Prepared in cooperation with North Dakota State University

Chemical and Biotic Characteristics of Prairie Lakes and Large Wetlands in South-Central North Dakota—Effects of a Changing Climate

Scientific Investigations Report 2015–5126

U.S. Department of the Interior
U.S. Geological Survey

Cover. Lakes and wetlands in the Crystal Springs area of North Dakota. Photograph by David M. Mushet, U.S. Geological Survey, July 30, 2014.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
milliliter (mL)	0.03382	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F=(1.8×°C)+32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C=(°F–32)/1.8.

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Note to USGS users: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas. Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it.

Chemical and Biotic Characteristics of Prairie Lakes and Large Wetlands in South-Central North Dakota—Effects of a Changing Climate

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Abstract

The climate of the prairie pothole region of North America is known for variability that results in significant interannual changes in water depths and volumes of prairie lakes and wetlands; however, beginning in July 1993, the climate of the region shifted to an extended period of increased precipitation that has likely been unequaled in the preceding 500 years. Associated changing water volumes also affect water chemical characteristics, with potential effects on fish and wildlife populations. To explore the effect of changing climate patterns, in 2012 and 2013, the U.S. Geological Survey revisited 167 of 178 prairie lakes and large wetlands of south-central North Dakota that were originally sampled in the mid-1960s to mid-1970s. During the earlier sampling period, these lakes and wetlands displayed a great range of chemical characteristics (for example, specific conductance ranged from 365 microsiemens per centimeter at 25 degrees Celsius to 70,300 microsiemens per centimeter at 25 degrees Celsius); however, increased water volumes have resulted in greatly reduced variation among lakes and wetlands and a more homogeneous set of chemical conditions defined by pH, specific conductance, and concentrations of major cations and anions. High concentrations of dissolved solids previously limited fish occurrence in many of the lakes and wetlands sampled; however, freshening of these lakes and large wetlands has allowed fish to populate and flourish where they were previously absent. Conversely, the freshening of previously saline lakes and wetlands has resulted in concurrent shifts away from invertebrate species adapted to live in these highly saline environments. A shift in the regional climate has changed a highly diverse landscape of wetlands (fresh to highly saline) to a markedly more homogeneous landscape that has reshaped the fish and wildlife communities of this ecologically and economically important region.

Introduction

The climate of the prairie pothole region (PPR) is well known for its dynamic shifts between periods of drought and deluge; however, recent increases in precipitation beginning in July 1993 have resulted in corresponding increases in water depths and volumes of the region's abundant lakes and wetlands, not likely experienced in the previous 500 years (Winter and Rosenberry, 1998). At a large scale, these climate-induced water-level increases have, in part, contributed to major flooding issues that have plagued parts of the PPR including the closed Devil's Lake basin of North Dakota (Todhunter and Rundquist, 2004; Vecchia, 2008). As with Devil's Lake, most other prairie lakes and wetlands are also within closed basins, resulting in similar water-level rises and flooding but on a smaller spatial and economic scale (fig. 1).

Proactive resource management will require an understanding of how the chemical composition and biotic communities of prairie lakes and wetlands shift in response to changes in climate (Euliss and others, 2004). Additionally, because most climate change models predict a greater frequency and severity of wet and dry periods (Schneider and others, 2007), baseline information gathered during the current (2015) high water-level conditions will be invaluable for understanding how these systems respond to future changes in climate.

During the summers of 2012 and 2013, we documented abiotic characteristics and biotic communities of 167 prairie lakes and large wetlands that were originally studied from 1966 to 1976 by Swanson and others (1988). Knowledge derived from the original sampling provided information on linkages between chemical composition of prairie lakes and wetlands and their use by wildlife. The resampling of these lakes and wetlands provided information equally useful given the emerging landscape-level threats that climate change poses to aquatic systems. This information will be especially important to inform management decisions made by U.S. Department of the Interior agencies that oversee a multitude of prairie lakes and wetlands (refuges, waterfowl production areas, and conservation easements). This information is of

Figure 1. Flooding caused by rising water levels in Lake 156 near Crystal Springs, North Dakota. Photograph by David M. Mushet, U.S. Geological Survey, September 28, 2011.

broad importance because public and private wetlands greatly affect U.S. Department of the Interior trust species and other ecosystem components valued by society.

The Swanson and others (1988) survey of prairie lakes and large wetlands focused primarily on quantifying chemical characteristics across a gradient from fresh to hypersaline waters (less than [<] 800 to greater than [>] 60,000 microsiemens per centimeter at 25 degrees Celsius [μS/cm at 25 °C]). Salinity nomenclature used in Swanson and others (1988) and this report follow the salinity classification in Cowardin and others (1979). Although Swanson and others (1988) performed only limited surveys of biotic communities, they were able to relate their findings to potential effects on fish and wildlife. The insights provided by Swanson and others (1988), relative to the biota of the lakes and wetlands sampled, are important because ecosystem structure is heavily affected by biotic interactions that often exceed the impacts of abiotic factors (Zimmer and others, 2002; Hanson and others, 2005; Anteau and others, 2011). Thus, during this re-sampling we surveyed fish, salamander, and aquatic invertebrate communities in these lakes and wetlands in addition to abiotic characteristics. The inclusion of detailed quantifications of biotic communities allowed us to better define associations between chemical characteristics of prairie lakes and wetlands and their biotic inhabitants. Specifically, we interpreted the occurrence of fish, amphibians, and a variety of invertebrate taxa in the context of pH, specific conductance, and major ion concentrations. We explore the effects on other wildlife species using known associations among predatory fish and salamanders, invertebrate abundance and biomass, and waterfowl.

Study Area

Swanson and others (1988) carried out their study in Stutsman County and Kidder County, North Dakota, because these two counties uniquely include three dominant physiographic features of the PPR within their borders (fig. 2). We resampled this area for the same reason and also to build on

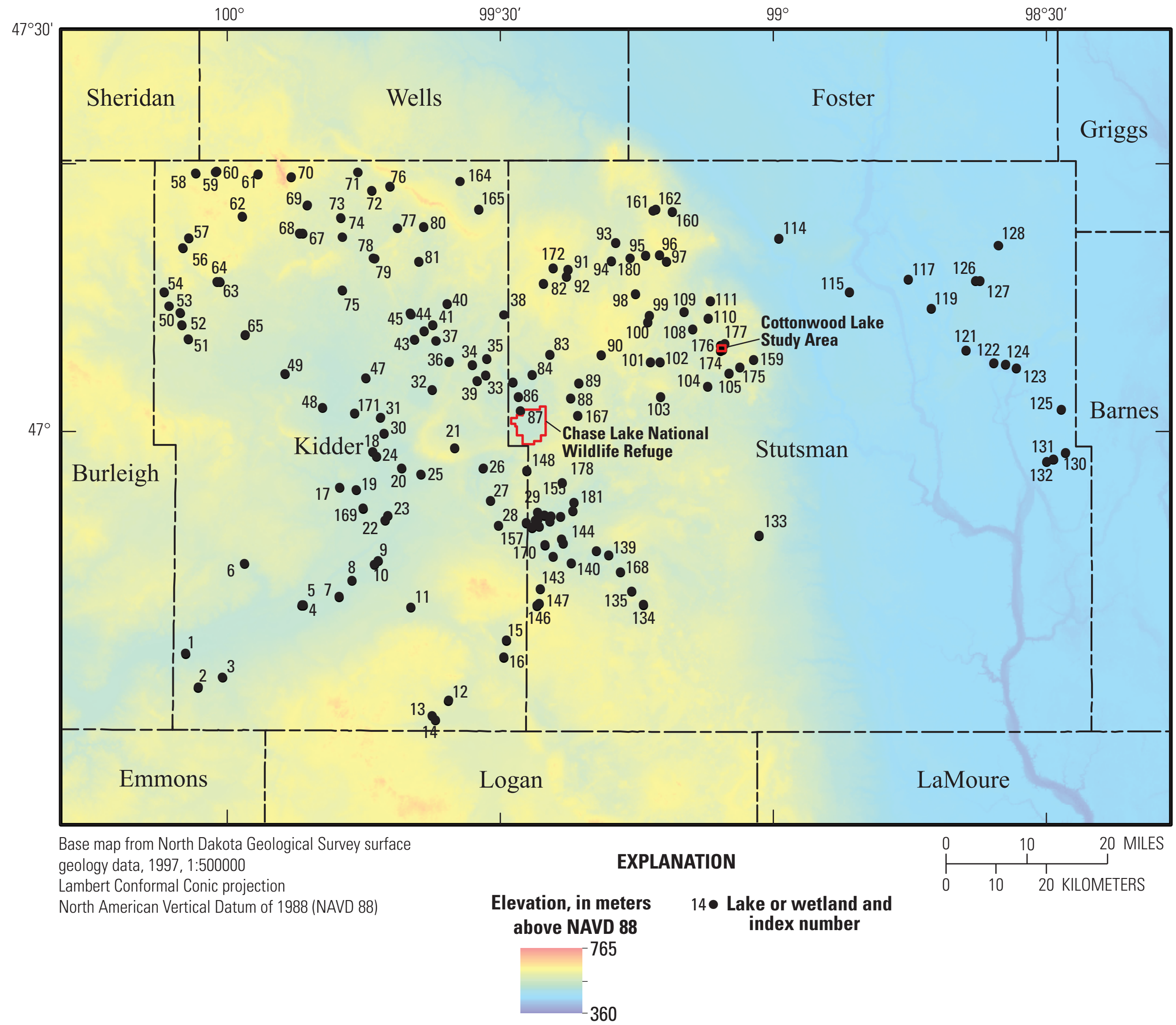


Figure 2. Location of 178 lakes and wetlands in Kidder and Stutsman Counties, North Dakota, originally sampled from 1966 to 1976 by Swanson and others (1988) and resampled (*N*=167) in 2012 and 2013.

the data assets from the original sampling effort. The western part of Stutsman County includes a glacial stagnation moraine known as the Missouri Coteau. The Missouri Coteau is characterized by a hummocky knob-and-kettle landscape formed by the melting of ice blocks buried by thick superglacial drift and the subsequent collapse of the drift into the resulting voids. Innumerable prairie pothole lakes and wetlands exist in the basins created within this poorly drained, collapsed, glacial topography. The eastern part of Stutsman County is primarily drift prairie where glaciers retreated at a fairly even rate leaving behind an undulating plain of low-relief ground moraine. Wetlands in the drift plain are less numerous and generally more shallow than those in the stagnation moraine of the Missouri Coteau. Kidder County is situated to the west of Stutsman County and encompasses a vast area of glacial outwash plain where meltwater from receding glaciers sorted substrate materials resulting in sandy, moderately drained soils (fig. 3).

A Changing Climate

The PPR is well known for its dynamic continental climate (Kantrud and others, 1989). Large variations in temperature and precipitation result from complex interactions among air masses originating from polar, Pacific, and Gulf of Mexico sources (Borchert, 1950; Bryson and Hare, 1974). Variations in temperature and moisture content of these competing air masses lead to great seasonal and interannual differences in precipitation and evaporation rates. Additionally, long-term (10 to 20 year) cycles between periods of drought (Woodhouse and Overpeck, 1998) and deluge (Winter and Rosenberry, 1998) can dominate the climate of the region. These wet/dry climate cycles can persist for 10 to 20 years (Duvick and Blasing, 1981; Karl and Koscielny, 1982; Karl and Riebsame, 1984; Diaz, 1983, 1986).

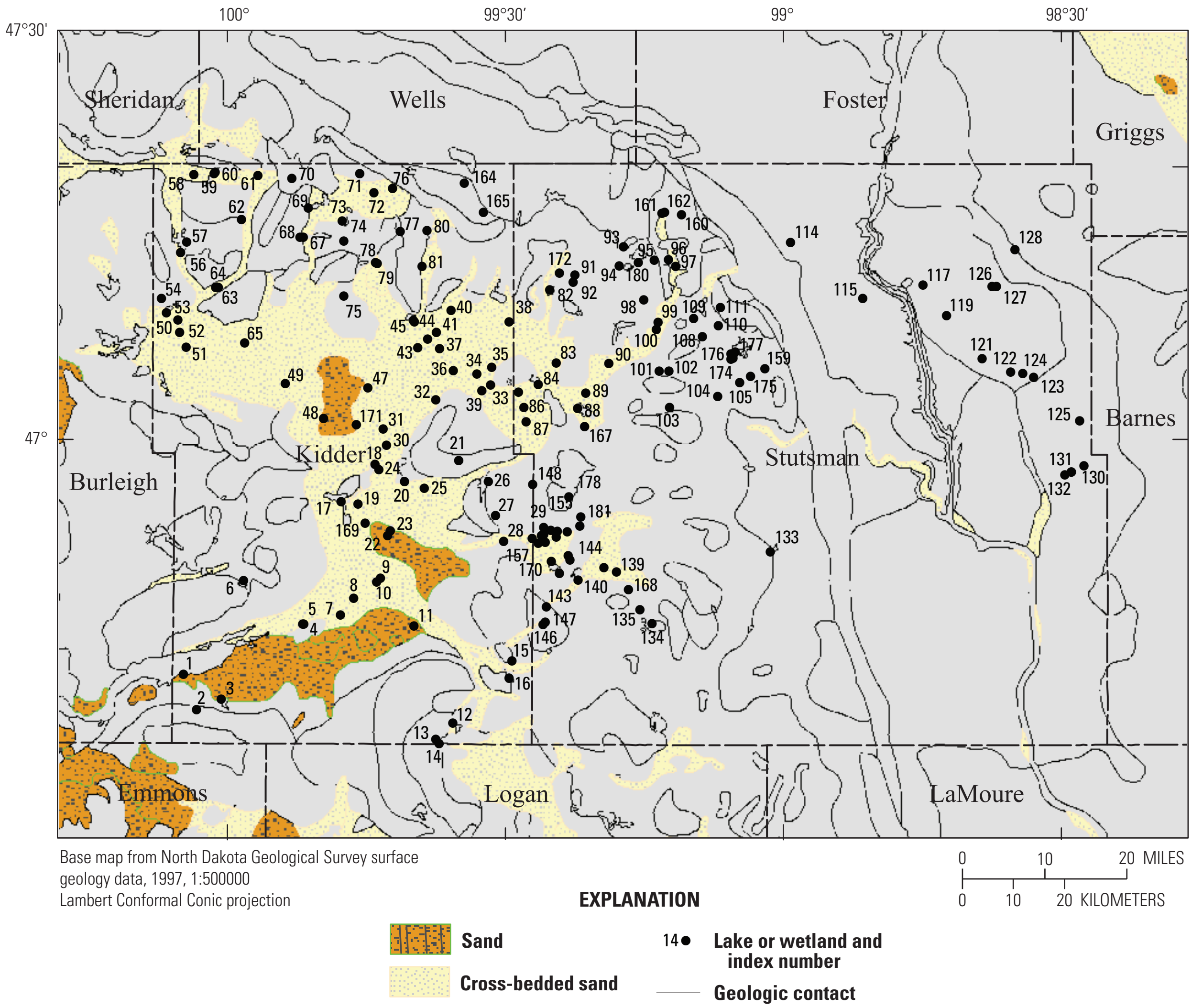


Figure 3. Location of select lakes and wetlands in southeastern North Dakota in relation to areas of sand.

Currently, lakes and wetlands in Stutsman and Kidder Counties, North Dakota, are experiencing the effects of an extended wet period. This wet period immediately followed a severe drought (1988 to July 1993; Winter and Rosenberry, 1998). The average annual precipitation for the study area (Climate Division 5 of North Dakota) immediately preceding the drought (1958 to 1987) was 44.68 centimeters (cm). The average annual precipitation during the drought (1988 to 1992) was 38.70 cm. The average annual precipitation for the 22-year period following the drought (1993 to 2014) was 50.54 cm, which was 5.86 cm above the 30-year pre-drought average, 11.84 cm above the average during the drought years, and 4.68 cm above the 45.86 average annual precipitation for the entire period of record (1895–2014; fig. 4; National Oceanic and Atmospheric Administration, 2015).

Precipitation that falls directly on the water surface represents the primary water input to wetlands, and loss of water by evapotranspiration represents the largest water losses (Shjeflo, 1968; Eisenlohr and others, 1972; Winter, 1989). Runoff is the second-most important input of water, occurring primarily as snowmelt runoff, which represents about 15 to 30 percent of annual water input and as much as 50 percent in some wetlands (Shjeflo, 1968; Eisenlohr and others, 1972). In some studies of wetlands, surface runoff has represented as little as 3 to 4 percent of total water input (Winter, 1989). Groundwater input and loss of water by flow to groundwater represent minor components of the water balance of prairie pothole wetlands, particularly those in glacial till (Shjeflo, 1968; Eisenlohr and others, 1972; Winter, 1989).

Increases in winter precipitation can be more influential on water levels of lakes and wetlands in the PPR than increases occurring at other times of the year when losses to infiltration and transpiration are much greater (Vecchia, 2008). The 30-year average for winter precipitation (October to March) for Climate Division 5 of North Dakota for the period immediately preceding the drought (1958 to 1987) was 9.89 cm. The average winter precipitation during the drought (1988 to 1992) was 6.85 cm. The average winter precipitation for the 22-year period following the drought (1993 to 2014) was 12.01 cm, 1.82 cm above the average winter precipitation

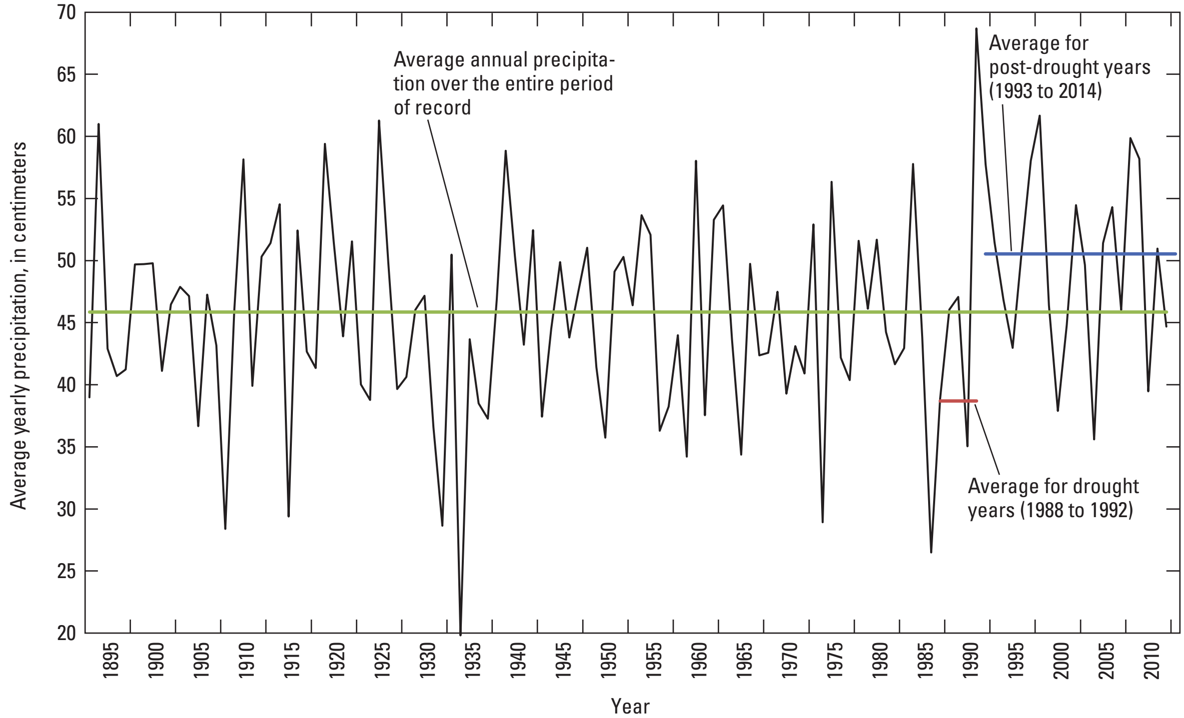


Figure 4. Average annual precipitation for North Dakota Climate Division 5, 1895 to 2014(National Oceanic and Atmospheric Administration, 2015).

for the entire period of record (10.19 cm; 1895–2014; National Oceanic and Atmospheric Administration, 2015). Correlation of amounts of winter precipitation to the relative importance of snowmelt runoff to pond water input the following spring can be problematic because snowmelt runoff exceeding direct rainfall input and runoff in the following open-water period only occurs when snow accumulates in cold winters until the spring and melts quickly when the ground is still frozen (Shjeflo, 1968). For example, Eisenlohr and others (1972) determined that, during their study, the year with the highest precipitation from November to April had the lowest basin inflow from that precipitation.

Average precipitation amounts for the remainder of the year (April through September, hereafter referred to as “growing season precipitation”) also were greater post drought. The 30-year average growing season precipitation for the period immediately preceding the drought (1958 to 1987) was 32.35 cm, whereas the average growing season precipitation for the 22-year period following the drought (1993 to 2014) was 36.00 cm, 2.6 cm above the average growing season precipitation for the entire period of record (33.40 cm; 1885–2014). The average growing season precipitation during the drought (1988 to 1992) was 28.19 cm (National Oceanic and Atmospheric Administration, 2015). Increased rain during the growing season can result in pronounced increases in wetland pond water levels such as occurred in 1964 and 1965 (Eisenlohr and others, 1972) and in 1993 (Rosenberry and Winter, 1997; Winter and Rosenberry, 1998).

Anthropogenic changes to the PPR hydrologic landscape through wetland drainage have undoubtedly increased the catchment area and thus the amount of water entering many of the region’s lakes and larger wetlands, especially those at lower elevations (Anteau, 2012); however, climate effects that include increases in precipitation following the 1988 to July 1993 drought (Winter and Rosenberry, 1998) likely have had an equal if not greater effect on water levels in the region of our study. The dominance of climate effects over drainage effects can be demonstrated by examining water-level changes in regional lakes and wetlands that have not been affected by drainage or similar landscape alterations. For example, a hydrograph of water elevations in Lake 112 clearly shows a shift to higher water levels following the drought conditions (figs. 2 and 5). Lake 112 (also known as wetland P1) is located in the Cottonwood Lake study area (fig. 2). The U.S. Fish and Wildlife Service purchased this area in 1962 and since that time the area has been managed as a Federal Waterfowl Production Area (Swanson and others, 2003). Most of the Cottonwood Lake study area has never been tilled and none of its wetlands have been drained. Additionally, the study area includes the local topographic high within its boundaries; therefore, there are no higher elevation wetlands outside of the study area with potential to affect water levels of lakes and wetlands within the study site. Given the undisturbed nature of the site’s hydrology, it was selected as a long-term wetland-monitoring site by U.S. Fish and Wildlife Service and USGS researchers in 1978 (Winter, 2003). In addition to wetland P1, other lakes and large wetlands within the Cottonwood Lake

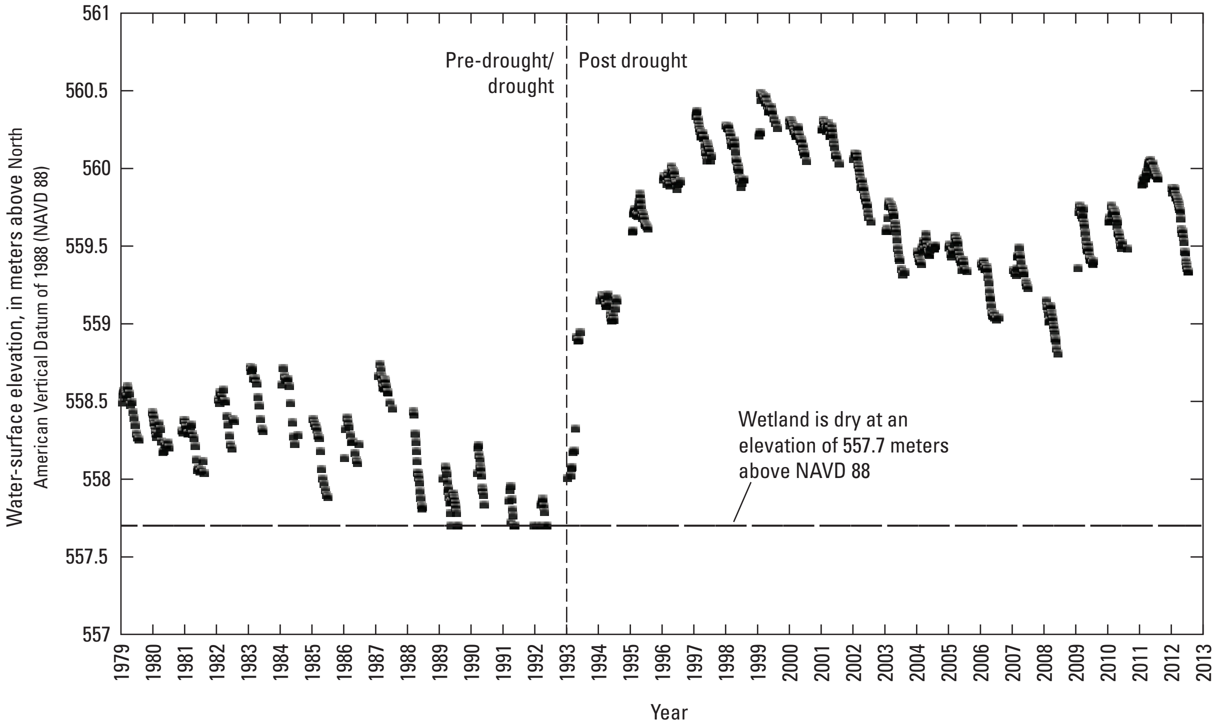


Figure 5. Water elevations for Cottonwood Lake study area wetland P1, North Dakota (Lake 112; fig. 2), 1978–2013.

study area displayed similar increases in water depths following the period of drought (1988 to 1992).

