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Cluster Analysis of Water-Quality Data for Lake Sakakawea, Audubon Lake, and McClusky Canal, Central North Dakota, 1990-2003

Scientific Investigations Report 2006-5202

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

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Conversion Factors, Abbreviations, and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Elevation, as used in this report, refers to distance above the vertical datum.

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 milligrams per liter (mg/L).

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Cluster Analysis of Water-Quality Data for Lake Sakakawea, Audubon Lake, and McClusky Canal, Central North Dakota, 1990-2003

By Karen R. Ryberg

Abstract

As a result of the Dakota Water Resources Act of 2000, the Bureau of Reclamation, U.S. Department of the Interior, identified eight water-supply alternatives (including a no-action alternative) to meet future water needs in portions of the Red River of the North (Red River) Basin. Of those alternatives, four include the interbasin transfer of water from the Missouri River Basin to the Red River Basin. Three of the interbasin transfer alternatives would use the McClusky Canal, located in central North Dakota, to transport the water. Therefore, the water quality of the McClusky Canal and the sources of its water, Lake Sakakawea and Audubon Lake, is of interest to water-quality stakeholders.

The Bureau of Reclamation collected water-quality samples at 23 sites on Lake Sakakawea, Audubon Lake, and the McClusky Canal system from 1990 through 2003. Physical properties and water-quality constituents from these samples were summarized and analyzed by the U.S. Geological Survey using hierarchical agglomerative cluster analysis (HACA). HACA separated the samples into related clusters, or groups. These groups were examined for statistical significance and relation to structure of the McClusky Canal system.

Statistically, the sample groupings found using HACA were significantly different from each other and appear to result from spatial and temporal water-quality differences corresponding with different sections of the canal and different operational conditions. Future operational changes of the canal system may justify additional water-quality sampling to characterize possible water-quality changes.

Introduction

The Dakota Water Resources Act, passed by the U.S. Congress on December 15, 2000, authorized the Secretary of the Interior to conduct a comprehensive study of the future water needs of the Red River Basin in North Dakota and of possible options to meet those water needs (U.S. Congress, 2000). Water needs are expected to increase in the basin due to population growth and the possibility of future drought.

As part of the comprehensive water needs study, the Bureau of Reclamation identified eight water-supply alternatives for the Red River Valley Water Supply Project (RRVWSP). Of those alternatives, four include the interbasin transfer of water from the Missouri River Basin to the Red River Basin. Three of the four interbasin transfer alternatives transfer water from the Missouri River Basin to the Red River Basin through Audubon Lake, the McClusky Canal, and a pipeline (U.S. Department of Interior, Bureau of Reclamation, 2005). The three options utilizing Audubon Lake and McClusky Canal (fig. 1) are identified as “GDU Import” in Bureau of Reclamation reports because they import water to the Red River Basin utilizing the Garrison Diversion Unit (GDU).

The GDU was created by the U.S. Congress on August 5, 1965. The GDU includes Snake Creek Pumping Plant on Lake Sakakawea, Audubon Lake, and the McClusky Canal. The original intent of the GDU was to provide water for agricultural irrigation in North Dakota. Congress passed the Garrison Diversion Unit Reformulation Act in 1986 changing the primary focus of the GDU from irrigation to municipal water supply. In 2000, Congress further amended the Garrison Diversion Unit Reformulation Act of 1986 with the Dakota Water Resources Act (DWRA). Section 8 of DWRA directed the Secretary of the Interior to prepare a report on the Red River Valley Needs and Options and an Environmental Impact Statement.

During the period of record, there have been no flows through the GDU into the Red River Basin as part of the RRVWSP. Also, there is no connection between the McClusky Canal and the New Rockford Canal (another part of the GDU). The possibility of the interbasin transfer of water from a basin that drains into the Gulf of Mexico (the Missouri River) to a basin that drains into Hudson Bay in Canada (the Red River) has caused concern among water-quality stakeholders in the Red River Basin in the United States and Canada.

