Illinois, , April 22, 2003, 10 p.
- Illinois Department of Transportation, 1999, Illinois Department of Transportation maintenance policy manual, Springfield, Illinois, State of Illinois.
- Kelly, W.R., and S. Wilson, 2002, Temporal changes in shallow groundwater quality in northeastern Illinois, in *Proceedings of the 12th Annual Research Conference of the Illinois Groundwater Consortium, Research on Agrichemicals in Illinois, Groundwater Status and Future Directions XII*, Carbondale, Illinois, April 22, 2003, , 16 p.
- Krapac, I.G., W.S. Dey, W.R. Roy, B.G. Jellerichs, C. Smyth, 2000, Groundwater quality near livestock manure pits: *Proceedings of the 8th International Symposium on Animal, Agricultural and Food Processing Wastes*, October 9–11, 2000, Des Moines, Iowa, American Society of Agricultural Engineers, Publication 701P0002, pp. 710–718.
- Krapac, I.G., W.S. Dey, C.A. Smyth, W.R. Roy, 1998, Impacts of bacteria, metals, and nutrients on groundwater at two hog confinement facilities: *Proceedings of the National Groundwater Association Animal Feeding Operations and Groundwater: Issues, Impacts, and Solutions—A Conference for the Future*, November 4–5, St. Louis, Missouri, pp. 29–50.
- Krauskopf, K.B., 1979, *Introduction to geochemistry*: New York, McGraw-Hill Book Company, 617 p.
- Landsberger, S., D.J. O’Kelly, and S. Panno, 2003, Determination of bromine, chlorine, and iodine in environmental aqueous samples by epithermal neutron activation analysis and Compton suppression: *Transactions of the American Nuclear Society*, v. 89, pp. 735–736.
- Larson, T.J., I.G. Krapac, W.W. Dey, and C.J. Suchomski, 1997, Electromagnetic terrain conductivity surveys used to screen swine confinement facilities for groundwater contamination: *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems*, Reno, Nevada, March 23–26, pp. 271–279.
- Mason, C.F., S.A. Norton, I.J. Fernandez, and L.E. Katz, 1999, Deconstruction of the chemical effects of road salt on stream water chemistry: *Journal of Environmental Quality*, v. 28, pp. 82–91.
- Moyland, R.L., 1980, City examines effects of road salting on its water supply: *City of Worcester, Massachusetts Public Works*, v. 111, no. 8, pp. 59–60.
- Naftz, D.L., and L.E. Spangler, 1994, Salinity increases in the Navajo Aquifer in southeastern Utah: *Water Resources Bulletin*, v. 30, no. 6, pp. 1119–1135.
- Panno, S.V., K.C. Hackley, and S. Greenberg, 2002, Source identification of sodium and chloride in natural waters: Preliminary results, in *Proceedings of the 12th Annual Research Conference of the Illinois Groundwater Consortium, Research on Agrichemicals in Illinois, Groundwater Status and Future Directions XII*, Carbondale, Illinois, April 22, 2002, 25 p.
- Panno, S.V., K.C. Hackley, H.H. Hwang, S. Greenberg, I.G. Krapac, S. Landsberger, and D.J. O’Kelly, Characterization and identification of Na-Cl sources in groundwater: *Ground Water*, in press.
- Panno, S.V., K.C. Hackley, C.-L. Liu, and K. Cartwright, 1994, Hydrochemistry of the Mahomet Bedrock Valley Aquifer, east-central Illinois: Indicators of recharge and groundwater flow: *Ground Water*, v. 32, no. 4, pp. 591–604.
- Panno, S.V., K.C. Hackley, and V.A. Nuzzo, 1998, Teaching of multidisciplinary environmental science in a wetland setting: *Journal of Geological Education*, v. 46, no. 2, pp. 157–163.
- Panno, S.V., I.G. Krapac, C.P. Weibel, and J.D. Bade, 1996, Groundwater contamination in karst terrain of southwestern Illinois: *Illinois State Geological Survey, Environmental Geology Series 151*, 43 p.

- Panno, S.V., V.A. Nuzzo, K. Cartwright, B.R. Hensel, and I.G. Krapac, 1999, Changes to the chemical composition of groundwater in a fen-wetland complex caused by urban development: *Wetlands*, v. 19, no. 1, pp. 236–245.
- Pfaff, J.D., 1993, Method 300.0: Determination of inorganic anions in water by ion chromatography, Revision 2.1: Cincinnati, Ohio, U.S. Environmental Protection Agency, 30 p.
- Raveh, A., and Y. Avnemelech, 1979, Total nitrogen analysis in water, soil and plant material with persulfate oxidation: *Water Research*, v. 13, p. 911.
- Richter, B.C., and C.W. Kreitler, 1993, Geochemical techniques for identifying sources of ground-water salinization: Boca Raton, C.K. Smoley, 258 p.
- Salt Institute, 2003. www.saltinstitute.org.
- Strellis, D.A., H.H. Hwang, T.F. Anderson, and S. Landsberger, 1996, A comparative study of IC, ICP–AES and NAA measurements of chlorine, bromine and sodium in natural waters: *Journal of Radioanalytical Nuclear Chemistry*, v. 211, pp. 473–484.
- Vennemann, T.W. and J.R. O'Neil, 1993, A simple and inexpensive method of hydrogen isotope and water analyses of minerals and rocks based on zinc reagent: *Chemical Geology*, v. 103, pp. 227–234.
- Whittemore, D.O., 1995, Geochemical differentiation of oil and gas brine from other saltwater sources contaminating water resources: Case studies from Kansas and Oklahoma: *Environmental Geosciences*, v. 2, no. 1, pp. 15–31.
- Wilcox, D.A., 1986a, The effects of deicing salts on vegetation in Pinhook Bog, Indiana: *Canadian Journal of Botany*, v. 64, pp. 865–874.
- Wilcox, D.A., 1986b, The effects of deicing salts on water chemistry in Pinhook Bog, Indiana: *Water Resources Bulletin*, v. 22, pp. 57–65.
- Willman, H.B., and J.N. Payne, 1942, Geology and mineral resources of the Marseilles, Ottawa, and Streator Quadrangles: Illinois State Geological Survey, Bulletin, no. 66, p. 31.
- Wood, W.W., 1981, Guidelines for collection and field analysis of groundwater samples for selected unstable constituents, *in* *Techniques of Water-Resources Investigations of the U.S. Geological Survey*, Book 1, Chapter D2, 24 p.