Similarly, Lake 87 (Chase Lake) is embedded within one of the largest tracts of native prairie in North Dakota. Chase Lake is fully encompassed within the 1,776-hectare (ha) Chase Lake National Wildlife Refuge (fig. 2), 1,683 ha of which was designated as a wilderness area in 1975. An additional 1,148 ha adjacent to the Chase Lake National Wildlife Refuge is owned and managed as a Wildlife Management Area by the North Dakota Game and Fish Department. Thus, anthropogenic impacts to surface waters around Chase Lake have been minimal. However, water levels in Chase Lake have risen markedly in the years of increased precipitation beginning in 1993. Chase Lake is home to one of the largest breeding colonies of *Pelecanus erythrorhynchos* (American white pelicans) in North America. These birds nest on several small islands within the lake. Rising water levels during the past 20 years have flooded these islands forcing the birds to nest on peninsulas and new islands that have formed as rising levels cut off peninsulas from their land connections and formed new islands. Another indicator of the rising waters in Chase Lake has been a marked freshening of its water to the point that this lake, formerly known for its lack of any aquatic vertebrate life, now supports populations of tiger salamanders *Ambystoma mavortium* (barred tiger salamanders) and *Pimephales promelas* (fathead minnows; Mushet and others, 2013).

Increasing water levels in areas with little drainage and other anthropogenic effects highlight the importance of increased precipitation; however, even in areas with greater anthropogenic disturbances, water levels increased in response to increased precipitation in the post-drought period. These increases can be seen in a hydrograph of Devils Lake water levels, the region’s largest closed-basin lake (fig. 6). The Devil’s Lake basin is dominated by agriculture with substantial wetland drainage and other hydrologic modifications. Although wetland drainage and land-use changes within the Devils Lake basin have undoubtedly affected water-level rises and resultant flooding issues to some degree, the recent (1993 to 2014) water-level increases can be attributed primarily to increased precipitation in the region (Vecchia, 2008). Todhunter and Rodenquist (2004) determined a similar increase in water discharge from the Sheyenne River just south of the Devils Lake basin that started in 1993 primarily as a result of greater runoff from precipitation increases rather than land-use change or wetland drainage effects (note the linear relationship but with a change in slope starting in 1993; fig. 7). Similarly, Landsat satellite imagery acquired before and after the 1988 to 1992 drought (fig. 8) show an increased abundance of water across the region’s landscape following the drought years (also see Liu and Schwartz, 2012) that cannot be accounted for by simple drainage effects that concentrate water from multiple smaller wetlands into larger wetlands and lakes at lower topographical positions (that is, consolidation drainage as discussed by Anteau [2012]).

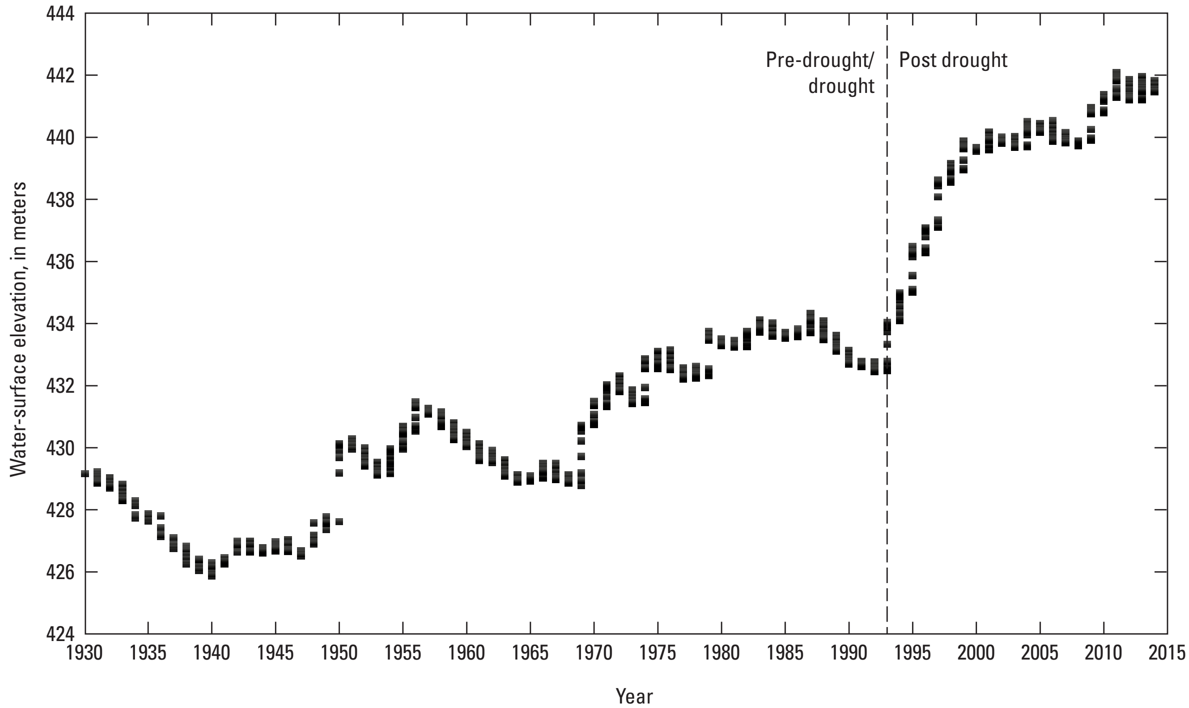


Figure 6. Water elevations of Devils Lake, North Dakota, 1930 to 2014, U.S. Geological Survey streamgage 05056500.

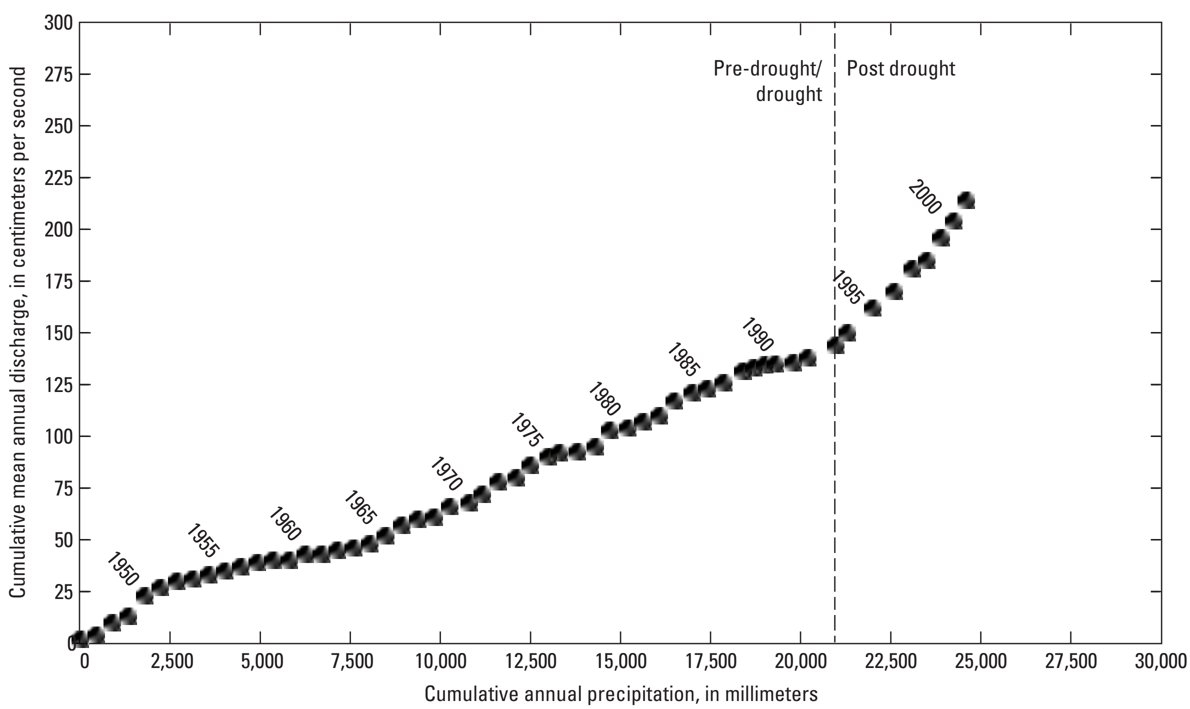


Figure 7. Cumulative annual precipitation and cumulative mean annual discharge of the Sheyenne River near Cooperstown, North Dakota, from double mass curve analysis (modified from Todhunter and Rodenquist, 2004).

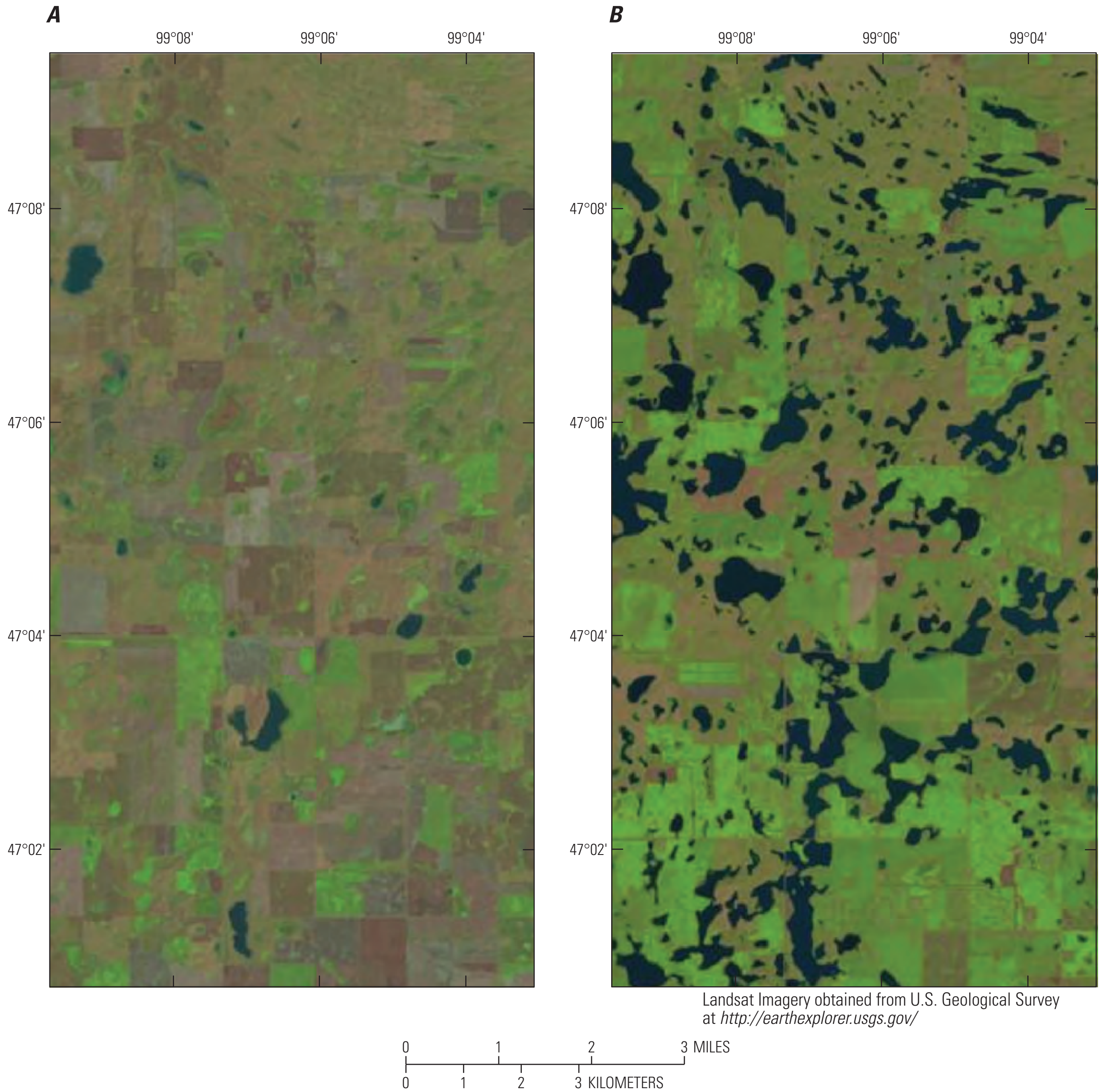


Figure 8. Satelite imagery of Stutsman County, North Dakota. *A*, September 2, 1992 (Landsat 5 bands 5, 4 and 3). *B*, May 23, 2013 (Landsat 8 bands 6, 5 and 4).

Methods

In 2012 and 2013 we revisited the lakes and wetlands studied by Swanson and others (1988) in 1966 to 1976. During our visit to each lake and wetland, we collected water samples, measured in-situ parameters including pH, water temperature, water depth, and water clarity. We also sampled aquatic vertebrate and macroinvertebrate communities.

Water Chemistry

We collected water samples for chemical analyses from 167 of the 178 lakes and wetlands sampled by Swanson and others (1988). Lakes for which landowners were unreachable or for which access was denied were not sampled. To ensure comparability of data, procedures for water sample collection and chemical analyses (appendix 1) closely matched previous methods (appendix 2). Samples were collected from the lake/wetland center or outside (that is, towards the center of the lake/wetland) of the deep-marsh zone as defined by Stewart and Kantrud (1971) at the 1.5-meter (m) depth contour, whichever was shallower. The order in which lakes and wetlands were sampled was adjusted to approximate the seasonal order in which the lakes and wetlands were originally sampled by Swanson and others (1988) and sample locations were selected to avoid effects of groundwater seepage. We sampled about one-half of the lakes and wetlands in 2012 (N=79) and the remainder (N=88) in 2013.

Before collecting a sample, we measured water pH, specific conductance, temperature, turbidity, and maximum depth (up to a depth of 3 m) of the lake or wetland. For lakes >3 m deep, maximum depth was recorded as >3 m. Specific conductance and temperature were measured using a WTW Model 315i meter with a TetraCon® 325 standard conductivity measuring cell, pH was measured with a Beckman Coulter model 250 pH meter equipped with a combination pH electrode, and turbidity was measured using a 20-cm diameter freshwater Secci disk. We then used a tube type water sampler (Swanson, 1978) to collect water samples so that the water collected was depth integrated (that is, representative of the overall water column rather than just a single depth interval). A single sample consisted of 3 liters of water stored in two 1.5-liter bottles. We rinsed sample bottles three times with lake/wetland water before filling with the sample water. Samples were stored on ice for transport to the USGS laboratory at the Northern Prairie Wildlife Research Center in Jamestown, N. Dak. Duplicate samples were collected from 8 percent of the lakes and wetlands as a quality-control measure.

All water samples were processed at the USGS laboratory in Jamestown on the same day as collected. Samples were filtered through a 0.45-millimeter (mm) pore size Supor® membrane (Pall Life Sciences part #66553) using a 142-mm diameter polycarbonate plate filter holder (Geotech part #83150009) and a Geopump™ equipped with silicone tubing (Geotech part #8705000). The first approximately 200 milliliter (mL) of filtered sample was discarded. A subsample for anion and alkalinity analyses was collected in a 250-mL polypropylene bottle and a subsample for cations was collected in a nitric-acid-washed 30-mL polypropylene bottle and preserved with 0.10 mL trace metal grade concentrated nitric acid. The plate filter assembly and tubing was rinsed thoroughly with deionized water between samples. All subsamples were shipped to the USGS National Research Program laboratory in Boulder, Colorado, for subsequent analysis. Anion and alkalinity subsamples were shipped and stored at 5 degrees Celsius (^{o}C).

Anions (sulfate [SO_4-], chloride [Cl^-]) were determined by ion chromatography with suppressed electrical conductivity detection. A Dionex DX 600 ion chromatograph equipped with an IonPac® AS18 analytical column, an IonPac® AG18 guard column, and an anion self-regenerating suppressor (ASRS Ultra II) was used to analyze SO_4- and Cl-. Detection limits for all anionic species were 0.1 milligrams per liter (mg/L). Cations (calcium [Ca^{2+}], potassium [K^+], magnesium [Mg^{2+}], sodium [Na+]) were analyzed by inductively coupled plasma-optical emission spectroscopy. A Perkin Elmer 7300 DV inductively coupled plasma-optical emission spectroscopy was used with a cesium chloride ionization buffer added in-line prior to sample nebulization to suppress the ionization of lithium and potassium.

Despite thorough rinsing of filtration equipment between samples, the very high salinities of some samples created the potential for sample carryover. A total of 10 filtration blanks of ultrapure water were filtered periodically throughout the 2-year sampling period as described above to assess the potential for sample carryover. Maximum concentrations of species determined in the blanks were as follows, Ca^{2+}=0.25 mg/L, Mg^{2+}=0.14 mg/L, Na^+ is less than or equal to (≤) 0.4 mg/L, K^+≤0.04 mg/L, Cl^-=0.3 mg/L, SO_4^{2-}=3.0 mg/L, and alkalinity as bicarbonate (HCO_3^-)=4.0 mg/L. The concentrations of all major cations, anions, and alkalinity in most samples were at least 20 times larger than the respective maximum concentrations detected in the blanks. The exceptions were one sample that had a Cl^- concentration 10 times larger than the maximum detected in blanks and eight samples that had SO_4^{2-} concentrations between 3 and 20 times larger than the maximum detected in blanks.

Duplicate samples were collected and analyzed from 14 lakes and wetlands. The concentrations of major ions and alkalinity for duplicate samples were all within 6 percent except for Cl^- in Lake 28, which was within 10 percent, and Na^+ in lake 75, which was within 8 percent. The majority of concentrations were within 2 percent. Charge imbalance calculations were carried out in WATEQ4F (Ball and Nordstrom, 1991). Seventy percent of samples had charge imbalance less than 5 percent, 97 percent of samples had charge imbalance less than 10 percent and all samples had charge balance less than or equal to 15 percent.

Aquatic Vertebrates

We sampled fish and salamander communities within lakes and wetlands concurrent with our sample collections for water chemistry analyses. Within each sampled lake and wetland, we placed seven aquatic vertebrate funnel traps (Mushet and others, 1997) at evenly spaced (30 m) intervals parallel to the shoreline along the 1-m depth contour or at the open water edge of any emergent vegetation, whichever was deeper (fig. 9). The tops of each trap extended beyond the water surface allowing captured individuals access to surface air thereby increasing survivorship (Mushet and others, 1997). We oriented the 2-m driftnet and elongate opening of each trap parallel to the shoreline. The location of each trap array in a particular lake or wetland was largely determined by ease of access and ability to obtain needed landowner permissions. All traps were in place for 24 hours before retrieval. Upon trap retrieval, we enumerate all captured fish, salamanders, and other vertebrates by species. Following identification and enumeration, we immediately released captured individuals back into the lake/wetland. We supplemented information on the presence or absence of game fish using stocking data obtained from the North Dakota Game and Fish Department.

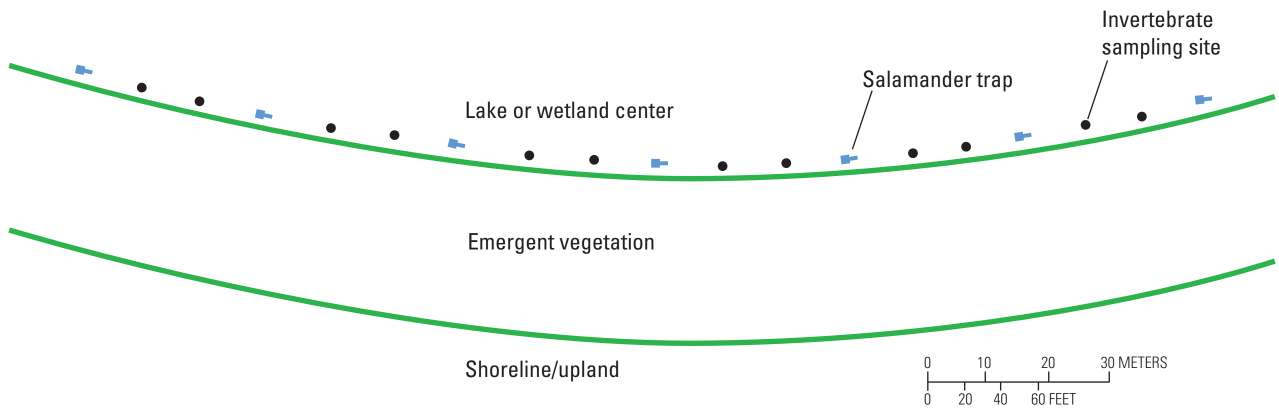


Figure 9. Aquatic vertebrate (fish, salamanders) and macroinvertebrate sampling locations in a typical lake or wetland with emergent vegetation.

Macroinvertebrates

Concurrent with fish and salamander sampling, we sampled aquatic macroinvertebrate communities using a 500-micron-mesh, D-shaped, aquatic dip-net. We collected dip-net samples at each of 12 locations evenly spaced among and along the same depth contour (1 m) as the 7 salamander/fish traps. The placement of salamander/fish traps and the relative location of macroinvertebrate sampling in a typical lake or wetland with an emergent vegetative zone are shown in figure 9. At each of the 12 sampling locations, we collected 1 vertical sample of the water column and 1 horizontal sample along the lake/wetland bottom. We collected the vertical sample by lowering the dip-net to the wetland bottom with the net opening and handle oriented vertical to the wetland bottom. We then tilted the handle so the net was in a horizontal position and quickly pulled it up through the water column to the wetland surface. We collected bottom samples in a similar manner except, instead of reorienting the direction of the net after lowering it to the lake/wetland bottom, we swept the vertically oriented net for a distance of 1 m along the bottom before pulling it to the surface. The net opening remained vertical to the wetland bottom during the pull to the surface to minimize the capture of invertebrates from the water column as the net was brought to the water surface.