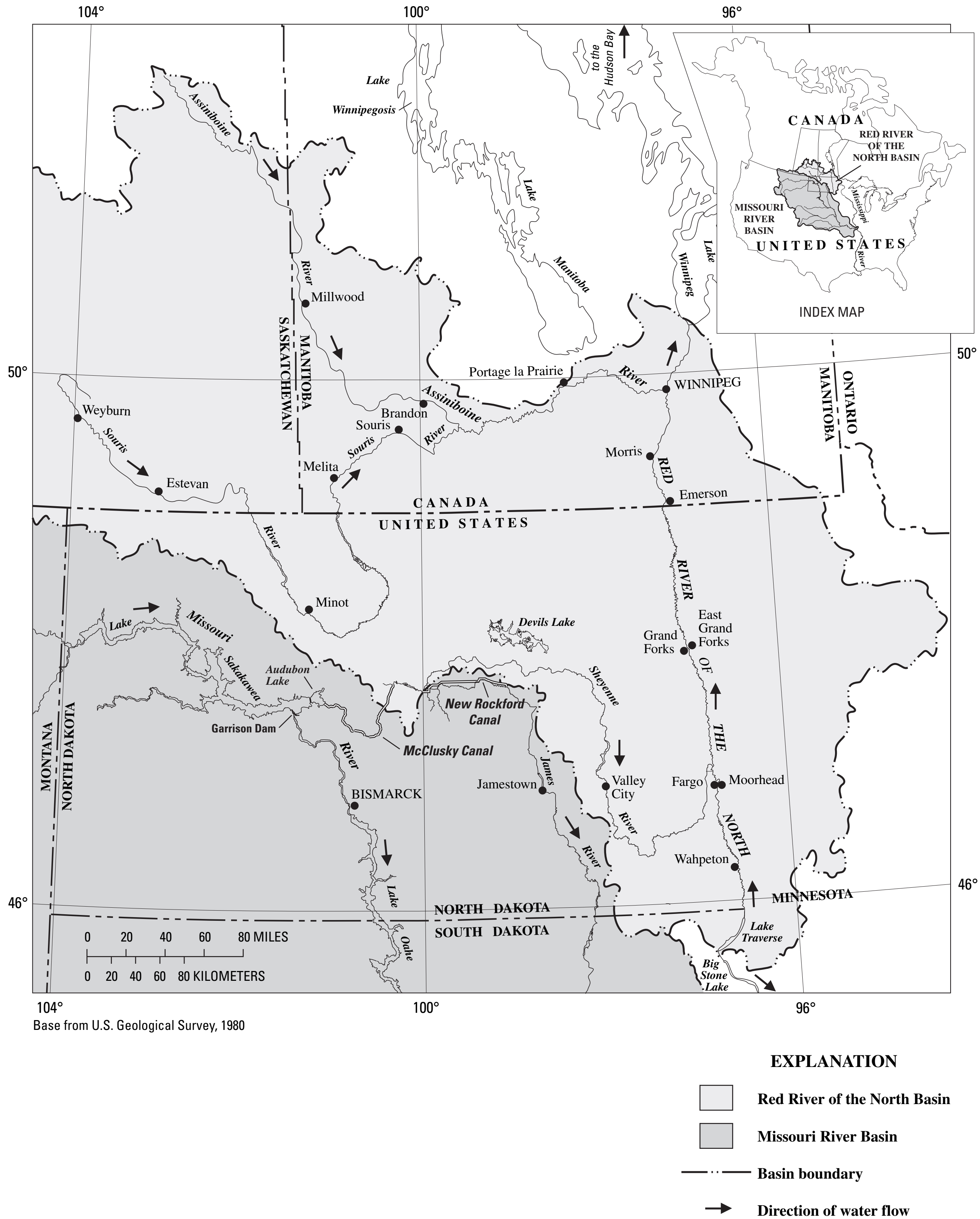

Figure 1. Location of Lake Sakakawea, Audubon Lake, and McClusky Canal in central North Dakota.

For the RRVWSP, the Bureau of Reclamation needs to have an understanding of the water quality of the potential source water for this project and an understanding of how the water quality is affected by present and potential future operations of the system. The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, performed a study to understand the water quality of the potential source water in Lake Sakakawea, Audubon Lake, and McClusky Canal for the RRVWSP.

Purpose and Scope

The purpose of this report is to summarize water-quality data collected by the Bureau of Reclamation from 23 sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal from May 1990 through September 2003 and to present the results of hierarchical agglomerative cluster analysis (HACA). Locations of these sites are shown in figure 2, and site descriptions, site locations, and period of record at each site are provided in table 1. The report summarizes the water-quality data and describes the HACA method and the resulting clustering of 409 samples in terms of the physical properties and major ions found in the water-quality samples. The clustering is related to temporal and spatial differences in water quality in Lake Sakakawea, Audubon Lake, and McClusky Canal.