Once a sample was collected, we concentrated invertebrates by rinsing the net contents through a 500-micron screened plankton cup and then transferring the screened contents from the plankton cup into a polypropylene sample storage jar. Ethyl alcohol was added to each jar until a concentration of 80 percent was reached to preserve the sample. We stored all samples in this 80 percent ethyl alcohol solution until processed in the lab. Processing consisted of pouring the contents of each sample jar through a 500-micron plankton cup, rinsing the sample with water to remove any excess ethyl alcohol, and separating macroinvertebrates from debris over a light table. We identified macroinvertebrates to the lowest taxonomic resolution possible and enumerated them by taxon.

Macroinvertebrates were statistically summarized by abundance and species metrics. For each lake and wetland sampled, we computed species richness (S), log sum of abundance, and Shannon-Weiner diversity index (H’). Lakes and wetlands were then categorized by salinity types (that is, fresh [0 to 800 µS/cm at 25 °C], oligosaline low [801 to 4,000 µS/cm at 25 °C], oligosaline high [4,001 to 8,000 µS/cm at 25 °C], mesosaline [8,001 to 30,000 µS/cm at 25 °C], and polysaline [30,001 to 45,000 µS/cm at 25 °C], based on the Cowardin and others [1979] salinity classification) and community metrics were compared by salinity type using an analysis of variance (ANOVA) followed by a Tukey’s Honestly Significant Difference (HSD) test for pairwise significance. The polysaline lake was not included in the ANOVA because only one lake fell into that category.

Chemical and Biotic Characteristics of Prairie Lakes and Large Wetlands

Water Chemistry

As expected from increased water volumes, water in the lakes and wetlands studied generally freshened since the original measurements by Swanson and others (1988) (fig. 10; appendix 3). Salinity, as measured by specific conductance, decreased from a median of 3,200 µS/cm at 25 °C from the 1966 to 1976 sampling to 1,794 µS/cm at 25 °C in 2012 and 2013 (table 1). When sampled by Swanson and others (1988), only 57 percent of the lakes and wetlands had specific conductance values <4,000 µS/cm at 25 °C. During our 2012 and 2013 sampling, lakes and wetlands had freshened such that 80 percent of those sampled had specific conductance values <4,000 µS/cm at 25 °C (fig. 11). All major ions, except Ca^{2+}, showed temporal reductions in concentration measures (that is, median, mean, minimum, maximum) (table 1). Alkalinity

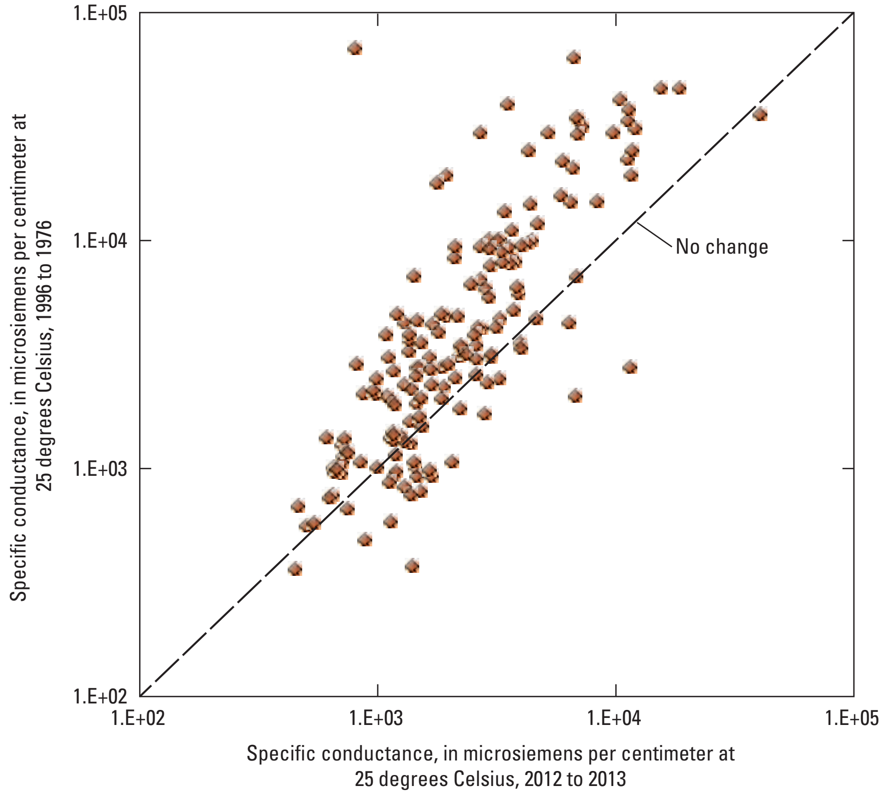


Figure 10. Comparison of specific conductance (microsiemens per centimeter at 25 degrees Celsius) of 167 prairie lakes and wetlands sampled from 1966 to 1976 (Swanson and others, 1988) and resampled in 2012 and 2013.

Table 1. Chemical characteristics of prairie lakes and wetlands sampled from 1966 to 1976 by Swanson and others (1988) and resampled in 2012 and 2013.

[HCO_3^-, hydrogen carbonate; mg/L, milligrams per liter]

Chemical characteristic	1966 to 1976				2012 and 2013			
	Median	Mean	Minimum	Maximum	Median	Mean	Minimum	Maximum
pH	9.0	[1]8.6	7.4	10.2	8.9	[1]8.8	8.1	9.9
Specific conductance	3,200	8,376	365	70,300	1,794	2,897	449	40,350
Alkalinity (as HCO_3^-)	600	928.9	150	10,800	562	613.5	223	2,290
Calcium (mg/L)	30	42.7	1	196	40	44.7	5.8	164
Magnesium (mg/L)	140	403.4	1	11,600	103	161.5	31.8	1,050
Sodium (mg/L)	475	2,011.0	3	21,800	255	574.0	9.0	13,000
Potassium (mg/L)	78	190.5	4	3,600	38	58.8	5.5	484
Sulfate (mg/L)	725	3,977	16	87,500	689	1,360	10.4	27,000
Chloride (mg/L)	105	613.5	5	13,470	44	153.5	2.9	2,520

[1]Determined from the mean hydrogen ion concentration.

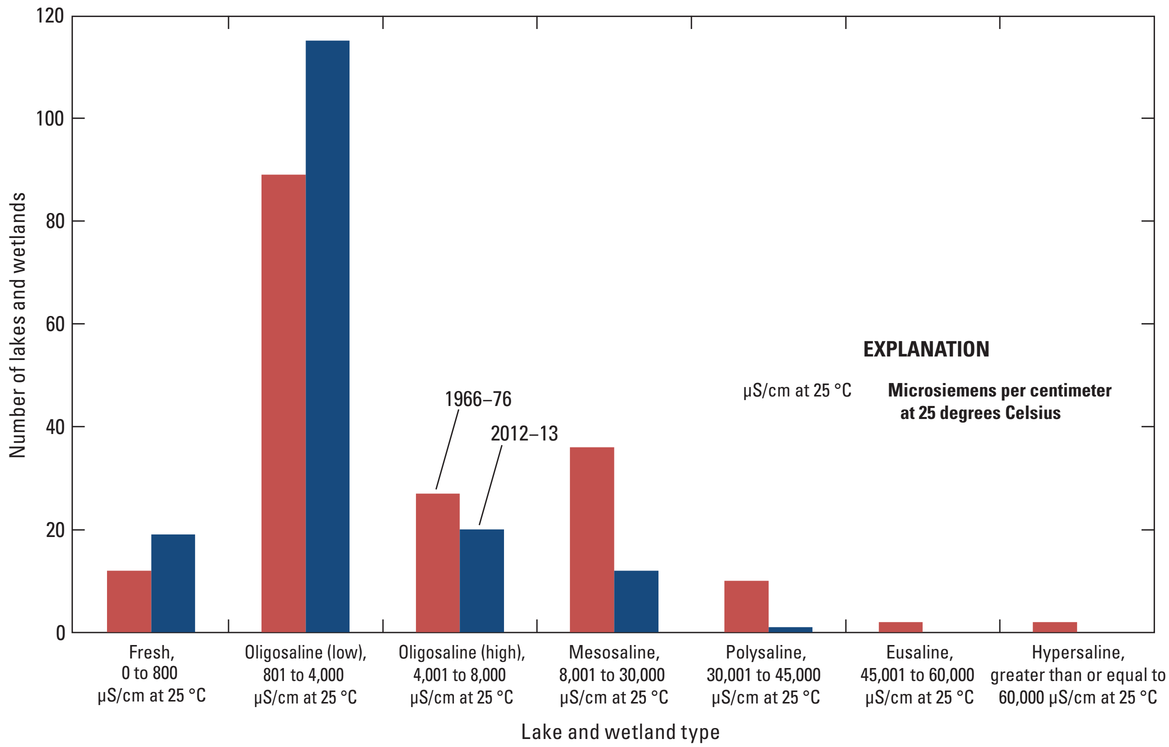


Figure 11. Histogram showing distribution of prairie lakes and wetlands among seven salinity classes based on specific conductance of their water.

as HCO_3-, K^+, Mg^{2+}, Na^+, and Cl^- displayed great changes between the two sampling periods (fig. 12*B*, *D*, *E*, *F*, *H*). Sulfate also had lower median and mean concentrations in 2012 and 2013 (table 1) but the decreasing trend (fig. 12*G*) was not as apparent as for other major ions. Calcium concentrations varied for individual wetlands between the two periods but without a distinct trend (fig. 12*C*). All lakes and wetlands were saturated or supersaturated with calcite during both original sampling and resampling so that Ca^{2+} concentrations are likely buffered by precipitation/dissolution of carbonate minerals. Likewise, little temporal variation in pH was observed due to buffering by high concentrations of HCO_3- (table 1; fig. 12*A*).

Swanson and others (1988) identified seven different water types in the study lakes and wetlands as determined from dominance of major cations and anions: calcium bicarbonate (*N*=2), magnesium bicarbonate (*N*=39), magnesium sulfate (*N*=30), sodium bicarbonate (*N*=18), sodium sulfate (*N*=81), sodium chloride (N=7), and magnesium chloride (*N*=1); however, in our 2012 to 2013 sampling of the same lakes and wetlands water of only four different chemical types occurred: magnesium bicarbonate (*N*=46), magnesium sulfate (*N*=38), sodium bicarbonate (*N*=14), and sodium sulfate (*N*=69). Plotting lakes and wetlands along the ion-defined axes of a Piper diagram (fig. 13) provides a visualization of the shifts towards more homogeneous water types that occurred between the two sample periods. All chemical characteristic changes were consistent with changes expected because of increased precipitation inputs and resultant dilution effects.

Of the 167 lakes and wetlands sampled in both the 1966 to 1976 and 2012 to 2013 periods, only 30 did not display a marked decrease in overall ion concentrations as measured by specific conductance (fig. 10).

Swanson and others (1988) also reported significantly larger concentrations of most major ions being associated with lakes and wetlands in outwash compared to ion concentrations of lakes and wetlands situated on glacial till. One exception was calcium, which occurred in higher concentrations in lakes and wetlands on till. We determined that the trend of lakes and wetlands on outwash having higher concentrations of major ions, excluding calcium, persisted in our 2012 to 2013 sampling (table 2). Additionally, we determined that the change in ion concentrations between the two sample periods was significant for all non-calcium, chemical characteristic comparisons (table 2).

To further explore the linkage between rising water levels and water chemical characteristics, we used Geochemists Workbench 10® modeling code (Bethke and Yeakel, 2015) to model major ion concentrations in Lake 87 (Chase Lake) with the dissolution of high magnesium calcite ($Ca_{0.9}Mg_{0.1}CO_3$) across a gradient of increasing water volumes. We used May 1973 starting concentrations as measured in the lake by Swanson and others (1988) and performed dilutions from 0 to a 3 fold increase in water volume. When ion concentrations from our June 22, 2012, sampling are plotted on the modeled concentrations (fig. 14), a 2.6 fold volume increase is suggested.

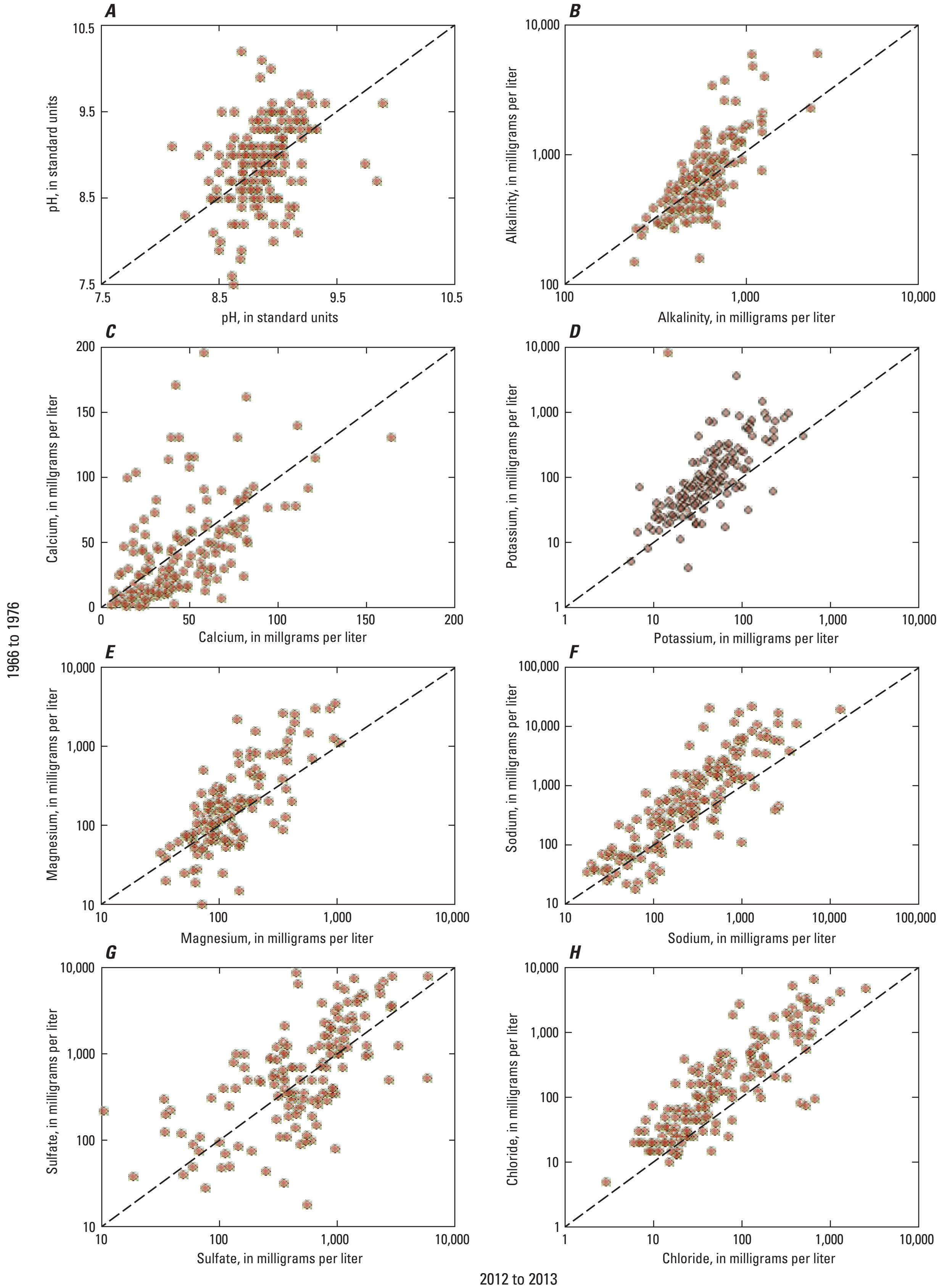


Figure 12. Comparison of chemical and other environmental characteristics of 167 prairie lakes and wetlands sampled from 1966 to 1976 (Swanson and others, 1988) and resampled in 2012 and 2013. *A*, pH; *B*, alkalinity as bicarbonate; *C*, calcium; *D*, potassium; *E*, magnesium; *F*, sodium; *G*, sulfate; *H*, chloride.

A. 1966 to 1976 (178 sites sampled)

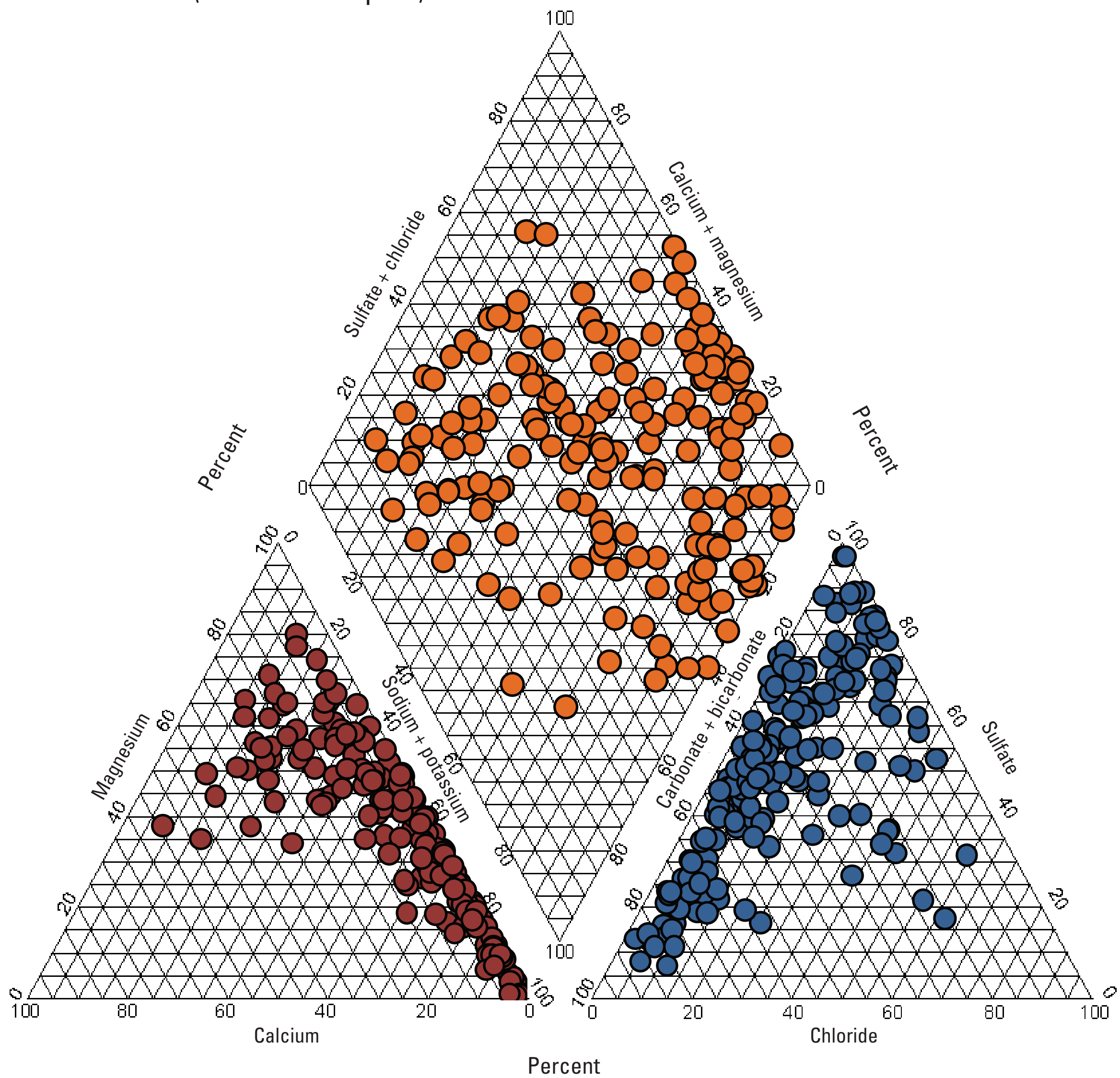


Figure 13. Piper diagram of water from prairie lakes and wetlands. *A*, 1966 to 1976 (*N*=178) and *B*, 2012 and 2013 (*N*=167).

Aquatic Vertebrates

Due to access and timing limitations, we only sampled aquatic vertebrates in 162 of the 167 lakes and wetlands sampled for water chemistry. In the lakes and wetlands sampled in 2012 and 2013, 10 fish and 2 amphibian species occurred (table 3; appendix 4). Fathead minnow was by far the most prevalent aquatic vertebrate species, occurring in 81.5 percent of the lakes and wetlands sampled. Fathead minnow was also the most abundant with an average of 2,186 individuals captured per site. *Culaea inconstans* (brook stickleback), tiger salamander, and *Perca flavescens* (yellow perch) were the next most commonly occurring species, captured in 38.3, 36.4, and 33.3 percent of sample sites, respectively. *Etheostoma exile* (Iowa darter) and *Lithobates pipiens* (northern leopard frog) occurred in 11.1 percent and 10.5 percent of sites sampled, respectively. All other aquatic vertebrate species, primarily game fish, occurred in less than 10 percent of the lakes and wetlands sampled. Chemical characteristics of lakes and wetlands in which specific taxa occurred are provided in tables 4–6.

Macroinvertebrates

In the lakes and wetlands sampled for aquatic macroinvertebrates (*N*=163), we captured specimens representing 117 unique taxa (appendix 5). Occurrence of macroinvertebrate taxa across the range of lakes and wetlands sampled

B. 2012 and 2013 (167 sites sampled)

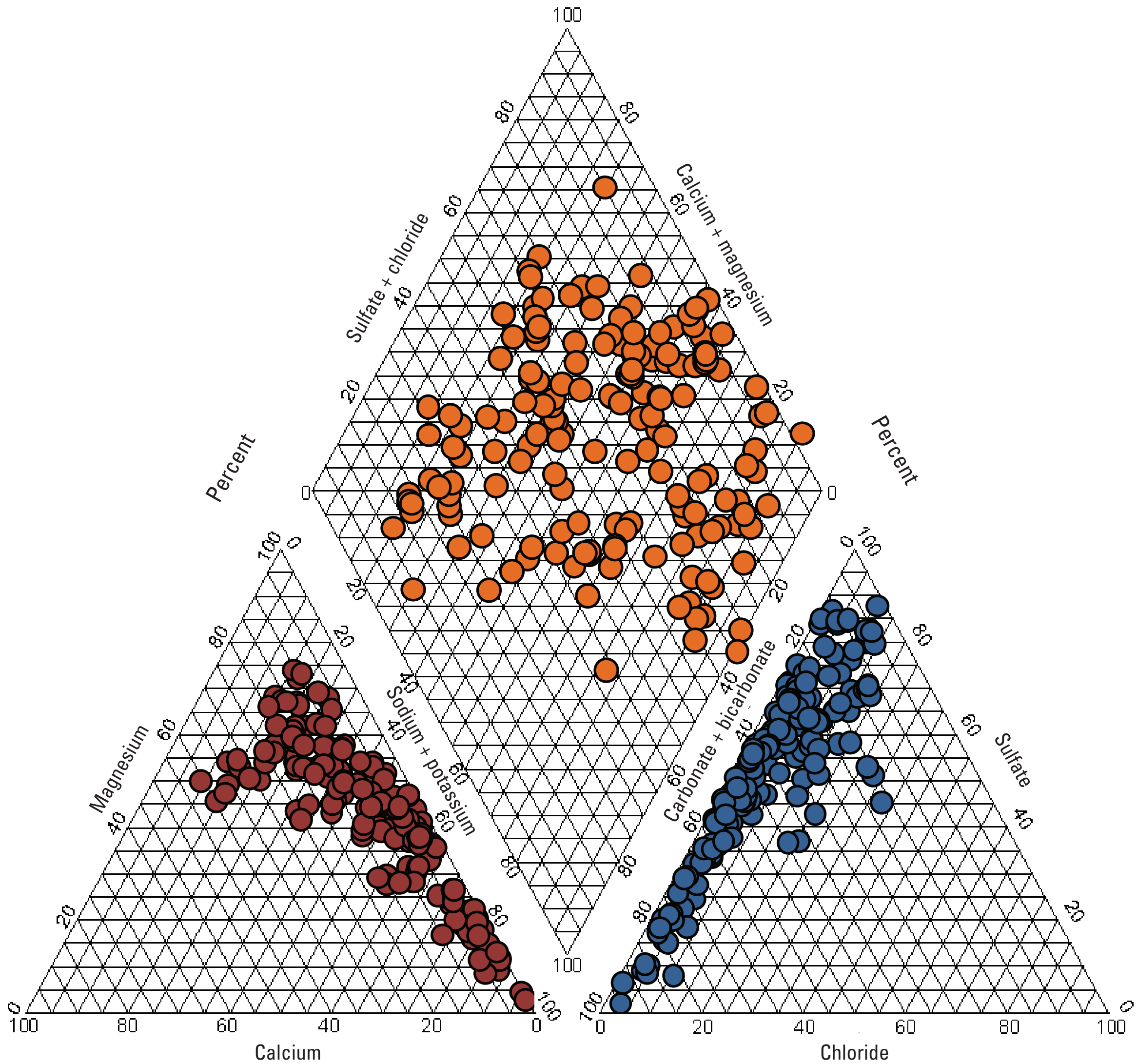


Figure 13. Piper diagram of water from prairie lakes and wetlands. *A*, 1966 to 1976 (*N*=178) and *B*, 2012 and 2013 (*N*=167)—Continued.

varied greatly, ranging from 10 taxa that occurred at >100 of the 163 lakes and wetlands sampled to 28 taxa that only occurred in a single lake or wetland. *Daphnia* (water flea), Calanoida (calinoid copepod), *Hyllela* (amphipod), *Gammarus* (lake amphipod), and Corixidae (water boatmen) were the most abundant taxa captured (range of total captures =39,315 [*Gammarus*] to 742,947 [*Daphnia*]). Water boatmen, Hydracarina (water mites), Chironominae (chironomid midges), amphipods, Orthocladiinae (orthoclad midges), Cyclopoida (cyclopoid copepods), *Trichocorixa* (a water boatman genus), calanoid copepods, water fleas and lake amphipods were the most prevalent taxa, occurring at 155, 151, 148, 148, 122, 120, 116, 110, 110, and 109 sites, respectively. Invertebrate species richness, total macroinvertebrate abundance, and Shannon-Wiener diversity index all differed significantly among salinity types (fig. 15). Oligosaline lakes and wetlands with specific conductance between 4,000 and 8,000 µS/cm at 25 °C had the highest species richness, whereas polysaline (30,001 to 45,000 µS/cm at 25 °C) and mesosaline (8,001 to 30,000 µS/cm at 25 °C) lakes and wetlands had the lowest species richness. In terms of macroinvertebrate abundance, mesosaline lakes and wetlands had the highest total abundance, whereas fresh sites (0 to 800 µS/cm at 25 °C) had the lowest total abundances of macroinvertebrates captured. The Shannon-Wiener diversity index indicated that fresh and oligosaline lakes and wetlands had similar invertebrate diversity and the lowest diversity occurred in mesosaline sites.

Table 2. Comparison of changes in mean values for concentrations of major ions (milligrams per liter), specific conductance (microsiemens per centimeter at 25 degrees Celsius), and pH between prairie lakes and wetlands in till and those in outwash, Stutsman County and Kidder County, North Dakota.

[*N*, number of sites; mg/L, milligrams per liter; %, percent; t, t-statistic; HCO_3^-, hydrogen carbonate]

Chemical characteristic	Geologic setting	*N*	Mean concentration (mg/L)		Change	Change (%)	*t*	*p*-value
			1966 to 1976	2012 to 2013				
Calcium (mg/L)	Till	50	56	59	3.5	6.3	-0.9588	0.3424
	Outwash	117	35	38	1.1	3.1	-0.3670	0.7167
Magnesium (mg/L)	Till	50	221	131	-90	-40.7	1.9660	0.0549
	Outwash	117	497	174	-322	-64.8	2.9968	0.0033
Sodium (mg/L)	Till	50	916	271	-645	-70.4	2.7500	0.0083
	Outwash	117	2,463	704	-1,759	-71.4	5.4173	0.0000
Potassium (mg/L)	Till	50	91	41	-49	-53.8	3.3740	0.0014
	Outwash	117	238	66	-171	-71.8	4.7911	0.0000
Chloride (mg/L)	Till	50	213	62	-151	-70.9	2.7300	0.0088
	Outwash	117	796	192	-603	-75.8	4.2761	0.0000
Sulfate (mg/L)	Till	50	1,546	810	-736	-47.6	1.8047	0.0776
	Outwash	117	5,444	1,595	-3,850	-70.7	4.0159	0.0001
Alkalinity (as HCO_3^-)	Till	50	586	516	-69	-11.8	1.4670	0.1480
	Outwash	117	1,085	655	-431	-39.7	3.9288	0.0001
Specific conductance	Till	50	4,284	2,116	-2,168	-50.6	3.0293	0.0039
	Outwash	117	10,159	3,750	-6,410	-63.1	5.9500	0.0000
pH	Till	50	[1]8.30	[1]8.75	0.44	5.1	-2.8724	0.0060
	Outwash	117	[1]8.85	[1]8.82	-0.02	-0.3	0.5865	0.5587

[1]Determined from mean hydrogen ion concentrations.

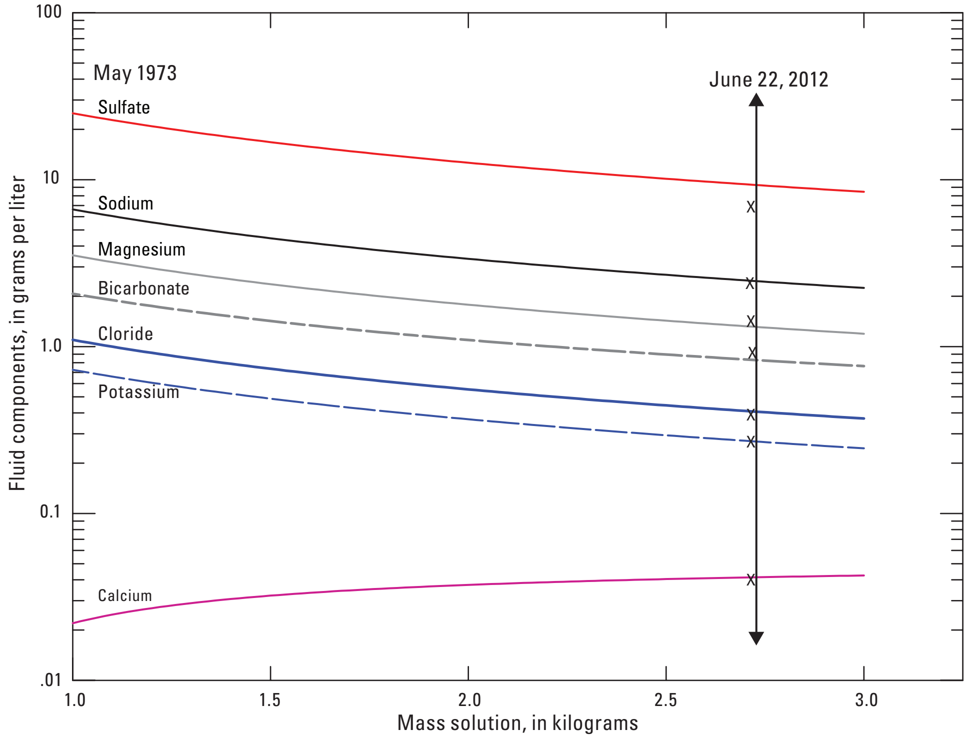


Figure 14. Major ion concentrations in Chase Lake, North Dakota (Lake 87), modeled using Geochemists Workbench modeling code and the dissolution of high magnesium calcite across a gradient of increasing water volumes. Starting concentrations are from the May 1973 sampling by Swanson and others (1988). Concentrations measured on June 22, 2012, are also indicated.

Table 3. Species occurrence and mean number of captures in 162 prairie lakes and wetlands sampled for aquatic vertebrates in 2012 and 2013.

Species	Frequency of occurrence, in percent	Mean captures
Fathead minnow (*Pimephales promelas*)	81.5	2,185.9
Brook stickleback (*Culaea inconstans*)	38.3	13.1
Tiger salamander (*Ambystoma mavortium*)	36.4	19.3
Yellow perch (*Perca flavescens*)	33.3	27.9
Iowa darter (*Etheostoma exile*)	11.1	1.8
Northern leopard frog (*Lithobates pipiens*)	10.5	8.5
Walleye (*Sander vitreus*)	7.4	0.2
Northern pike (*Esox lucius*)	3.1	0.4
Common carp (*Cyprinus carpio*)	1.8	0.6
Black bullhead (*Ameiurus melas*)	1.8	0.4
Smallmouth bass (*Micropterus dolomieu*)	0.6	0.7
Bluegill (*Lepomis macrochirus*)	0.6	0.3

Table 4. Specific conductance, pH, and turbidity (Secchi depth) characteristics of prairie lakes and wetlands containing aquatic vertebrates and fishless lakes and wetlands from 2012 and 2013 sampling of lakes and wetlands in Stutsman County and Kidder County, North Dakota.

[*N*, number of sites; µS/cm at 25 ºC; microsiemens per centimer at 25 degrees Celsius; m, meter]

Species	*N*	Specific conductance (µS/cm at 25 °C)			pH			Turbidity by Secchi depth (m)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean[1]	Minimum	Maximum	Mean
Fathead minnow (*Pimephales promelas*)	132	449	15,430	2,508.8	8.1	9.9	8.83	0.2	3.0	0.78
Brook stickleback (*Culaea inconstans*)	62	500	15,430	2,534.8	8.2	9.9	8.80	0.2	2.6	0.74
Tiger salamander (*Ambystoma mavortium*)	59	461.8	12,000	3,560.7	8.4	9.9	8.85	0.2	3.0	0.87
Yellow perch (*Perca flavescens*)	54	449	6,900	2,112.1	8.3	9.3	8.84	0.2	3.0	0.83
Iowa darter (*Etheostoma exile*)	18	672	2,361	1,656.6	8.1	9.8	8.74	0.2	3.0	0.91
Northern leopard frog (*Lithobates pipiens*)	17	707	3,838	1,679.7	8.2	9.7	8.74	0.3	3.0	0.79
Walleye (*Sander vitreus*)	12	651	3,128	1,833.2	8.1	9.1	8.70	0.2	3.0	1.17
Northern pike (*Esox lucius*)	5	246	670	443.6	8.6	8.9	8.73	0.3	1.1	0.71
Common carp (*Cyprinus carpio*)	3	867	1,434	1,239.3	8.7	8.8	8.74	0.6	1.67	1.10
Black bullhead (*Ameiurus melas*)	3	651	1,845	1,385.7	8.7	8.9	8.76	0.2	0.5	0.40
Smallmouth bass (*Micropterus dolomieu*)	1	644	644	644	9.0	9.0	9.00	1.0	1.0	1.00
Bluegill (*Lepomis macrochirus*)	1	672	672	672	8.9	8.9	8.90	0.64	0.64	0.64

[1]Determined from mean hydrogen ion concentration.

Table 5. Major cation characteristics of prairie lakes and wetlands containing aquatic vertebrates and fishless lakes and wetlands from 2012 and 2013 sampling of lakes and wetlands in Stutsman County and Kidder County, North Dakota.

[*N*, number of sites; mg/L, milligrams per liter]

Species	*N*	Calcium (mg/L)			Magnesium (mg/L)			Sodium (mg/L)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Fathead minnow (*Pimephales promelas*)	132	8.6	164.0	42.8	31.8	970.0	141.9	9.2	3,460	444.1
Brook stickleback (*Culaea inconstans*)	62	8.6	164.0	50.0	35.2	615.0	146.2	9.5	3,460	423.0
Tiger salamander (*Ambystoma mavortium*)	59	5.8	121.1	44.6	35.3	970.0	195.9	31.5	2,650	706.5
Yellow perch (*Perca flavescens*)	54	11.0	82.0	41.3	31.8	414.0	134.2	9.2	1,460	349.0
Iowa darter (*Etheostoma exile*)	18	10.0	82.9	55.5	64.6	154.0	109.1	21.4	287	161.6
Northern leopard frog (*Lithobates pipiens*)	17	12.7	86.2	44.8	52.8	414.0	115.2	21.3	1,227	252.2
Walleye (*Sander vitreus*)	12	23.1	82.9	43.2	45.1	217.0	101.8	30.1	512	223.7
Northern pike (*Esox lucius*)	5	15.6	64.7	36.5	35.2	98.5	74.9	9.5	200	66.7
Common carp (*Cyprinus carpio*)	3	31.3	82.9	59.4	66	112.0	88.3	66.0	109	86.9
Black bullhead (*Ameiurus melas*)	3	651	1,845	53.7	45.1	112.0	87.7	36.1	166	119.4
Smallmouth bass (*Micropterus dolomieu*)	1	15.1	15.1	15.1	72.8	72.8	72.8	27.3	27.3	27.3
Bluegill (*Lepomis macrochirus*)	1	31.1	31.1	31.1	64.6	64.6	64.6	21.4	21.4	21.4

Table 6. Major anion characteristics of prairie lakes and wetlands containing aquatic vertebrates and fishless lakes and wetlands from 2012 and 2013 sampling of lakes and wetlands in Stutsman County and Kidder County, North Dakota.

[*N*, number of sites; mg/L, milligrams per liter]

Species	*N*	Sulfate (mg/L)			Chloride (mg/L)			Carbonate/bicarbonate (mg/L)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Fathead minnow (*Pimephales promelas*)	132	33.8	8,560.0	1,054.7	6.0	984.0	125.1	223	1,272	595.3
Brook stickleback (*Culaea inconstans*)	62	59.4	8,560.0	1,061.7	6.8	984.0	128.8	229	1,236	560.8
Tiger salamander (*Ambystoma mavortium*)	59	10.4	7,314.0	1,706.3	7.5	759.0	177.6	262	2590	725.0
Yellow perch (*Perca flavescens*)	54	18.5	2917.0	843.4	2.9	616.0	114.1	223	6,900	2,112.1
Iowa darter (*Etheostoma exile*)	18	112.0	924.0	566.4	6.8	66.2	32.5	305	644	433.4
Northern leopard frog (*Lithobates pipiens*)	17	47.5	2,917.0	632.0	9.8	615.0	82.9	229	712	494.5
Walleye (*Sander vitreus*)	12	59.5	1,140.0	581.8	13.2	163.0	48.3	254	707	501.6
Northern pike (*Esox lucius*)	5	33.8	304.0	151.5	6.9	26.6	15.1	246	670	443.6
Common carp (*Cyprinus carpio*)	3	137.0	515.0	381.0	16.9	23.2	20.5	330	421	377.7
Black bullhead (*Ameiurus melas*)	3	121.0	619.0	449.3	13.3	57.4	40.9	254	353	298.3
Smallmouth bass (*Micropterus dolomieu*)	1	66.9	66.9	66.9	7.5	7.5	7.5	390	390	390
Bluegill (*Lepomis macrochirus*)	1	112.0	112.0	112.0	6.8	6.8	6.8	342	342	342

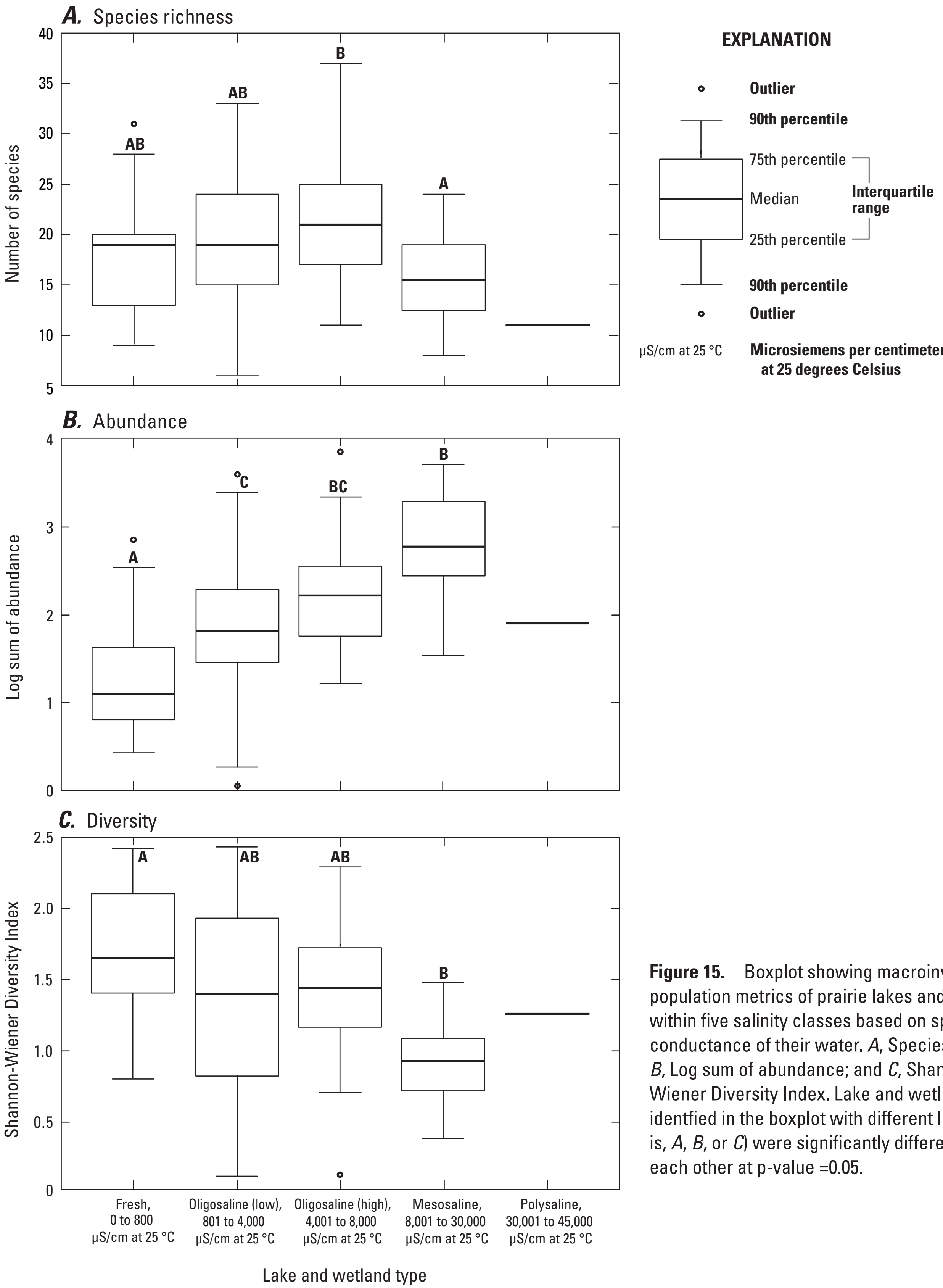


Figure 15. Boxplot showing macroinvertebrate population metrics of prairie lakes and wetlands within five salinity classes based on specific conductance of their water. *A*, Species Richness; *B*, Log sum of abundance; and *C*, Shannon-Wiener Diversity Index. Lake and wetland types identfied in the boxplot with different letters (that is, *A*, *B*, or *C*) were significantly different from each other at p-value =0.05.

Discussion

Increased precipitation since July 1993 has resulted in increased depths and volumes in prairie lakes and wetlands, the dilution of most major ion concentrations, the expansion of fish throughout the region, and shifts in macroinvertebrate communities towards those favoring fresh waters. The freshing of the region's aquatic habitats has likely affected other taxa not specifically evaluated in this effort, for example, waterfowl.

Water Chemistry

The freshening of saline lakes and wetlands resulted in the complete absence of eusaline and hypersaline habitat types and only a single polysaline lake during the 2012 and 2013 sample period. The freshening of lakes and wetlands that occurred following the 1988 to July 1993 drought also resulted in a decrease in the number of water types into just four of the seven determined by Swanson and others (1988). The absence of sodium chloride and magnesium chloride water types in our 2012 and 2013 sampling is undoubtedly related to the reduction in chloride concentrations between the two sample periods (1966 to 1976 range =5 to 13,470 mg/L; 2012 to 2013 range =2.9 to 2,520 mg/L). Only 1 saline lake had a specific conductance value >20,000 µS/cm at 25 °C during the 2012 and 2013 sampling, and only 11 lakes and wetlands had a specific conductance >10,000 µS/cm at 25 °C. This lack of saline lakes and wetlands is in stark contrast to the 1966 to 1976 sampling when 22 lakes and wetlands had specific conductance values >20,000 µS/cm at 25 °C and 38 had values >10,000 µS/cm at 25 °C.

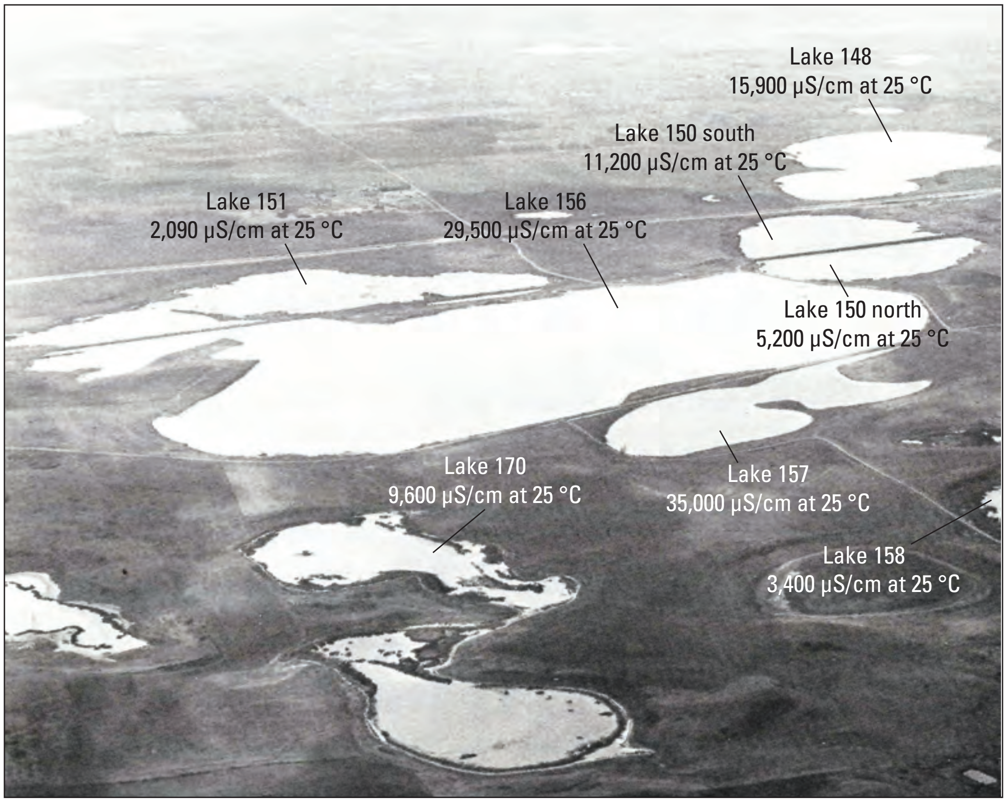
The freshening of Lake 153 provides an example of the great shifts in chemical characteristics of lakes and wetlands that occurred between the two sampling periods (fig. 16). In the 1966 to 1976 sampling, this hypersaline lake was the most saline lake or wetland sampled with a specific conductance of 70,300 µS/cm at 25 °C (appendix 3). By 2013, it had become an oligosaline lake with a specific conductance of 8,000 µS/cm at 25 °C. Sulfate concentrations in Lake 153 dropped from 87,500 mg/L in 1972 to 1,424 mg/L in 2013, chloride concentrations decreased from 1,738 to 229 mg/L, magnesium concentrations decreased from 11,600 to 239 mg/L, sodium concentrations decreased from 20,600 to 430 mg/L, and potassium concentrations dropped from 3,600 to 85.5 mg/L during this same period.

Although the salinity of most lakes and wetlands was lowered by wetter conditions occurring after 1992, some remained relatively unchanged and the salinity of others increased. In the majority of cases in which an increase in salinity occurred, the change was the result of rising water levels causing a lake or wetland with lower dissolved ion concentrations to merge with another water body containing higher dissolved ion concentrations. As an example, Swanson and others (1988) highlighted a lake complex in the Crystal Springs, N. Dak. area. Of particular interest were four lakes (Lake 150, Lake 151, Lake 156 [Stink Lake], and Lake 157). When sampled by Swanson and others (1988), the specific conductance of these four lakes was 7,000; 2,090; 29,500; and 35,000 µS/cm at 25 °C, respectively (appendix 3). Following the 1988–1992 drought, rising water levels caused these four lakes to merge into a single water body. Specific conductance values, measured in 2012 at the four original lake locations sampled by Swanson and others (1988), had changed to 6,810; 6,740; 6,900; and 6,830 µS/cm at 25 °C, respectively, reflecting the ability of water within these three lakes to freely mix once connected into a single water body (fig. 17). Although Lakes 156 and 157 showed marked decreases in specific conductance values between the two periods, Lake 150 changed very little and Lake 151 increased due to the mixing of waters from four lakes with a wide range of ion concentrations into a single water body with homogeneous chemical characteristics. This merging of lakes and wetlands, and intermixing of water, occurred throughout the study region during the post-drought years, which contributed to the loss of diversity in chemical characteristics that included increases in salinity in some lakes and wetlands.

Of the six lakes and wetlands displaying increases in specific conductance >1,000 µS/cm at 25 °C between the sample periods (Lakes 3, 14, 16, 144, 151, and 175), increases in four were the direct result of merging with other water bodies with higher concentrations of dissolved solids; however, Lakes 3 and 144 did not merge with any other water bodies during the study period. The reason for the salinity increase in these two lakes may be related to groundwater effects with potential to overcome dilution effects from increased precipitation and surface runoff into basins. The response of the entire hydrologic unit, upland plus wetland plus salts and water in the subsurface, can lead to complex changes under unusually wet conditions (Heagle and others, 2013; Nachshon and others, 2014). Lake 144 (1973 specific conductance value =36, 000 µS/cm at 25 °C; 2013 specific conductance value =40,350 µS/cm at 25 °C; appendix 3) is of special interest because it was the only lake or wetland sampled that was classified as polysaline (that is, specific conductance between 30,000 and 45,000 µS/cm at 25 °C). The next closest lake or wetland in terms of 2012 to 2013 salinity was Lake 43, which had a specific conductance value of 18,430 µS/cm at 25 °C. An examination of aerial imagery of Lake 144 revealed that, although within a closed basin and lacking a surface spill point, this lake varied little in size between the two sample periods as compared to surrounding lakes and wetlands in similar settings (note how Lake 144 changes little in size between the two years while surrounding wetlands are substantially larger in 1997; fig. 18). Also, this lake was located near the intersection of an area of low permeability glacial till and an area of high permeability outwash. The unique location of this lake at the intersection of two areas with greatly different hydrologic conductivities may have set the stage for a stronger effect of groundwater on the water budget than for other lakes and wetlands sampled; however, additional work is needed to verify this hypothesis.

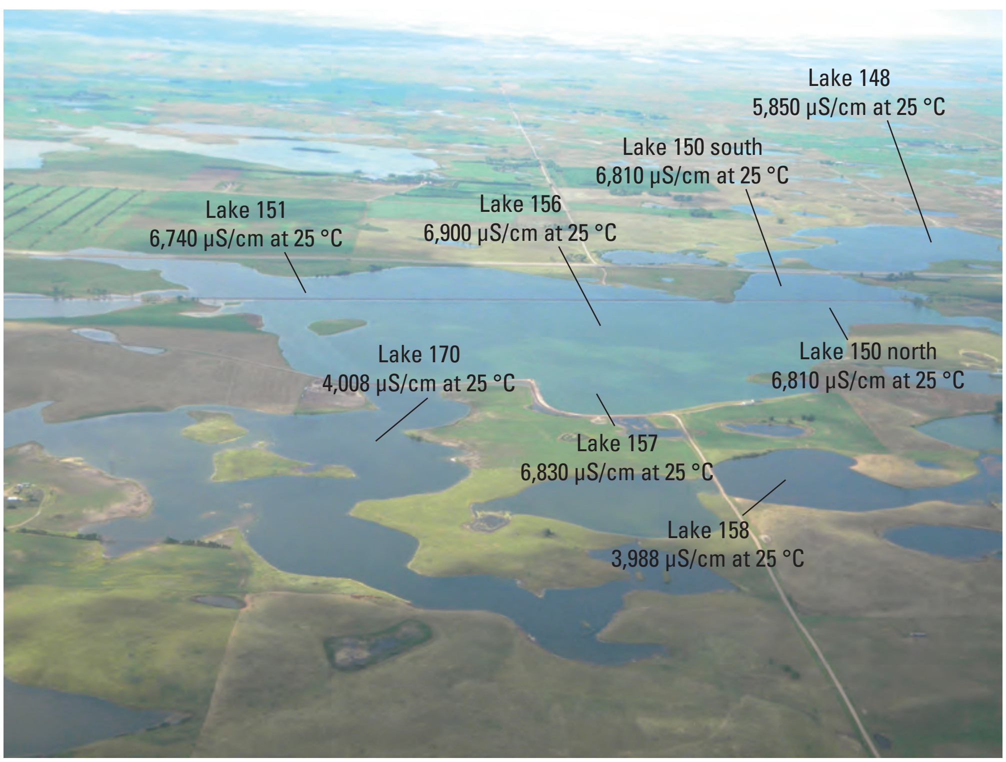
Figure 16. Aerial photographs showing Lake 153, Stutsman County, North Dakota. *A*, September 24, 1997, and *B*, September 25, 2012.

A



Swanson and others, 1988

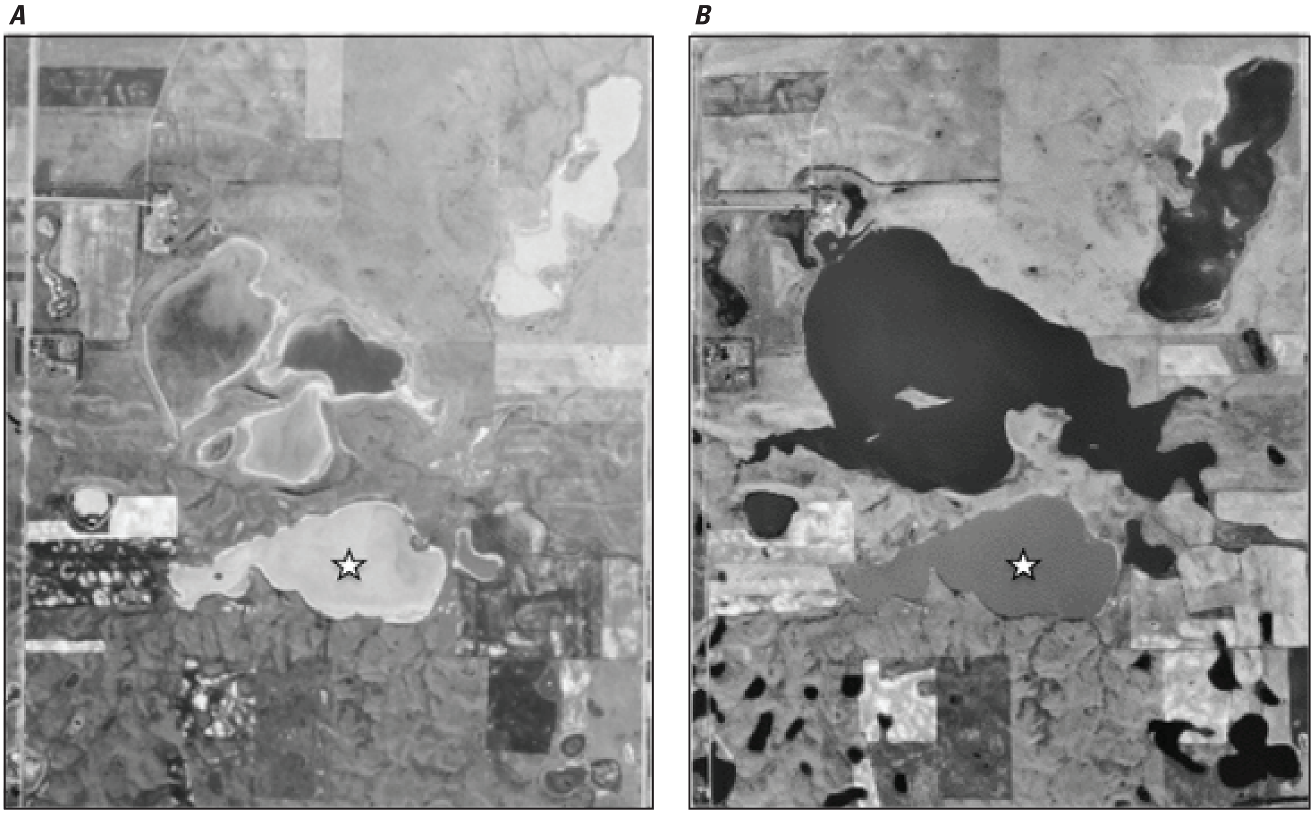
B



EXPLANATION

µS/cm at 25 °C **Microsiemens per centimeter at 25 degrees Celsius**

Figure 17. Specific conductance of lakes in the Crystal Springs, North Dakota, area from sampling conducted in *A*, 1966 to 1976 (aerial photograph reproduced from Swanson and others, 1988) and *B*, 2012 and 2013 (aerial photograph from July 2012).



National Aerial Photography Program (NAPP) imagery obtained through EarthExplorer (*earthexplorer.usgs.gov*)

Figure 18. National Aerial Photography Program (NAPP) photographs of Lake 144 (indicated with a star) from *A*, July 13, 1990, and *B*, September 25, 1997.

Aquatic Vertebrates

Fish presence has been historically limited by shallow water levels and high salinities that are characteristic of prairie lakes and wetlands (McCarraher, 1960; McCarraher and Thomas, 1968; Rawson and Moore, 1944). The changes that occurred to lakes and wetlands between the two sample periods resulted in a landscape much more favorable for fish habitation (that is, deeper and fresher lakes and wetlands); in fact, fish were caught in 86 percent of the 162 lakes and wetlands sampled for fish. The presence of gamefish increased from 9 lakes during sampling in the 1960s and 1970s (Swanson and others, 1988) to 62 lakes during the 2012–13 sampling. Shallow lakes have generally been defined as lakes with a maximum depth of less than 3 m (for example, Minnesota Department of Natural Resources, 2012. Of the 167 lakes and wetlands we sampled in 2012 and 2013, only 34 would be considered shallow following this definition (that is, 133 of the lakes and wetlands had maximum water depths greater than or equal to 3 m).

When salamanders are considered in addition to fish, 97 percent of the lakes and wetlands supported vertebrates (fish, salamanders, or both) during 2012 to 2013. Our findings of fish and salamander presence along alkalinity and specific conductance gradients are consistent with species thresholds identified in previous studies. Fathead minnows typically do not occur in alkaline waters above 2,000 mg/L (McCarraher and Thomas, 1968). The maximum alkalinity for a lake or wetland with fathead minnows during our sampling was 1,272 mg/L. Brook sticklebacks are also limited to alkalinities below 2,000 mg/L (Scott and Crossman, 1973). The maximum alkalinity of lakes and wetlands with brook sticklebacks was 1,236 mg/L. Similarly, brook sticklebacks, yellow perch, and barred tiger salamanders are limited to waters with a specific conductance <25,000 µS/cm at 25 °C (Scott and Crossman, 1973); 4,500 µS/cm at 25 °C (Koel and Peterka, 1995); and 12,500 µS/cm at 25 °C (Swanson and others, 1988), respectively. In our sampling, we determined these species to be completely absent in waters above 15,430 µS/cm at 25 °C (brook stickleback); 6,900 µS/cm at 25 °C (yellow perch); and 12,000 µS/cm at 25 °C (barred tiger salamanders). The occurrence of fathead minnows in lakes and wetlands was mostly consistent with known thresholds (that is, maximum =12,000 µS/cm at 25 °C; Burnham and Peterka, 1975); however, we did find fathead minnows in one lake with a specific conductance of 15,530 µS/cm at 25 °C. It should also be noted that although tiger salamanders have similar tolerances to salinity as fathead minnows (12,500 and 12,000 µS/cm at 25 °C, respectively), we found that they were more tolerant of alkalinity and thrived in alkaline waters >1,500 mg/L where fish were absent. In addition to the three common fish species already discussed, Iowa darters were only captured in lakes and wetlands with specific conductance between 672 and 2,361 µS/cm at 25 °C, indicating a preference for fresh water.

Macroinvertebrates

Swanson and others (1988) present several examples of invertebrate shifts that occur in response to changes in salt concentrations. As an example, they describe how *Lymnaea stagnalis* (swamp lymnaea) was restricted to lakes and wetlands with relatively low dissolved salt concentrations (that is, specific conductance <5000 µS/cm at 25 °C). Above 5,000 µS/cm at 25 °C, the swamp lymnaea is replaced by *Stagnicola* spp. as the dominant pond snail; however, *Stagnicola* is restricted to water with salt concentrations <10,000 µS/cm at 25 °C. Swanson and others (1988) also describe how relatively few species can tolerate salt concentrations of highly saline lakes and wetlands and that these highly saline sites have invertebrate communities dominated by *Artemia salina* (brine shrimp), *Ephydra* spp. (brine flies) and Corixidae (water boatmen). Gleason and others (2009) also determined that many aquatic invertebrate taxa occur across a relatively broad range of salt concentrations; however, the most highly saline waters are populated by relatively few taxa, including brine shrimp, copepods, and a small number of Coleoptera (beetle) and Diptera (fly) species.

Our 2012 and 2013 sampling of macroinvertebrate communities identified associations of invertebrates to salinity gradients that paralleled those presented by Swanson and others (1988) and reviewed by Gleason and others (2009). *Lymnaea stagnalis* occurred in lakes and wetlands with specific conductance values ranging from 721 to 3,587 µS/cm at 25 °C, well below the 5,000-µS/cm at 25 °C threshold identified by Swanson and others (1988). *Stagnicola* spp. were present in waters ranging from 1,153 to 6,740 µS/cm at 25 °C. Only a single lake or wetland sampled in 2012 to 2013 had salt concentrations resulting in a specific conductance >35,000 µS/cm at 25 °C (Lake 144). Invertebrates in this lake were restricted to only 10 taxa: brine shrimp, two copepods (Calanoida and Harpactocoida), a water flea, ostracods, water boatmen, one beetle (*Hygrotus*), and three flies (Ephydridae, Stratiomyidae, and *Eristalis*). This polysaline lake was the only lake sampled in which brine shrimp, *Eristalis* (hover flies), and harpacticoid copepods (Harpacticoida) occurred. We suspect that, at the even higher salt concentrations observed from 1966 to 1976, additional taxa would fall out of the community until only brine shrimp, brine flies, and salt-tolerant copepods and water boatmen remained as described by Swanson and others (1988); however, the freshening of lakes and wetlands throughout our study region has made macroinvertebrate communities that are dominated by only the most salt-tolerant species a very rare occurrence. Instead, diverse macroinvertebrate assemblages that include representatives from the wide range of less salt-tolerant species are more likely to reside in the more homogeneous habitat types resulting from the recent freshening of the region's saline lakes and wetlands.

The decline of species richness with increasing salinities is consistent with findings of Swanson and others (1988) and findings from similar closed basin lakes in Wyoming, Canada, and Australia (Timms, 1981; Hammer and others, 1990; and Wollheim and Lovvorn, 1995). Additionally, lakes and wetlands with high salinities had increased invertebrate abundances. Similar studies indicate this increase in invertebrate abundance in saline lakes and wetlands with low diversity is caused by a shift to small, but highly abundant, suspended macroinvertebrates such as copepods and corixids dominating the more saline lakes (Rawson and Moore, 1944; Timms, 1981; Galat and Robisnson, 1983; Wollheim and Lovvorn, 1995). The increased availability of lower salinity habitats may likely benefit most waterfowl species that consistently prey on macroinvertebrates such as amphipods and snails but would not favor shorebirds such as phalaropes, avocets, and yellowlegs, species that consistently feed on the diving beetles and corixids commonly present at higher salinities (Wollheim and Lovvorn, 1995).

Implications for Waterfowl

Waterfowl breeding populations are surveyed annually by the U.S. Fish and Wildlife Service, and populations of most species are known to favorably respond to the number of early season breeding habitats (May ponds) available on the landscape (Zimpfer and others, 2014). Wetland modeling efforts in the PPR (Johnson and others, 2005, 2010) have predicted that under a warming climate, increases in evapotranspiration will likely overcome any precipitation increases associated with a changing climate and favorable waterfowl habitat conditions will shift from the traditionally more productive areas of North Dakota, South Dakota, and Canada, such as the area we sampled, to the eastern edges of the region where wetland drainage and other alterations affecting wetlands have been greatest; however, May pond numbers throughout the PPR of the United States were high during much of the 1993 to 2014 period because of the trend towards increased precipitation. The increased water on the landscape of our study region generally provided favorable conditions for most waterfowl; in fact, six waterfowl species have displayed marked population increases since 1993 reflective of the increased availability of aquatic habitats (including May ponds) across the region (Zimpfer and others, 2014; fig. 19).

Although many waterfowl species responded favorably to increased availability of water on the landscape, some species failed to show a positive response (fig. 20), indicating that other factors were more important population effects for these species. One of the waterfowl species that failed to increase during the post-drought years of our study was *Anas americana* (American wigeon). Swanson and others (1988) highlighted this waterfowl species and suggested that high salt

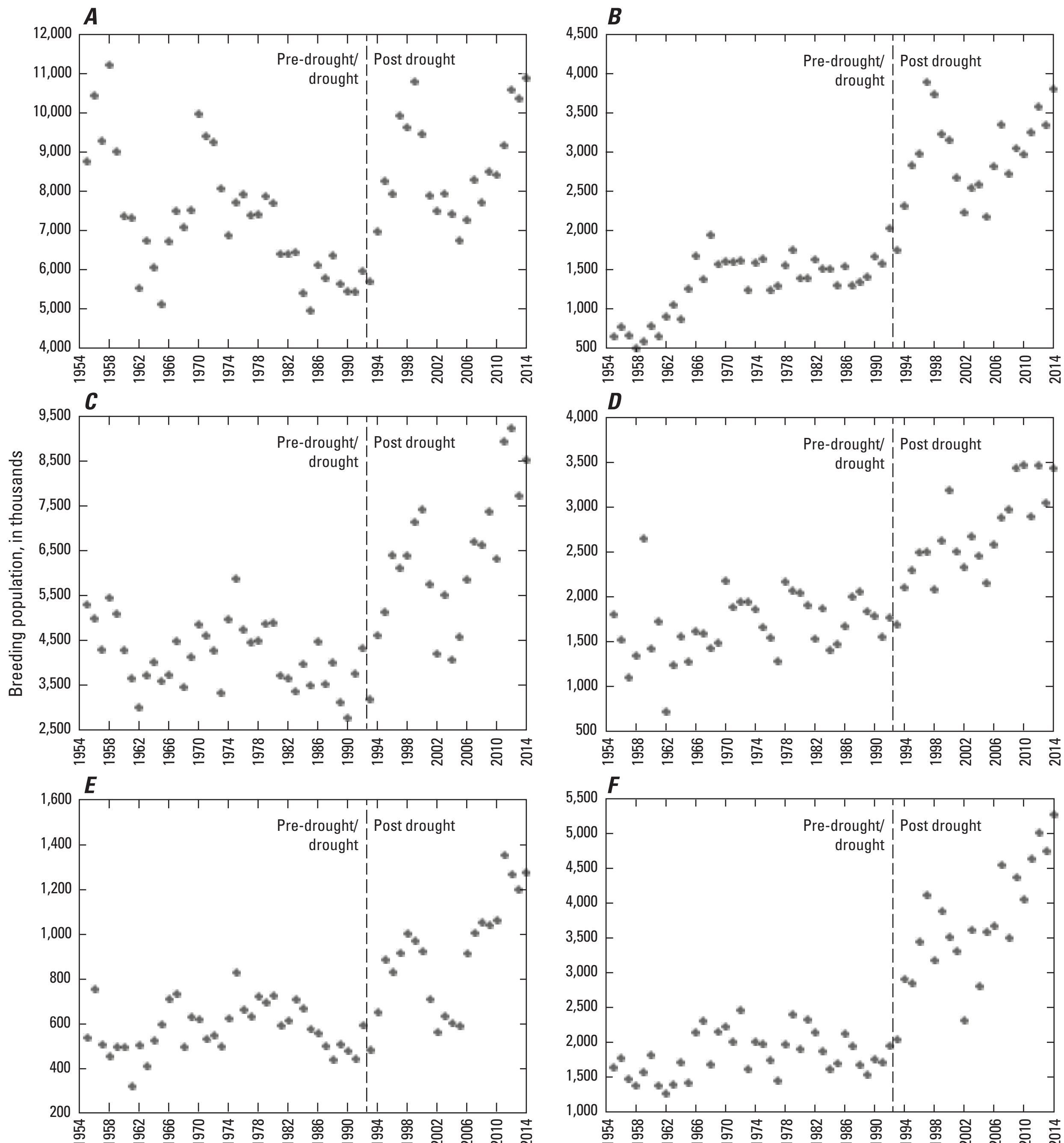


Figure 19. Breeding population of six waterfowl species that displayed marked increases during the 1993 to 2014 post-drought period. *A*, Anas platyrhynchos (mallard); *B*, Anas strepera (gadwall); *C*, Anas discors (blue-winged teal); *D*, Anas crecca (green-winged teal); *E*, Aythya americana (redhead); and *F*, Anas clypeata (northern shoveler). Data from Zimpher and others, (2014).

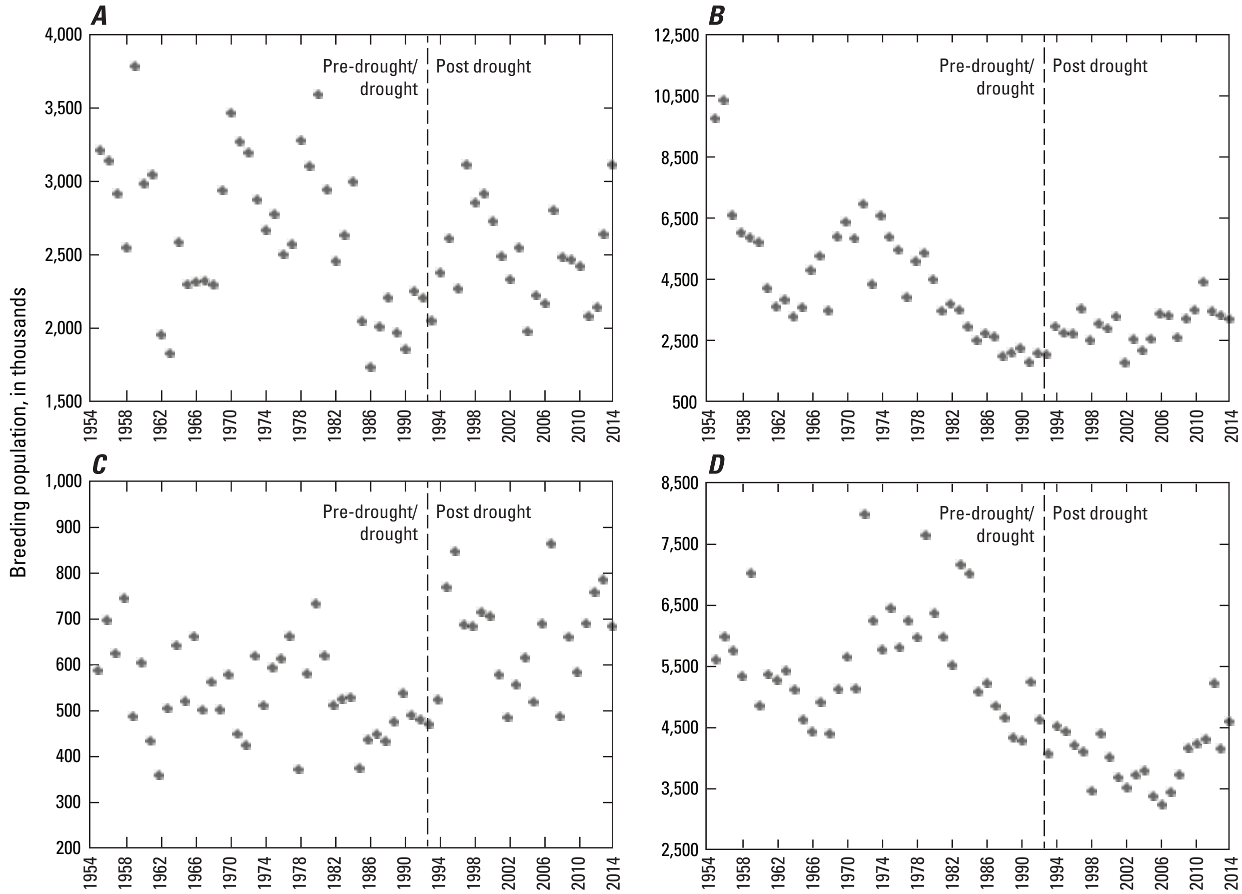


Figure 20. Breeding population of four waterfowl species that did not display marked increases during the 1993 to 2014 post-drought period. *A*, American wigeon (Anas americana); *B*, northern pintail (Anas acuta); *C*, canvasback (Aythya valisineria); and *D*, lesser scaup (Aythya affinis). Data from Zimpher and others (2014).

concentrations affected this species through the positive association of *Ruppia maritima* (widgeongrass) with higher water salinities. As its name implies, widgeongrass is a plant species favored by American wigeon. Widgeongrass is dominant over other less salt-tolerant plant species in lakes and wetlands with high salt concentrations. Due to its tolerance of high salinity water, widgeongrass is commonly present in coastal bays and other marine environments but also occurs in brackish and saline inland waters (Gleason and others, 2009). Although we did not sample plant communities in this study, it is likely that the freshening of most lakes and wetlands led to less favorable conditions for the growth of widgeongrass, which is outcompeted in fresher environments, and concurrently for the American wigeon populations that this plant supports; however, another waterfowl species that is known to respond positively to widgeongrass, the redhead, showed a marked increase in the post-drought years despite less favorable conditions for widgeongrass growth.

Although likely negatively influencing widgeongrass, the freshening of lakes and wetlands likely produced conditions more favorable to deep-marsh emergent plants such as cattails (*Typha* spp.) and bulrushes (*Schoenoplectus* spp.) that flourish in waters with lower salt concentrations (Gleason and others, 2009). Swanson and others (1988) listed four features of prairie lakes and wetlands that largely affect use by waterfowl: (1) plant and invertebrate communities needed to meet waterfowl nutritional requirements, (2) overwater nesting cover, (3) a source of suitable (fresh) drinking water, and (4) escape cover for flightless birds. Both American wigeon and redhead populations would likely have been affected similarly by decrease in widgeongrass availability. Also, availability of drinking water and escape cover (deep-marsh emergent vegetation) would have both been positively affected for these species; however, the redhead is an overwater nesting species, whereas the American wigeon is an upland nester. Thus, the increased availability of overwater nesting habitat in the form of increased stands of cattails and bulrushes surrounding lakes and wetlands may have affected redhead populations in a manner that compensated for negative effects from decreased availability of widgeongrass. Likewise, the American wigeon could have been affected by both a decrease in nutrient availability and a decline in nesting habitat if conditions in the uplands also were negatively affected by agricultural development or other upland land-cover effects. To fully understand the ultimate effect of changing chemical characteristics on waterfowl, populations and their unique habitat requirements must be considered at the species level. Additionally, other factors influencing waterfowl populations (for example, land-cover in surrounding uplands, wintering habitat conditions, conditions along migratory corridors) must also be considered.

Conclusions

Between the original 1966 to 1976 sampling and our 2012 to 2013 sampling, most prairie lakes and wetlands in Stutsman County and Kidder County, North Dakota, have increased markedly in size, depth, and water volume. These increases are largely related to precipitation increases that started following a drought that persisted from 1988 to July 1993. Increased water volumes in prairie lakes and wetlands have resulted in lower concentrations of most major ions through dilution. The freshening of these water bodies has resulted in a reduction in the diversity of water types that have historically supported diverse plant and animal communities in the region. Many lakes and wetlands were previously too salty for fish; however, the freshening of these wetlands to levels favorable to fish and an increase in surface connections facilitating fish movements into new areas have resulted in most sampled lakes and wetlands now containing fish, primarily fathead minnows and brook sticklebacks, but also including several game-fish species. This increase in fish prevalence across the prairie pothole landscape has resulted in tiger salamander populations being restricted primarily to sites where salt concentrations have remained high enough to restrict fish populations and to sites that have remained isolated in the terms of lacking surface water connections suitable for fish movements. The changed chemical characteristics, fish communities, and invertebrate communities of sampled prairie lakes and wetlands likely also affect the suitability and use of these sites by waterfowl and other wildlife; however, effects, both positive and negative, will need to be assessed on a species specific basis. Whether these high water conditions, which have resulted in the fresh, relatively homogeneous habitat conditions for a region known for its diversity, will continue is unknown; however, the response of habitats and dependent wildlife to changing climate conditions will likely be far more complicated than has been indicated by previous modeling efforts suggesting an overall drying trend resulting from increased temperatures.

Acknowledgments

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Appendixes 1–5

Appendix 1. Analytical laboratory methods used in 2012 and 2013 sampling of prairie lakes and wetlands in south-central North Dakota.

[Temp, temperature; mV, millivolts; mg/L, milligrams per liter; nm, nanometer]

Field methods	
pH	Beckman Coulter 250 pH/Temp/mV meter (part #511201) with Beckman Coulter combination pH electrode (part #511053). Two point standardization with 7.00 and 10.01 pH buffers.
Specific conductance	WTW Model 315i meter with a TetraCon 325 standard conductivity measuring cell.
Laboratory methods	
Total alkalinity	Titrimetric: Endpoint titration with sulfuric acid using a Thermo 940-960 autotitrator.
Sulfate	Ion chromatography detection limit 0.1 mg/L.
Chloride	Ion chromatography detection limit 0.1 mg/L.
Magnesium	Inductively coupled plasma-optical emission spectroscopy; wavelength 285.211 nm.
Calcium	Inductively coupled plasma-optical emission spectroscopy; wavelength 317.933 nm.
Sodium	Inductively coupled plasma-optical emission spectroscopy; wavelength 589.592 nm.
Potassium	Inductively coupled plasma-optical emission spectroscopy; wavelength 766.495 nm.

Appendix 2. Analytical laboratory methods used in 1966 to 1976 sampling of 178 prairie lakes and wetlands in south-central North Dakota (reproduced from Swanson and others, 1988).

[A 50-milliliter (mL) aliquot was placed in a 100-mL volumetric flask. The pH level was adjusted with hydrochloric acid to about 4, and 5 mL of 10-percent lanthanum solution was added. The volume was brought to 100 mL (the resulting solution had a lanthanum content of 1 percent). Calcium, magnesium, sodium, and potassium were then determined through atomic absorption spectrometry. ±, plus or minus; °C, degrees Celsius; nm, nanometer; Å, angstrom; mg/L, milligram per liter]

Field methods	
pH	Colorimetric: Model 17-N wide range pH comparator (Hach Chemical Co., Loveland, CO). Electrometric: Portomatic Model 175 I. L. pH meter with combination electrode (Instrumentation Laboratory, Watertown, Mass.).
Specific conductance	Electrometric: portable Model Mark IV Lectro mho-meter with unbreakable sprole cell K–1 (Labline Instruments Inc., Melrose, Ill.).
Laboratory methods	
pH	Electrometric: research Model 7415 L. N. pH-meter with combination electrode (Leeds & Northrup Co., Philadelphia, Pa.).
Total alkalinity	Titrimetric: sulfuric acid titration with phelolphthalein and brom cresol green-methyl red indicators.
Specific conductance	Electrometric: multipurpose Model 4959 resistance/conductance bridge with glass/platinum electrodes (Leeds & Northrup Co., Philadelphia, Pa.).
Fixed residue	Gravimetric: furnace heating at 550 ± 5 °C.
Total residue	Gravimetric: oven heating at 103 ± 2 °C.
Sulfate	Turbidimetric: wavelength at 450 nm.
Chloride	Titrimetric: mercuric nitrate titration with buffered diphenylcarbazone indicator.
Magnesium	Spectrometric: Model 303 P-E spectrometer (Analytical Methods, Perkin-Elmer Corp., Norwalk, Conn.). Primary wavelength at 2,852 Å and burner at 90 °C to optical path for 0.1–60 mg/L; secondary wavelength at 2,025 Å and burner at 90 °C to optical path for 0.1–600 mg/L.
Calcium	Primary wavelength at 4,227 Å and for 0.1–1.5 mg/L; Primary wavelength and burner at 90 °C to optical path for 0.1–150 mg/L.
Sodium	Primary wavelength at 5,890 Å for 0.1–75 mg/L; secondary wavelength at 3,302 Å for 0.1–700 mg/L.
Potassium	Primary wavelength at 7,665 Å for 0.1–20 mg/L; primary wavelength and burner at 90 °C to optical path for 0.1–100 mg/L; secondary wavelength at 4,044 Å for 0.1–140 mg/L.

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
1	5/1969	9.1	860	4,150	1,185	105	28	8	860	60
1	6/7/2013	9.0	771	2,723	899	49.5	64.9	22.3	573	52.6
2	3/1973	9.1	1,170	4,600	1,250	70	1	3	1,280	48
2	6/5/2013	9.0	861	4,614	1,780	34.6	55.2	22.3	1,000	28.8
3	9/1972	9.3	980	4,400	1,250	30	58	18	975	70
3	8/10/2012	9.1	741	6,350	3,301	49.8	150	44.8	1,395	98.9
4	6/1969	9.6	3,760	19,500	8,750	15	140	4	1,600	704
4	7/1/2013	9.0	748	1,933	448	45.1	88.6	18	296	47.2
5	6/1969	8.9	850	2,150	400	65	143	18	23	43
5	7/1/2013	8.8	421	867	137	16.9	66	31.3	66	14.7
6	9/1972	8.8	460	30,000	30,000	480	2,640	131	4,040	870
6	9/10/2013	8.9	470	5,180	2,970	66.3	348	44	857	92.4
7	3/1973	8.8	570	2,800	700	85	42	14	546	81
7	6/27/2012	8.5	644	1,850	494	41.0	81.3	38.4	273	35.2
8	6/1969	9.1	960	2,300	350	55	109	3	292	45
8	6/27/2012	8.1	605	1,885	522	41.4	72.6	41.3	285	32.9
9	9/1972	9.3	1,540	4,700	1,050	155	124	10	1,055	150
9	8/10/2012	9.3	839	1,934	357	44.4	95.9	8.69	282	46.2
10	9/1972	8.7	950	3,300	875	110	134	25	574	80
10	8/10/2012	9.8	615	1,347	270	30.4	78.8	9.99	186	29.7
11	6/1969	9.2	1,550	4,350	1,200	65	62	8	1,280	72
11	6/10/2013	9.0	804	1,693	306	19	59.2	18.3	344	38
12	6/1969	9.0	1,300	7,850	2,630	350	228	9	1,440	302
12	7/12/2013	8.9	715	2,969	1,020	77.8	96.8	31.5	536	62.7
13	6/1969	9.0	760	3,100	1,000	120	120	15	400	75
13	7/12/2013	8.9	707	2,972	1,030	77	101	31.6	512	65.6
14	7/1972	9.1	480	1,750	350	25	64	31	280	38
14	7/12/2013	8.7	657	2,804	966	70.4	92.9	38.5	450	56.2
15	5/1973	9.3	2,120	23,050	8,000	1,555	666	8	5,760	522
15	6/25/2012	8.9	1,246	11,190	5,902	663	377	27.4	2,650	225
16	7/1972	9.4	760	2,800	525	95	128	10	456	60
16	6/25/2012	8.9	1,228	11,450	5,827	668	367	27.6	2,610	221
17	9/1972	9.0	680	2,800	700	35	60	15	530	46
17	7/16/2013	9.0	482	1,450	413	14.5	60.2	26.3	221	23.9
18	11/1972	9.4	2,590	10,200	2,200	260	59	8	2,780	170
18	7/26/2013	9.2	867	2,925	864	52.3	61.8	16.9	610	51.2

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
19	7/1970	9.6	6,040	42,000	8,000	6,670	1	2	11,500	960
19	7/16/2013	9.4	2,590	10,410	2,940	652	64.6	5.8	2,550	179
20	7/1972	9.1	830	7,050	2,125	300	170	25	1,564	167
20	8/5/2013	9.0	619	1,414	357	32.6	112	22.3	177	30.8
21	7/1970	9.4	5,960	64,000	22,500	13,470	62	2	21,800	660
21	7/18/2012	9.2	1,077	6,640	2,031	474	128	24.5	1,296	122
22	3/1973	9.1	610	25,000	10,250	2,470	910	15	5,920	814
22	6/10/2013	8.6	670	11,700	5,530	656	373	48.1	2,310	295
23	9/1972	8.7	1,410	34,000	13,750	3,485	1,560	24	10,760	1,460
23	7/15/2013	8.8	832	6,950	2,860	457	203	34.9	1,490	168
24	7/1970	9.6	10,800	40,000	13,750	2,775	27	3	12,000	972
24	8/5/2013	9.3	1,050	3,498	1,090	94	60.6	13.8	817	64.7
25	6/1969	9.1	450	960	95	45	75	17	33	70
25	6/27/2012	8.4	354	698	100	8.1	51.4	49.0	37	6.88
26	7/1972	9.0	1,420	31,300	15,500	2,295	2,984	7	8,160	800
26	6/25/2012	8.6	593	12,530	6,964	759	873	68.0	1,880	189
27	7/1969	9.1	380	30,100	18,750	2,480	1,492	83	6,880	348
27	7/15/2013	8.8	538	9,730	5,390	552	572	77.7	1,640	204
28	7/1972	9.0	800	2,140	310	60	192	8	192	80
28	7/11/2012	8.6	560	979	85	19.8	98.5	15.6	54	29.7
29	10/1976	8.2	270	1,020	250	20	62	35	67	15
29	7/9/2012	8.7	254	651	121	13.2	45.1	27.7	36	9.84
30	6/1967	9.3	1,720	14,900	6,875	945	200	100	3,660	245
30	7/31/2013	9.3	1,040	6,440	2,480	388	176	14.6	1,460	103
31	9/1972	9.3	640	3,900	1,000	240	190	11	595	80
31	7/31/2013	9.2	592	1,081	163	32	82.2	18.1	135	22.9
32	9/1973	8.9	700	32,000	14,500	2,405	1,580	56	8,400	652
32	7/22/2013	8.9	619	7,210	3,490	371	405	24.9	1,300	121
33	5/1971	9.1	620	1,280	225	25	174	104	40	26
33	7/2/2013	9.0	477	706	38	12.6	81.2	19.7	29	15.2
34	5/1971	9.1	500	1,380	300	35	174	28	48	30
34	7/2/2013	8.9	374	607	34	11.6	61.4	25.1	20	10.8
35	5/1971	8.9	240	565	49	15	39	52	14	5
35	7/2/2013	8.6	246	500	59	10.5	35.2	47.5	10	5.54
36	5/1971	9.2	670	1,360	200	30	170	18	70	36
36	7/25/2012	9.2	456	721	35	15.5	81.4	18.7	26	12.2

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
37	5/1971	8.9	700	2,350	500	70	204	27	208	78
37	7/25/2012	9.2	676	1,290	216	32.4	108	11.4	156	41.8
38	11/1972	9.0	530	1,140	90	35	59	10	64	76
38	7/5/2012	8.8	404	712	60	17.9	62.0	23.1	30	28.0
39	5/1971	9.5	150	365	40	20	45	17	11	8
39	7/18/2012	8.5	223	449	49	6.0	31.8	32.4	9	8.58
40	5/1971	8.3	400	690	48	15	73	50	22	11
40	7/20/2012	9.1	521	462	104	9.2	95.8	18.1	49	19.9
41	11/1972	9.0	350	770	75	20	52	13	36	15
41	7/24/2012	9.0	390	644	67	7.5	72.8	15.1	27	11.4
42	5/1971	8.7	590	3,500	1,250	140	282	61	264	74
42	8/7/2013	9.2	843	2,580	709	107	105	18.6	480	91.6
43	5/1971	8.9	1,250	47,000	33,750	4,255	3,024	68	11,200	960
43	7/25/2012	9.0	939	18,430	9,556	1,292	657	24.2	4,147	330
44	7/1972	9.4	1,280	10,200	3,125	575	424	8	1,950	280
44	7/25/2012	9.2	926	3,262	962	136	197	8.86	433	69.2
45	7/1972	9.4	1,280	8,150	1,850	410	412	7	1,530	188
45	7/24/2012	9.1	931	3,762	1,188	179	212	11.7	524	72.6
46	7/1971	8.8	560	1,440	125	145	156	27	106	36
46	--	--	--	--	--	--	--	--	--	--
47	5/1971	9.3	930	4,400	1,000	280	192	13	562	184
47	6/10/2013	9.1	719	1,293	139	46.1	98.4	19.6	142	36.9
48	7/1969	9.5	1,510	10,100	1,625	1,720	10	1	1,860	174
48	7/18/2012	9.2	1,236	4,422	843	354	71.6	14.2	857	61.0
49	9/1972	9.3	890	3,700	900	160	110	12	746	55
49	8/7/2013	8.9	670	1,359	275	26.6	90.4	29.7	200	21.1
50	9/1972	8.4	700	2,100	400	35	194	47	240	50
50	8/1/2012	9.1	646	1,089	108	13.4	89.5	12.7	119	20.5
51	9/1972	9.3	1,940	12,000	5,000	45	75	13	3,780	280
51	8/1/2012	8.8	1,220	4,687	1,623	77.1	80.5	19.6	966	88.8
52	9/1972	9.4	1,290	8,500	2,750	160	134	12	2,000	170
52	8/1/2012	8.8	873	3,652	1,338	37.6	91.9	35.7	687	48.6
53	9/1972	9.5	2,630	11,200	4,375	265	101	10	3,910	250
53	7/26/2013	9.0	745	3,651	1,480	27.7	85.9	35.6	797	49
54	5/1973	9.3	840	13,500	7,500	390	103	73	5,000	240
54	6/17/2013	9.0	561	3,392	1,390	22.3	80.4	30.3	659	41.3

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
55	9/1972	8.5	720	2,230	440	35	52	39	418	53
55	--	--	--	--	--	--	--	--	--	--
56	9/1972	10.0	320	1,950	550	15	62	25	280	60
56	7/26/2013	8.9	603	1,449	348	11.6	80.4	21.3	218	34.5
57	9/1972	9.2	980	3,600	1,000	35	122	9	630	80
57	8/3/2012	9.0	609	1,514	352	14.3	86.9	11.0	216	34.4
58	9/1972	9.4	810	3,100	800	70	280	8	375	104
58	8/6/2012	8.8	648	1,109	132	23.0	99.4	24.1	88	41.3
59	9/1972	9.3	920	3,100	700	85	164	10	350	150
59	8/6/2012	9.0	717	1,642	418	38.5	143	23.1	165	87.0
60	9/1972	8.4	390	750	28	15	70	30	25	25
60	8/6/2012	8.8	353	625	76	8.8	57.9	25.1	30	17.8
61	9/1972	9.2	1,040	2,220	220	65	152	11	270	110
61	8/9/2013	8.7	748	958	10	14.6	103	31.6	64	32.1
62	9/1972	8.8	800	2,700	600	50	232	29	250	100
62	8/9/2013	8.8	521	1,160	295	13.5	101	34.9	94	40.2
63	8/1973	9.6	3,430	18,000	6,500	25	500	12	4,840	424
63	8/3/2012	9.1	634	1,768	464	17.5	73.6	26.5	255	32.0
64	8/1973	8.7	920	4,000	230	25	118	29	755	84
64	8/3/2012	8.9	633	1,794	457	17.6	74.4	26.6	259	32.5
65	9/1972	8.8	460	1,200	125	45	86	16	135	22
65	8/7/2013	9.0	460	740	34	35	66.6	22.8	62	11.3
66	10/1972	9.2	1,100	4,800	1,500	150	67	22	1,260	80
66	--	--	--	--	--	--	--	--	--	--
67	9/1972	9.5	1,400	5,900	2,500	350	166	5	1,980	110
67	7/30/2012	9.0	820	3,876	1,347	129	102	11.8	768	46.5
68	9/1972	9.7	4,040	34,000	21,250	3,250	860	1	17,120	430
68	7/30/2012	9.2	1,272	11,200	4,577	513	185	21.5	2,572	129
69	9/1972	9.5	970	2,800	550	60	142	3	424	90
69	7/30/2012	9.0	659	1,487	316	26.4	94.5	13.6	169	39.6
70	9/1972	9.3	1,410	6,800	2,000	295	162	24	2,320	140
70	8/9/2013	8.9	734	2,689	886	72.5	80.9	36.6	551	46.2
71	10/1972	8.9	910	6,200	2,500	175	464	35	1,215	150
71	8/12/2013	8.9	494	2,826	1,220	46	183	56.5	366	48.1
72	9/1972	9.0	320	580	38	5	54	11	35	14
72	7/18/2013	8.3	350	537	19	2.9	38.3	37.6	18	6.56

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
73	9/1972	9.6	1,790	3,600	1,000	210	73	4	1,330	100
73	7/18/2013	9.9	1,230	3,956	1,020	125	58.7	8.6	830	56.8
74	9/1972	9.3	1,330	4,500	855	205	188	6	835	80
74	7/18/2013	9.1	578	1,459	308	43.4	80.6	25	184	21.5
75	9/1972	10.2	390	4,200	1,375	200	164	13	576	80
75	7/22/2013	8.7	608	2,626	996	107	191	26.9	298	54.7
76	9/1972	9.1	490	1,020	75	30	79	12	64	50
76	7/27/2012	9.0	474	990	187	16.9	97.5	17.3	55	40.9
77	9/1972	9.5	900	8,000	4,000	780	396	13	2,300	198
77	8/12/2013	9.2	622	3,587	1,230	181	126	29.5	666	67.7
78	5/1973	9.6	4,840	25,000	6,250	5,240	80	30	17,280	244
78	6/17/2013	--	1,090	4,290	1,010	374	89.1	15.4	927	53.2
79	5/1973	9.7	920	3,200	500	215	43	7	605	82
79	6/17/2013	9.3	945	2,993	609	234	65.5	17.4	578	55.4
80	9/1972	9.4	570	3,900	1,000	285	192	14	582	80
80	7/29/2013	9.0	630	2,546	877	138	167	36.3	373	53.3
81	9/1972	8.6	670	2,000	450	126	119	19	374	62
81	7/29/2013	8.8	427	1,148	292	44.9	83.5	41	119	22.9
82	6/1967	8.8	480	3,140	1,250	95	200	58	384	80
82	7/16/2012	8.7	446	2,190	851	47.4	154	51.4	213	50.7
83	6/1967	8.3	270	1,075	500	15	72	108	38	17
83	7/6/2012	8.2	229	707	173	19.2	52.8	49.8	21	8.81
84	9/1972	8.7	590	2,900	700	75	256	11	220	62
84	7/6/2012	8.9	364	812	163	9.8	70.9	32.8	41	15.4
85	7/1972	8.7	480	1,920	475	50	150	39	215	42
85	7/6/2012	9.1	487	1,175	223	21.9	97.7	26.7	96	24.5
86	5/1973	8.5	550	1,180	120	20	111	47	40	19
86	6/22/2012	8.6	513	747	48	13.3	80.3	31.6	30	14.0
87	5/1973	9.1	1,700	38,000	25,000	1,925	3,520	22	6,640	726
87	6/22/2012	8.7	992	11,310	7,304	431	970	40.8	1,920	234
88	5/1973	8.8	1,200	8,500	2,300	335	610	16	1,360	224
88	6/27/2012	8.7	587	2,094	781	57.4	148	44.0	243	48.2
89	5/1973	8.7	1,000	9,500	3,900	400	810	28	1,560	264
89	6/29/2012	8.7	565	2,102	740	54.1	144	46.4	233	47.2
90	7/1972	7.9	290	800	100	25	53	59	44	37
90	6/27/2012	8.5	327	1,509	600	18.7	114	74.1	100	20.3

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
91	7/1972	9.0	300	1,020	300	25	65	46	86	36
91	7/16/2012	8.7	330	1,434	515	21.4	112	64.1	86	21.9
92	7/1972	9.5	290	930	260	25	91	34	73	33
92	7/16/2012	9.0	324	1,677	689	28.2	136	49.5	124	19.5
93	6/1972	9.1	270	1,080	240	30	79	50	108	39
93	7/5/2012	8.8	382	1,417	491	23.2	86.8	82.9	109	19.8
94	7/1972	9.4	310	1,080	290	30	61	89	105	31
94	7/5/2012	9.2	305	2,045	825	35.9	118	82.7	189	23.6
95	6/1972	8.5	550	2,250	500	100	140	43	285	58
95	6/25/2013	9.0	490	1,384	358	34.1	104	39.6	120	32.5
96	6/1972	8.8	700	3,900	1,375	165	200	36	542	94
96	6/25/2013	9.0	494	1,355	347	33.3	101	40.7	115	30.8
97	6/1972	8.6	430	1,625	350	50	161	45	153	46
97	6/25/2013	8.8	492	1,365	360	33.5	103	39.7	116	31.8
98	7/1972	9.9	520	1,550	360	70	126	41	196	54
98	8/24/2013	8.8	562	1,527	431	38.5	119	58.7	131	35.7
99	7/1972	9.2	580	1,300	140	20	130	15	89	28
99	7/2/2012	8.6	397	1,366	442	10.7	124	40.0	64	11.0
100	7/1972	9.1	430	1,160	190	20	108	13	60	24
100	7/2/2012	8.8	319	1,184	387	15.4	92.9	58.7	55	12.9
101	6/1972	8.5	360	940	110	20	94	44	60	25
101	6/19/2013	9.0	428	1,166	328	15.9	89.9	56.2	72	24.8
102	6/1972	9.5	600	4,800	650	165	310	32	760	168
102	6/19/2013	8.9	438	1,201	348	17.7	95.3	56.6	81	27.5
103	6/1972	8.1	480	2,530	500	100	134	66	336	82
103	6/19/2013	9.2	562	2,109	757	77.4	123	78.6	246	77.2
104	6/1972	9.0	420	930	90	50	67	51	86	36
104	6/26/2013	8.7	416	1,456	488	28	112	45.3	120	29
105	6/1967	8.5	570	1,700	150	40	100	48	105	67
105	6/14/2012	8.5	743	1,495	667	50.8	129	66.9	242	84.0
106	6/1972	8.5	380	1,380	325	20	162	91	64	42
106	6/18/2012	9.0	465	1,125	315	7.5	110	58.0	48	25.0
107	6/1972	8.4	610	2,500	500	60	154	59	322	65
107	--	--	--	--	--	--	--	--	--	--
108	6/1972	8.7	390	8,100	2,750	435	524	93	1,690	152
108	6/18/2012	8.8	431	3,340	1,719	126	204	86.2	442	64.0

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 °C, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 °C)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
109	6/1972	7.8	370	980	110	45	65	47	87	40
109	6/18/2012	8.7	464	1,192	375	27.6	86.1	69.4	104	31.2
110	6/1972	8.2	490	3,200	400	110	184	66	530	68
110	8/20/2013	9.1	449	2,308	924	44.6	148	60	260	46.3
111	6/1972	7.9	310	670	50	15	52	50	28	38
111	6/14/2012	8.7	438	743	122	9.2	62.1	62.7	32	21.7
112	10/1972	8.7	440	2,500	1,000	20	290	115	134	58
112	6/27/2013	8.4	387	3,220	1,850	20.8	370	121	196	40.6
113	10/1972	8.4	440	1,750	350	50	118	65	86	54
113	--	--	--	--	--	--	--	--	--	--
114	6/1972	8.2	620	2,350	400	115	109	83	475	104
114	9/9/2013	9.0	712	1,681	359	43.9	76	59.6	240	61.9
115	6/1972	8.4	630	5,000	700	82	216	131	700	65
115	6/21/2013	8.7	568	3,714	1,110	459	207	77	491	47.6
116	6/1972	8.4	560	10,800	1,500	2,135	14	21	2,430	132
116	--	--	--	--	--	--	--	--	--	--
117	5/1972	9.5	530	4,600	350	940	4	18	1,110	33
117	6/13/2013	9.0	505	3,250	820	449	36.3	37.1	695	20.3
118	5/1972	9.0	410	3,330	300	585	4	19	700	30
118	--	--	--	--	--	--	--	--	--	--
119	5/1972	8.5	390	6,300	1,200	200	80	40	1,360	52
119	8/2/2013	8.6	579	3,838	1,220	318	60	43.1	821	35
120	5/1972	9.0	970	6,280	1,000	555	56	22	960	54
120	--	--	--	--	--	--	--	--	--	--
121	5/1972	9.0	750	2,050	190	155	50	26	470	24
121	8/19/2013	9.0	436	1,852	613	51.9	72.1	40.2	293	21.1
122	5/1972	9.0	330	2,400	350	320	19	24	490	32
122	8/19/2013	9.0	592	2,875	760	195	62.9	59.7	507	36.5
123	5/1972	9.0	390	2,750	290	160	160	29	380	46
123	8/19/2013	8.7	288	1,661	619	52	106	62.5	156	21.6
124	5/1972	9.0	530	4,800	1,125	470	196	60	800	72
124	8/19/2013	8.8	353	1,845	608	57.4	112	71	166	24.2
125	5/1972	8.1	370	5,700	2,000	225	430	140	720	95
125	9/10/2013	8.4	379	2,917	1,430	67	226	111	303	49.2
126	5/1972	9.0	660	4,700	800	500	104	24	1,020	45
126	6/20/2012	8.5	498	2,155	760	126	89.0	80.5	336	27.1

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
127	5/1972	9.0	640	9,500	2,000	1,065	294	57	2,030	100
127	8/20/2013	9.0	547	2,697	881	137	105	76.9	407	33.7
128	5/1972	8.5	320	6,500	1,625	485	270	87	1,200	75
128	6/20/2012	8.7	494	2,461	782	124	88.8	81.8	304	27.4
129	5/1972	8.5	300	1,400	300	25	100	78	67	24
129	6/4/2012	8.4	306	1,252	427	25.4	86.5	104	42	16.8
130	5/1972	8.5	330	1,340	300	25	90	92	54	20
130	6/4/2012	8.4	338	1,162	405	24.0	81.1	117	41	15.2
131	5/1972	8.0	310	1,460	350	30	110	78	66	26
131	6/4/2012	8.5	347	1,153	407	24.0	84.6	110	44	16.2
132	5/1972	9.0	650	3,400	700	275	200	62	407	92
132	6/5/2012	8.7	512	2,240	804	157	134	58.9	298	55.4
133	6/1967	9.2	330	490	44	20	25	40	18	25
133	7/8/2013	9.0	262	879	248	13.6	50.7	50.7	62	26.3
134	9/1972	8.9	490	3,500	300	325	216	56	400	118
134	7/8/2013	8.8	505	2,224	690	149	160	66.3	203	44.2
135	9/1972	9.0	1,000	30,000	15,000	1,870	2,200	116	9,800	720
135	7/8/2013	8.9	506	2,687	1,040	78.7	142	52.4	366	42.2
136	9/1972	8.9	370	970	110	30	76	24	75	23
136	7/1/2013	8.7	380	656	68	7.9	53.1	42.2	31	11.6
137	9/1972	9.8	170	7,000	1,500	915	262	60	1,200	150
137	--	--	--	--	--	--	--	--	--	--
138	6/1967	8.6	410	12,500	3,750	1,740	209	268	1,300	190
138	--	--	--	--	--	--	--	--	--	--
139	6/1967	8.8	660	9,400	3,500	1,225	210	45	1,556	175
139	8/22/2013	8.9	514	3,547	1,020	379	190	23.4	514	68.3
140	9/1972	8.5	450	2,060	500	45	118	56	243	50
140	7/9/2013	8.8	447	1,512	487	23.2	103	42.8	137	22.4
141	5/1972	8.9	430	47,000	35,000	3,000	704	131	3,900	380
141	6/6/2013	8.7	717	15,430	8,560	984	615	164	3,460	182
142	5/1972	8.5	380	14,600	4,750	1,990	780	131	2,690	192
142	6/6/2013	8.9	604	4,359	1,670	318	270	39.5	632	80.8
143	9/1972	9.1	750	10,140	5,625	125	728	30	2,730	325
143	7/9/2013	9.0	591	3,181	1,150	153	182	38.5	431	69.6
144	5/1973	9.5	610	36,000	25,000	4,785	1120	77	19,520	428
144	6/6/2013	8.6	580	40,350	27,000	2,520	1050	94.1	13,000	484

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
145	9/1972	8.9	550	2,500	550	50	187	43	320	37
145	8/8/2012	9.7	395	984	283	17.7	84.3	18.2	107	15.2
146	9/1972	8.9	500	21,000	12,750	885	2020	52	5,500	570
146	8/8/2012	8.9	635	6,580	3,684	166	437	82.3	989	109
147	9/1972	9.3	810	22,500	14,750	935	2560	68	5,800	580
147	8/8/2012	8.9	545	5,950	3,307	140	437	81.3	905	114
148	7/1969	9.5	570	15,900	5,000	1,295	816	30	3,200	250
148	7/13/2012	8.9	659	5,850	2,321	429	310	69.4	865	97.4
150	11/1966	8.6	580	7,000	3,500	555	390	116	1,432	180
150	7/9/2012	8.7	677	6,810	2,836	534	345	49.7	977	118
151	5/1969	9.0	530	2,090	500	75	88	31	112	31
151	7/13/2012	8.8	631	6,740	2,760	528	347	62.2	989	116
152	6/1967	8.6	510	9,000	3,625	1,005	200	162	1,420	132
152	7/11/2012	8.5	676	3,306	2,917	615	414	82.0	1,227	110
153	9/1972	8.2	770	70,300	87,500	1,738	11,600	90	20,600	3,600
153	7/11/2012	8.6	598	8,000	1,424	229	239	67.9	430	85.5
154	9/1972	9.4	750	4,200	1,500	235	320	22	580	140
154	7/24/2013	8.8	585	3,128	1,140	163	217	65.3	377	59.9
155	12/1975	9.3	1,550	9,300	1,875	640	825	20	1,435	316
155	8/22/2013	8.8	574	2,939	1,090	153	205	59.3	332	54.4
156	8/1976	10.1	560	29,500	21,250	3,355	841	30	6,400	532
156	7/9/2012	8.9	617	6,900	2,894	544	348	57.4	959	118
157	5/1969	8.4	560	35,000	21,250	3,000	1180	196	6,440	752
157	7/13/2012	8.8	623	6,830	2,900	548	379	58.0	1,048	127
158	5/1969	8.6	480	3,400	950	100	106	82	148	56
158	9/5/2013	8.9	576	3,988	1,760	163	293	77.4	544	67
159	6/1972	8.7	430	1,320	250	45	124	76	104	38
159	6/14/2012	8.6	536	1,297	387	30.4	112	50.5	111	29.0
160	5/1967	8.5	320	1,420	360	20	113	60	90	36
160	6/12/2013	8.8	361	1,165	387	9.3	97.9	66.9	60	16.4
161	5/1967	8.9	640	1,080	85	20	104	21	90	50
161	6/12/2013	9.1	428	844	144	9.6	88.2	32.8	34	19.3
162	10/1973	8.3	460	1,000	70	30	106	83	40	40
162	6/21/2013	8.9	342	672	112	6.8	64.6	31.1	21	10.7
164	9/1973	8.4	390	1,850	345	50	88	62	212	50
164	8/12/2013	9.1	494	2,209	909	39.3	136	80.5	287	37.7

Appendix 3. Chemical characteristics of prairie lakes and wetlands (major Ions).—Continued

[HCO_3^-, hydrogen carbonate; mg/L, milligrams per liter; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; --, no data]

Lake number[1]	Date sampled	pH	Alkalinity (as HCO_3^-) (mg/L)	Specific conductance (µS/cm at 25 ºC)	Sulfate (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
165	9/1973	8.5	1,200	2,600	80	100	84	62	330	96
165	7/20/2012	8.8	530	2,578	964	45.3	141	75.3	285	34.9
166	9/1972	9.0	1,280	8,800	4,750	815	560	11	2,470	220
166	--	--	--	--	--	--	--	--	--	--
167	7/1970	8.6	1,580	19,500	12,000	720	1260	114	3,500	400
167	6/22/2012	8.7	955	11,570	7,314	435	939	38.0	1,850	226
168	9/1973	8.6	720	3,200	400	125	220	26	470	82
168	7/9/2013	8.8	503	2,361	919	66.2	149	54.9	268	43.1
169	6/1967	8.8	870	9,800	4,500	425	200	44	1,688	170
169	7/16/2013	8.9	850	4,252	1,560	177	156	23.4	755	77.8
170	6/1967	9.0	420	9,600	4,000	915	204	171	2,000	235
170	7/24/2013	9.0	545	4,008	1,480	235	263	42.1	534	77.2
171	6/1967	9.3	2,300	15,000	6,000	890	20	13	394	133
171	8/5/2013	9.3	2,370	8,320	2,290	574	35.3	6.7	2,380	104
172	6/1967	8.6	380	880	175	20	76	42	45	24
172	7/2/2012	8.8	368	1,118	304	6.9	89.1	64.7	51	10.3
173	4/1968	8.7	385	840	97	13	60	64	26	20
173	6/12/2012	8.6	556	1,292	540	18.3	148	74.3	98	30.2
174	4/1968	8.2	320	775	115	15	55	46	32	19
174	6/12/2012	8.6	555	1,373	553	18.3	148	73.4	91	30.0
175	4/1968	7.5	160	375	18	13	15	34	3	19
175	6/12/2012	8.6	535	1,390	556	18.2	148	73.5	91	29.9
176	7/1975	7.6	290	990	200	10	70	54	36	19
176	6/27/2013	8.6	666	1,647	448	15.1	159	42.9	118	34.9
177	8/1975	7.4	300	590	32	15	25	59	8	4
177	9/12/2013	9.0	451	1,131	352	15.9	107	50.5	78	24.3
178	6/1967	8.3	530	2,575	1,250	60	182	45	264	68
178	7/15/2013	8.8	608	1,448	377	23.6	118	32.2	118	29.2
180	10/1973	8.0	390	2,900	725	105	168	84	240	68
180	7/20/2012	9.0	408	1,970	726	31.4	145	81.2	153	26.1
181	6/1967	8.7	670	3,050	1,175	125	204	50	360	17
181	8/22/2013	8.7	467	2,582	1,090	58.9	184	60.4	270	63.5

[1]There are no lakes numbered 149, 163, and 179.

Appendix 4. Aquatic vertebrate captures in prairie lakes and wetlands.

[--, not sampled]

Lake number[1]	Fathead minnows	Brook stickleback	Iowa darter	Yellow perch	Northern pike	Walleye	Smallmouth bass	Bluegill	Common carp	Black bullhead	Barred tiger salamander	Northern leopard frog
1	392	0	0	0	0	0	0	0	0	0	0	0
2	267	0	0	0	0	0	0	0	0	0	0	0
3	4,642	2	0	0	0	0	0	0	0	0	0	0
4	10	0	0	2	0	0	0	0	0	0	0	0
5	1,046	0	18	0	0	0	0	0	2	0	0	0
6	--	--	--	--	--	--	--	--	--	--	--	--
7	11	0	16	0	0	0	0	0	0	0	0	0
8	2	0	1	0	0	3	0	0	0	0	0	0
9	386	0	0	0	0	0	0	0	0	0	1	0
10	56	1	1	0	0	0	0	0	0	0	10	0
11	1,745	0	0	0	0	0	0	0	0	0	0	0
12	2	0	0	15	0	0	0	0	0	0	0	0
13	55	0	0	142	0	1	0	0	0	0	0	0
14	212	0	0	565	0	0	0	0	0	0	0	0
15	2,419	0	0	0	0	0	0	0	0	0	2	0
16	872	0	0	0	0	0	0	0	0	0	17	0
17	6,100	12	0	0	0	0	0	0	0	0	1	179
18	85	47	0	1	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	24	0
20	51	0	0	137	0	0	0	0	0	0	0	0
21	5,888	0	0	0	0	0	0	0	0	0	2	0
22	0	0	0	0	0	0	0	0	0	0	6	0
23	0	0	0	0	0	0	0	0	0	0	426	0
24	998	0	0	124	0	0	0	0	0	0	16	0
25	1,842	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	25	0
27	0	4	0	0	0	0	0	0	0	0	250	0
28	0	0	0	11	1	0	0	0	0	0	0	0
29	3	0	0	54	0	1	0	0	0	4	0	0
30	51	0	0	4	0	0	0	0	0	0	0	0
31	1,167	12	0	0	0	0	0	0	0	0	0	0
32	758	4	0	0	0	0	0	0	0	0	1	0
33	--	--	--	--	--	--	--	--	--	--	--	--
34	256	0	0	15	1	0	0	0	0	0	0	0
35	484	1	0	29	1	0	0	0	0	0	0	0
36	38	0	0	14	0	0	0	0	0	0	0	0
37	1,712	0	0	0	0	0	0	0	0	0	2	0

Appendix 4. Aquatic vertebrate captures in prairie lakes and wetlands.—Continued

[--, not sampled]

Lake number[1]	Fathead minnows	Brook stickleback	Iowa darter	Yellow perch	Northern pike	Walleye	Smallmouth bass	Bluegill	Common carp	Black bullhead	Barred tiger salamander	Northern leopard frog
38	8	0	0	0	0	1	0	0	0	0	0	0
39	42	0	0	52	0	0	0	0	0	0	0	0
40	3,671	0	0	2	0	0	0	0	0	0	1	0
41	0	0	0	0	0	0	5	0	0	0	0	0
42	254	0	0	0	0	0	0	0	0	0	20	0
43	0	0	0	0	0	0	0	0	0	0	0	0
44	1,610	5	0	0	0	0	0	0	0	0	0	0
45	141	17	0	0	0	0	0	0	0	0	0	0
46	--	--	--	--	--	--	--	--	--	--	--	--
47	5,733	6	0	1	0	0	0	0	0	0	0	0
48	113	1	0	0	0	0	0	0	0	0	0	0
49	3	0	0	0	1	0	0	0	0	0	0	0
50	1,349	43	0	0	0	0	0	0	0	0	24	1
51	2,114	1	0	0	0	0	0	0	0	0	19	0
52	2,781	4	0	0	0	0	0	0	0	0	28	0
53	2,018	0	0	0	0	0	0	0	0	0	63	0
54	9,169	1	0	0	0	0	0	0	0	0	0	0
55	--	--	--	--	--	--	--	--	--	--	--	--
56	1	0	0	20	0	0	0	0	0	0	0	0
57	50	0	0	24	0	0	0	0	0	0	0	0
58	580	0	0	0	0	0	0	0	0	0	21	0
59	54	0	0	9	0	0	0	0	0	0	0	0
60	1	0	0	10	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0	0	0	13	0
62	0	0	0	0	0	0	0	0	0	0	139	0
63	219	0	0	3	0	3	0	0	0	0	0	0
64	8	0	0	3	0	1	0	0	0	0	0	0
65	4	0	0	0	0	0	0	0	0	0	11	0
66	--	--	--	--	--	--	--	--	--	--	--	--
67	543	0	0	0	0	0	0	0	0	0	0	0
68	534	0	0	0	0	0	0	0	0	0	143	0
69	576	1	0	9	0	0	0	0	0	0	12	0
70	0	0	0	0	0	0	0	0	0	0	0	0
71	52	0	0	183	0	0	0	0	0	0	0	0
72	0	0	0	81	0	0	0	0	0	0	0	0
73	1,348	41	0	0	0	0	0	0	0	0	96	0
74	3	0	0	162	0	2	0	0	0	0	0	0

Appendix 4. Aquatic vertebrate captures in prairie lakes and wetlands.—Continued

[--, not sampled]

Lake number[1]	Fathead minnows	Brook stickleback	Iowa darter	Yellow perch	Northern pike	Walleye	Smallmouth bass	Bluegill	Common carp	Black bullhead	Barred tiger salamander	Northern leopard frog
75	0	0	0	282	0	0	0	0	0	0	2	0
76	--	--	--	--	--	--	--	--	--	--	--	--
77	0	0	0	773	0	0	0	0	0	0	33	0
78	4	0	0	0	0	0	0	0	0	0	0	0
79	13,809	67	0	0	0	0	0	0	0	0	0	0
80	144	1	0	369	0	0	0	0	0	0	0	0
81	67	0	0	117	0	0	0	0	0	0	0	0
82	7	1	1	17	0	3	0	0	0	0	0	0
83	3,286	14	0	0	0	0	0	0	0	0	0	1
84	1,868	0	0	0	0	0	0	0	0	0	0	14
85	2,129	0	0	0	0	0	0	0	0	0	11	8
86	2,573	0	0	0	0	0	0	0	0	0	0	27
87	15	0	0	0	0	0	0	0	0	0	10	0
88	144	0	0	91	0	0	0	0	0	0	0	0
89	8	1	0	29	0	0	0	0	0	0	0	0
90	8,350	35	0	0	0	0	0	0	0	0	0	0
91	184	1	45	0	0	0	0	0	10	0	0	0
92	921	55	50	0	0	0	0	0	0	0	0	0
93	101	12	4	0	0	1	0	0	1	0	0	0
94	4,122	7	3	0	0	0	0	0	0	0	1	0
95	19,167	4	0	0	0	0	0	0	0	0	0	0
96	7,769	33	0	0	0	0	0	0	0	0	0	0
97	13,756	32	0	0	0	0	0	0	0	0	0	0
98	--	--	--	--	--	--	--	--	--	--	--	--
99	3,370	31	52	0	0	0	0	0	0	0	0	0
100	4,081	69	58	0	0	0	0	0	0	0	0	0
101	739	0	0	1	0	0	0	0	0	0	0	0
102	1,167	0	0	1	0	0	0	0	0	0	0	0
103	74	0	0	1	0	0	0	0	0	0	0	0
104	10,276	19	0	0	0	0	0	0	0	0	0	1
105	19,552	208	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	2	0
107	--	--	--	--	--	--	--	--	--	--	--	--
108	1,266	0	0	0	0	0	0	0	0	0	2	15
109	2,852	35	1	0	0	0	0	0	0	0	41	19
110	214	1	10	27	0	0	0	0	0	0	0	0
111	3,534	0	0	0	0	0	0	0	0	0	9	0

Appendix 4. Aquatic vertebrate captures in prairie lakes and wetlands.—Continued

[--, not sampled]

Lake number[1]	Fathead minnows	Brook stickleback	Iowa darter	Yellow perch	Northern pike	Walleye	Smallmouth bass	Bluegill	Common carp	Black bullhead	Barred tiger salamander	Northern leopard frog
112	0	0	0	0	0	0	0	0	0	0	54	0
113	--	--	--	--	--	--	--	--	--	--	--	--
114	0	0	0	0	0	0	0	0	0	0	38	20
115	3,053	327	0	0	0	0	0	0	0	0	0	0
116	--	--	--	--	--	--	--	--	--	--	--	--
117	11,324	0	0	0	0	0	0	0	0	0	0	0
118	--	--	--	--	--	--	--	--	--	--	--	--
119	355	2	0	0	0	0	0	0	0	0	39	1
120	--	--	--	--	--	--	--	--	--	--	--	--
121	12,183	24	0	3	0	0	0	0	0	0	0	0
122	963	0	0	129	0	0	0	0	0	0	0	0
123	0	0	0	0	0	1	0	0	0	3	0	0
124	542	0	4	234	0	0	0	0	0	2	0	0
125	--	--	--	--	--	--	--	--	--	--	--	--
126	1,675	0	0	113	0	0	0	0	0	0	1	0
127	1,284	1	0	56	0	0	0	0	0	0	3	0
128	0	51	0	0	0	0	0	0	0	0	3	0
129	9,549	93	0	0	0	0	0	0	0	0	0	0
130	13,517	29	0	0	0	0	0	0	0	0	0	0
131	7,764	331	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	0	0	0	25	0
133	1,156	128	0	0	0	0	0	0	0	0	1	0
134	6,204	0	0	0	0	0	0	0	0	0	1	0
135	4,784	0	0	0	0	0	0	0	0	0	0	247
136	53	0	0	0	0	0	0	0	0	0	0	0
137	--	--	--	--	--	--	--	--	--	--	--	--
138	--	--	--	--	--	--	--	--	--	--	--	--
139	8,835	0	0	0	0	0	0	0	0	0	0	0
140	13,996	25	0	0	0	0	0	0	0	0	1	46
141	11,060	22	0	0	0	0	0	0	0	0	0	0
142	257	2	0	0	0	0	0	0	0	0	0	0
143	3,471	19	0	0	0	0	0	0	0	0	0	0
144	0	0	0	0	0	0	0	0	0	0	0	0
145	842	87	0	0	0	0	0	0	0	0	0	2
146	0	0	0	0	0	0	0	0	0	0	243	0
147	0	0	0	0	0	0	0	0	0	0	163	0
148	3,962	15	0	0	0	0	0	0	0	0	0	0

Appendix 4. Aquatic vertebrate captures in prairie lakes and wetlands.—Continued

[--, not sampled]

Lake number[1]	Fathead minnows	Brook stickleback	Iowa darter	Yellow perch	Northern pike	Walleye	Smallmouth bass	Bluegill	Common carp	Black bullhead	Barred tiger salamander	Northern leopard frog
150	101	0	0	7	0	0	0	0	0	0	0	0
151	200	67	0	2	0	0	0	0	0	0	0	0
152	857	2	0	77	0	0	0	0	0	0	0	1
153	41	19	0	8	0	0	0	0	0	0	0	0
154	422	0	0	10	0	1	0	0	0	0	0	0
155	14	1	0	231	0	0	0	0	0	0	0	0
156	297	0	0	15	0	0	0	0	0	0	0	0
157	137	0	0	91	0	0	0	0	0	0	0	0
158	--	--	--	--	--	--	--	--	--	--	--	--
159	8,064	0	0	0	0	0	0	0	0	0	0	0
160	9,131	4	0	0	0	0	0	0	0	0	0	0
161	11	0	0	54	0	0	0	0	0	0	0	0
162	10	1	0	12	0	0	0	2	0	0	0	0
164	237	2	8	0	0	0	0	0	0	0	0	0
165	13,339	9	11	0	0	0	0	0	0	0	1	0
166	48	0	0	49	0	0	0	0	0	0	0	0
167	106	0	0	0	0	0	0	0	0	0	48	0
168	31	0	3	0	0	20	0	0	0	0	0	0
169	0	0	0	0	0	0	0	0	0	0	419	0
170	737	2	0	56	0	0	0	0	0	0	1	0
171	0	0	0	0	0	0	0	0	0	0	294	0
172	1	0	0	0	2	0	0	0	0	0	0	0
173	0	0	0	0	0	0	0	0	0	0	3	0
174	0	0	0	0	0	0	0	0	0	0	9	0
175	0	0	0	0	0	0	0	0	0	0	7	0
176	0	0	0	0	0	0	0	0	0	0	285	0
177	568	0	0	0	0	0	0	0	0	0	0	798
178	7,879	0	0	0	0	0	0	0	0	0	0	5
180	4,975	35	6	0	0	0	0	0	0	0	1	0
181	0	0	0	0	0	0	0	0	0	0	5	0

[1]There are no lakes numbered 149, 163, and 179.

Appendix 5. Range of major ion concentrates for prairie lakes and wetlands in which macro-invertebrate taxa occurred.

[*N*, number of samples; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; mg/L, milligrams per liter; HCO_3-, hydrogen carbonate]

Taxon	*N*	Specific conductance (µS/cm at 25 ºC)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Alkalinity as HCO_3- (mg/L)
		Minimum/maximum							
Corixidae (nymphs)	155	461.8/40,350	8.10/9.89	5.8/164	35.2/1050	9.5/13,000	10.4/27,000	2.9/2,520	229/2,590
Hydracarina	151	448.8/18,430	8.10/9.89	5.8/121	31.8/970	9.22/4,147	10.4/9,556	2.9/1,292	223/2,590
Chironominae	148	448.8/15,430	8.10/9.89	5.8 /164	31.8/970	9.22/3,460	10.4/8,560	2.9/984	223/2,590
Hyalella azteca	148	448.8/18,430	8.10/9.89	8.6/82.9	31.8/970	9.22/4,147	10.4/9,556	2.9/1,292	223/1,272
Orthocladiinae	122	461.8 /15,430	8.10/9.89	6.7/164	35.3/970	17.8/3,460	18.5/8,560	2.9/984	254/2,370
Cyclopoida	120	448.8/15,430	8.10/9.84	6.7/164	31.8/939	9.22/3,460	10.4/8,560	2.9/984	223/2,370
Trichocorixa	116	461.8/12,000	8.10/9.89	8.6/117	36.3/939	21.3/2,650	10.4/7,314	6.9/759	229/1,272
Calanoida	110	448.8/40,350	8.10/9.89	5.8/164	31.8/1050	9.22/13,000	10.4/27,000	6/2,520	223/2,590
Daphnia	110	448.8/40,350	8.10/9.40	5.8/164	31.8/1050	9.22/13,000	10.4/27,000	6/2,520	223/2,590
Gammarus lacustris	109	461.8/7,210	8.10/9.74	8.69/121	35.2/437	9.5/1,395	10.4/3,684	6.8/615	229/1,220
Oligochaeta	99	448.8/ 18,430	8.10/9.84	9.99/121	31.8/970	9.22/4,147	18.5/9,556	2.9/1,292	223/1,246
Haliplus	97	448.8/15,430	8.10/9.89	6.7/164	31.8/939	9.22/3,460	18.5/8,560	2.9/984	223/2,370
Ostracoda	97	537/40,350	8.10 /9.74	5.8/164	35.3/1050	17.8/13,000	18.5/27,000	2.9/2,520	288/2,590
Callibaetis	88	448.8/11,570	8.10/9.89	6.7/121	31.8/939	9.22/2,610	10.4/7,314	2.9/668	223/2,370
Enallagma	81	448.8/18,430	8.10/9.89	6.7/164	31.8/970	9.22/4,147	10.4/9,556	2.9/1,292	223/2,370
Caenis	78	448.8/11,200	8.10/9.84	8.69/117	31.8/437	9.22/2,572	18.5/4,577	2.9/615	223/1,272
Nehalennia	78	448.8/12,000	8.10/9.89	6.7/121	31.8/873	9.22/2,572	34.4/6,964	6/759	223/2,370
Tanypodinae	76	448.8/18,430	8.10/9.74	6.7/121	31.8/970	9.22/4,147	18.5/9,556	2.9/1,292	223/2,370
Mystacides	74	448.8/7,210	8.10/9.84	8.86/104	31.8/405	9.22/1,460	10.4/3,490	2.9/548	223/1,220
Sigara	64	461.8/11,200	8.10/9.89	8.6/121	51.4/437	21.3/2,572	10.4/4,577	6.9/513	229/1,272
Simocephalus	56	448.8/7,210	8.10/9.84	8.69/121	31.8/437	9.22/1,490	18.5/3,684	2.9/615	223/1,236
Collembola	52	500/12,000	8.10/9.20	19.6/121	35.2/939	9.5/2,650	59.4/7,314	7.9/759	229/1,272
Cenocorixa	51	712/18,430	8.10/9.40	5.8/164	35.3/970	30.1/4,147	10.4/9,556	14.6/1,292	327/2,590
Oecetis	51	500/15,430	8.33/9.89	5.8/164	35.2/615	9.5/3,460	18.5/8,560	2.9/984	246/2,590
Notonecta	46	712/11,570	8.50/9.89	6.7/86.2	35.3/939	30.1/2,380	10.4/7,314	13.4/574	262/2,370
Gyraulus circumstriatus	45	448.8/5,950	8.10/9.84	8.69/121	31.8/437	9.22/905	18.5/3,307	2.9/459	223/867
Physa gyrina	43	537/6,900	8.10/9.74	11/121	38.3/437	17.8/1.227	18.5/3,684	2.9/615	288/734
Diaphanosoma	41	448.8/6,350	8.10/9.29	8.86/82	31.8/414	9.22/1,395	49.3/3,301	6/615	223/1,236
Helobdella	38	537/6,580	8.33/9.22	8.86/121	38.3/437	17.8/989	10.4/3,684	2.9/459	288/926
Phryganea	33	448.8/12,000	8.52/9.74	8.69/82.9	31.8/873	9.22/1,880	49.3/6,964	6/759	223/1,077
Pisidiidae	33	448.8/2,308	8.33/9.74	11.4/104	31.8/148	9.22/344	10.4/924	2.9/44.9	223/804
Chaoborus	32	607/11,200	8.41/9.74	12.7/121	61.4/572	19.8/2,572	10.4/5,390	7.5/615	288/1,272
Laccophilus	29	537/6,640	8.10/9.89	8.6/121	38.3/370	17.8/1,296	18.5/2,031	2.9/474	254/1,230
Triaenodes	29	800/12,000	8.10/9.89	6.7/82.3	35.3/873	135/2,572	163/6,964	32/759	494/2,370
Hydroporus	28	672/15,430	8.51/9.84	6.7/164	35.3/939	21.4/3,460	112/8,560	6.8/984	330/2,370
Physa jennessi	27	537/6,900	8.33/9.18	16.9/110	38.3/379	17.8/1,048	18.5/2,900	2.9/548	288/867
Peltodytes	26	537/9,730	8.10/9.11	15.4/121	38.3/572	17.8/1,640	18.5/5,390	2.9/552	254/1090
Dasycorixa	24	1,125/11,570	8.10/9.33	6.7/86.2	35.3/939	48.1/2,650	275/7,314	7.5/663	431/2,370

Appendix 5. Range of major ion concentrates for prairie lakes and wetlands in which macro-invertebrate taxa occurred.—Continued

[*N*, number of samples; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; mg/L, milligrams per liter; HCO_3-, hydrogen carbonate]

Taxon	*N*	Specific conductance (µS/cm at 25 ºC)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Alkalinity as HCO_3- (mg/L)
		Minimum/maximum							
Molanna	24	448.8/4,422	8.40/9.20	11.4/104	31.8/204	9.22/857	38.1/1,719	6/354	223/1,236
Bezzia	22	625/18,430	8.48/9.20	15.4/82	55.2/939	26.3/4,147	34.4/9,556	6.9/1,292	353/1,090
Ceriodaphnia	22	448.8/8,300	8.10/9.33	6.7/82.3	31.8/437	9.22/2,380	49.3/3,684	6/574	223/2,370
Limnephilus	17	656/6,580	8.43/9.74	12.7/117	53.1/437	31.1/989	68.2/3,684	7.9/166	306/707
Erpobdella	15	698/2,582	8.40/9.2	18.6/110	51.4/184	37.4/480	10.4/1,090	7.5/149	305/843
Pleuroxus	13	800/11,570	8.10/8.96	17.3/82.3	66/939	54.5/1,850	137/7,314	16.9/548	288/955
Oreodytes	12	537/11,700	8.33/9.17	27.6/117	38.3/970	17.8/2,610	18.5/7,314	2.9/668	338/1,228
Cymatia	10	1,661/7,210	8.10/9.89	8.6/121	58.7/437	156/1,300	522/3,684	20.8/371	288/1,230
Stagnicola elodes	10	1,153/6,740	8.48/9.14	26.3/110	60.2/437	44.1/1,227	407/3,684	14.5/615	347/734
Buenoa	9	958/6,950	8.69/9.29	13.8/82.3	60.6/437	64.4/1,490	10.4/3,684	14.6/474	545/1,077
Glossiphonia	8	537/2,209	8.33/9.20	11.4/80.5	38.3/148	17.8/287	18.5/909	2.9/39.3	350/676
Sida	8	537/1,934	8.33/9.84	8.69/37.6	38.3/112	17.8/282	18.5/357	2.9/44.4	350/839
Anax	7	958/5,950	8.74/9.84	9.99/81.3	78.8/437	50.6/905	10.4/3,307	6.9/140	319/748
Enochrus	7	656/2,875	8.43/9.17	31.6/117	53.1/123	30.2/507	47.5/760	7.9/195	319/592
Gyrinus	7	625/2,109	8.50/9.17	25.1 82.7	57.9/123	29.7/293	76/825	8.8/77.4	288/562
Ilybius	7	1,153/11,570	8.41/8.77	38/121	84.6/939	44.1/1,850	375/7,314	15.1/435	347/955
Placobdella	7	984/3,876	8.68/9.74	11.8/82.7	84.3/141	95.5/768	223/1,347	17.7/129	305/820
Eurycercus	6	537/1,514	8.33/9.20	11/41	38.3/112	17.8/218	18.5/357	2.9/44.9	350/619
Gyraulus parvus	6	721/3,587	8.87/9.20	18.7/80.5	81.4/190	26.3/666	34.9/1,230	15.5/379	449/670
Lymnaea stagnalis	6	984/3,340	8.70/9.74	18.2/86.2	84.3/204	107/442	283/1,719	17.7/126	395/587
Sphaeromias	6	672/3,220	8.41/8.88	15.6/121	64.6/370	21.4/366	85.4/1,850	6.8/78.7	342/565
Theromyzon	6	740/2,578	8.68/9.10	22.8/75.3	66.6/141	61.6/285	34.4/964	17.5/45.3	330/670
Planorbella trivolvis	5	537/1,527	8.33/8.85	37.6/110	38.3/119	17.8/131	18.5/515	2.9 38.5	330/562
Stratiomyidae	5	1,153/40,350	8.51/9.29	13.8/110	55.2/1,050	44.1/13,000	407/27,000	24/2,520	347/1,050
Acentria	4	1,456/3,262	8.72/9.22	8.86/80.5	112/197	120/433	431/962	28/136	416/926
Agraylea	4	740/3,262	8.77/9.22	8.86/64.7	66.6/197	50.6/433	34.4/962	6.9/136	368/926
Coptotomus	4	1,192/2,689	8.61/8.94	36.6/74.3	80.9/148	98/551	375/886	18.3/157	464/734
Dytiscus	4	1,192/3,220	8.41/9.17	45.3/121	86.1/370	104/246	375/1,850	20.8/77.4	387/562
Hesperocorixa	4	984/1,347	8.43/9.84	9.99/117	78.8/89.5	41.2/186	108/405	13.4/30.4	338/646
Hygrotus	4	1,162/40,350	8.43/8.70	15.4/164	81.1/1,050	41.2/13,000	405/27,000	24/2,520	338/1,090
Strictotarsus	4	712/11,200	8.68/9.22	8.86/69.4	62/197	30.1/2,572	59.5/4,577	17.9/513	404/1,272
Culicoides	3	6,640/15,430	8.70/9.20	24.5/164	128/615	1,296/3,460	2,031/8,560	474/984	717/1,228
Cyphon	3	656/15,430	8.70/8.82	34.9/164	53.1/615	31.1/3,460	68.2, 8,560	7.9/984	380/717
Graphoderus	3	958/2,109	8.68/9.17	31.6/78.6	86.1/123	64.4/246	10.4/757	14.6/77.4	464/748
Leydigia	3	2,094/3,340	8.70/8.77	44/86.2	144/204	233/442	740/1,719	54.1/126	431/587
Neoplea	3	537/1,162	8.33/8.78	23.1/117	38.3/81.1	17.8/41.2	18.5/405	2.9/24	338/404
Aeshna	2	1,347/1,768	9.10/9.84	9.99/26.5	73.6/78.8	186/255	270/464	17.5/30.4	615/634
Agabus	2	1,384/2,109	9.00/9.17	39.6/78.6	104/123	120/246	358/757	34.1/77.4	490/562

Appendix 5. Range of major ion concentrates for prairie lakes and wetlands in which macro-invertebrate taxa occurred.—Continued

[*N*, number of samples; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; mg/L, milligrams per liter; HCO_3-, hydrogen carbonate]

Taxon	*N*	Specific conductance (µS/cm at 25 ºC)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Alkalinity as HCO_3- (mg/L)
		Minimum/maximum							
Armiger crista	2	537/800	8.33/8.61	37.6/67.9	38.3/239	17.8/430	18.5/1,424	2.9/229	350/598
Branchinecta	2	2,723/4,614	8.98/9.01	22.3/22.3	55.2/64.9	573/1,000	899/1,780	34.6/49.5	771/861
Corisella	2	5,950/6,350	8.91/9.10	44.8/81.3	150/437	905/1,395	3301/3,307	49.8/140	545/741
Crenitis	2	1,162/1,252	8.43/8.45	104/117	81.1/86.5	41.2/41.7	405/427	24/25.4	306/338
Cyrnellus	2	1,118	8.77/ 8.83	58/64.7	89.1/379	50.6/1,048	304/2,900	6.9/548	368/623
Donacia	2	1,160/3,587	8.82/9.15	29.5/34.9	101/126	94.4/666	295/1,230	13.5/181	521/622
Ephydra	2	3,547/40,350	8.63/8.87	23.4/94.1	190/1,050	514/13,000	1,020/27,000	379/2,520	514/580
Hydroptila	2	644/1,933	8.95/9.01	15.1/18	72.8/88.6	27.3/296	66.9/448	7.5/45.1	390/748
Orconectes	2	1,153/1,417	8.51/8.78	82.9/110	84.6/86.8	44.1/109	407/491	23.2/24	347/382
Paracymus	2	1,192/2,804	8.68/8.71	38.5/69.4	86.1/92.9	104/450	375/966	27.6/70.4	464/657
Rhantus	2	2,109/3,220	8.41/9.17	78.6/121	123/370	196/246	757/1,850	20.8/77.4	387/562
Saldula	2	1,355/2,804	8.71/8.97	38.5/40.7	92.9/101	115/450	347/966	33.3/70.4	494/657
Valvata tricarinata	2	448.8/1,845	8.52/8.85	32.4/71	31.8/112	9.22/166	49.3/608	6/57.4	223/353
Agrypnia	1	1,434	8.68	64.1	112	85.9	515	21.4	330
Alboglossiphonia	1	1,160	8.82	34.9	101	94.4	295	13.5	521
Amnicola limosus	1	651	8.71	27.7	45.1	36.1	121	13.2	254
Anabolia	1	1,292	8.61	74.3	148	98	540	18.3	556
Artemia	1	40,350	8.63	94.1	1050	13000	27000	2520	580
Berosus	1	3,306	8.48	82	414	1227	2917	615	676
Cercyon	1	12,000	8.6	68	873	1880	6964	759	593
Cernotina	1	625	8.8	25.1	57.9	29.7	76	8.8	353
Chydorus	1	1,850	8.5	38.4	81.3	273	494	41	644
Dubiraphia	1	3,838	8.58	43.1	60	821	1220	318	579
Empididae	1	1,414	9.02	22.3	112	177	357	32.6	619
Eristalis	1	40,350	8.63	94.1	1050	13000	27000	2520	580
Harpacticoida	1	40,350	8.63	94.1	1050	13000	27000	2520	580
Hebrus	1	2,993	9.26	17.4	65.5	578	609	234	945
Hydrellia	1	1,509	8.5	74.1	114	100	600	18.7	327
Hydrobius	1	500	8.56	47.5	35.2	9.5	59.4	10.5	246
Ilyocryptus	1	1,292	8.61	74.3	148	98	540	18.3	556
Laccobius	1	2,102	8.7	46.4	144	233	740	54.1	565
Libellula	1	8,320	9.33	6.7	35.3	2380	2290	574	2370
Merragata	1	3,714	8.69	77	207	491	1110	459	568
Moina	1	2,723	8.98	22.3	64.9	573	899	49.5	771
Palmacorixa	1	1,661	8.73	62.5	106	156	619	52	288
Pericoma	1	656	8.72	42.2	53.1	31.1	68.2	7.9	380
Polycentropus	1	1,677	8.95	49.5	136	124	689	28.2	324
Prionocera	1	1,153	8.51	110	84.6	44.1	407	24	347

Appendix 5. Range of major ion concentrates for prairie lakes and wetlands in which macro-invertebrate taxa occurred.—Continued

[*N*, number of samples; µS/cm at 25 ºC, microsiemens per centimer at 25 degrees Celsius; mg/L, milligrams per liter; HCO_3-, hydrogen carbonate]

Taxon	*N*	Specific conductance (µS/cm at 25 ºC)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Alkalinity as HCO_3- (mg/L)
		Minimum/maximum							
Probezzia	1	4,614	9.01	22.3	55.2	1000	1780	34.6	861
Promenetus exacuous	1	537	8.33	37.6	38.3	17.8	18.5	2.9	350
Scapholeberis	1	979	8.62	15.6	98.5	53.6	85.4	19.8	560

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