The information in this report can be used by the Bureau of Reclamation to determine future water-quality sampling needs. The methods used in this report can be applied nationwide to help describe water-quality data in terms of temporal and spatial differences.

Description of Study Area

The study area includes Snake Creek Pumping Plant on Lake Sakakawea, Audubon Lake, and McClusky Canal, which are all part of the GDU (fig. 2). The water level of Lake Sakakawea, the reservoir created by Garrison Dam (earthwork was completed in 1954) on the Missouri River, is controlled by U.S. Army Corps of Engineers releases from the dam. The water level of Lake Sakakawea may fluctuate in response to many factors including downstream water needs, Rocky Mountain snowmelt, surface-water runoff, and flood-control needs.

Lake Sakakawea and Audubon Lake are separated by the U.S. Highway 83 causeway. The Snake Creek Pumping Plant, constructed from 1969 to 1976, pumps Missouri River water from Lake Sakakawea to Audubon Lake. Audubon Lake was filled in 1975 and acts as a holding reservoir for water before it is released into the McClusky Canal. Water in Audubon Lake is kept at an almost constant level. Audubon Lake had a mean water-surface elevation of 1,845.8 ft during the period of this study. Each spring, the Snake Creek Pumping Plant is used to fill Audubon Lake to an elevation of 1,847.0 ft and to maintain the lake at that level through August. From September through mid-November, the lake is lowered to an elevation of 1,845.0 ft by releasing water down the McClusky Canal, down Painted Woods Creek to the Missouri River, and through a conduit in the Snake Creek embankment that returns water to Lake Sakakawea. The fall drawdown helps maintain freshness in Audubon Lake and protects constructed island stabilization measures from ice damage (R. Nelson, Bureau of Reclamation, written commun., 2006). The variation in the elevations of Lake Sakakawea and Audubon Lake from 1990 through 2005 is shown in figure 3.

The McClusky Canal (figs. 1 and 2) is a 73.6-mi-long canal originally designed as the principal GDU supply feature that would transport Missouri River water to central and eastern North Dakota for project purposes, including water supply for communities in the Red River Valley. The canal crosses the divide between the Gulf of Mexico drainage basin and the Hudson Bay drainage basin near canal mile 59, where it is plugged to prevent flow of untreated Missouri River water into the Hudson Bay Basin.

The first 31 mi of the canal were filled with water from Audubon Lake in 1979. The remaining 42.6 mi of the canal filled naturally with surface-water runoff and ground-water contributions. Water in the canal consists of five sections separated by radial gates or plugs (fig. 4). These sections are designated by “WS,” for water surface, and a number. Section WS 1 from the canal headworks, sampling site 3B-2, to the radial gate at canal mile 20, site 3E-1, has an operational target elevation of 1,843.0 to 1,845.5 ft. Section WS 2, also known as the Chain of Lakes, includes that part of the canal from site 3E-2 to the plug at canal mile 52, site 3H-1. The section has a target elevation of 1,839.0 to 1,840.5 ft and is the section from which water is released down Painted Woods Creek. Section WS 2 is a combination of former WS 2 and former WS 3, which were connected as part of the canal freshening program. For the time period of this study, there was no WS 3. Section WS 4, from site 3H-2 to the radial gate at site 3I-1, has a target elevation of 1,839.0 to 1,840.5 ft. Section WS 5, also known as Hoffer Lake, from site 3I-2 through site 3K, has a target elevation of 1,839.0 to 1,840.5 ft. Section WS 6, also known as Skunk Lake, which includes site 3J, has a target elevation of 1,831.0 to 1,837.0 ft (M. Marohl, Bureau of Reclamation, oral commun., 2006, and unpublished data on file with the Bureau of Reclamation).

The Audubon Lake-McClusky Canal freshening program began in 1984 when the headworks at Audubon Lake were opened. Since that time, water has continued to flow through the canal to New Johns Lake (see section WS 2 in figure 2). Releases from New Johns Lake to Painted Woods Creek also began in 1984. Releases at the headworks varied from 0 to 100 ft^3/s from 1984 through 1999 and from 0 to 40 ft^3/s from 2000 through 2003. Releases down Painted Woods Creek varied from 0 to 40 ft^3/s from 1984 through 1999 and from 0 to 20 ft^3/s from 2000 through 2003 (M. Marohl., Bureau of Reclamation, oral commun., 2006, and unpublished data on file with the Bureau of Reclamation).

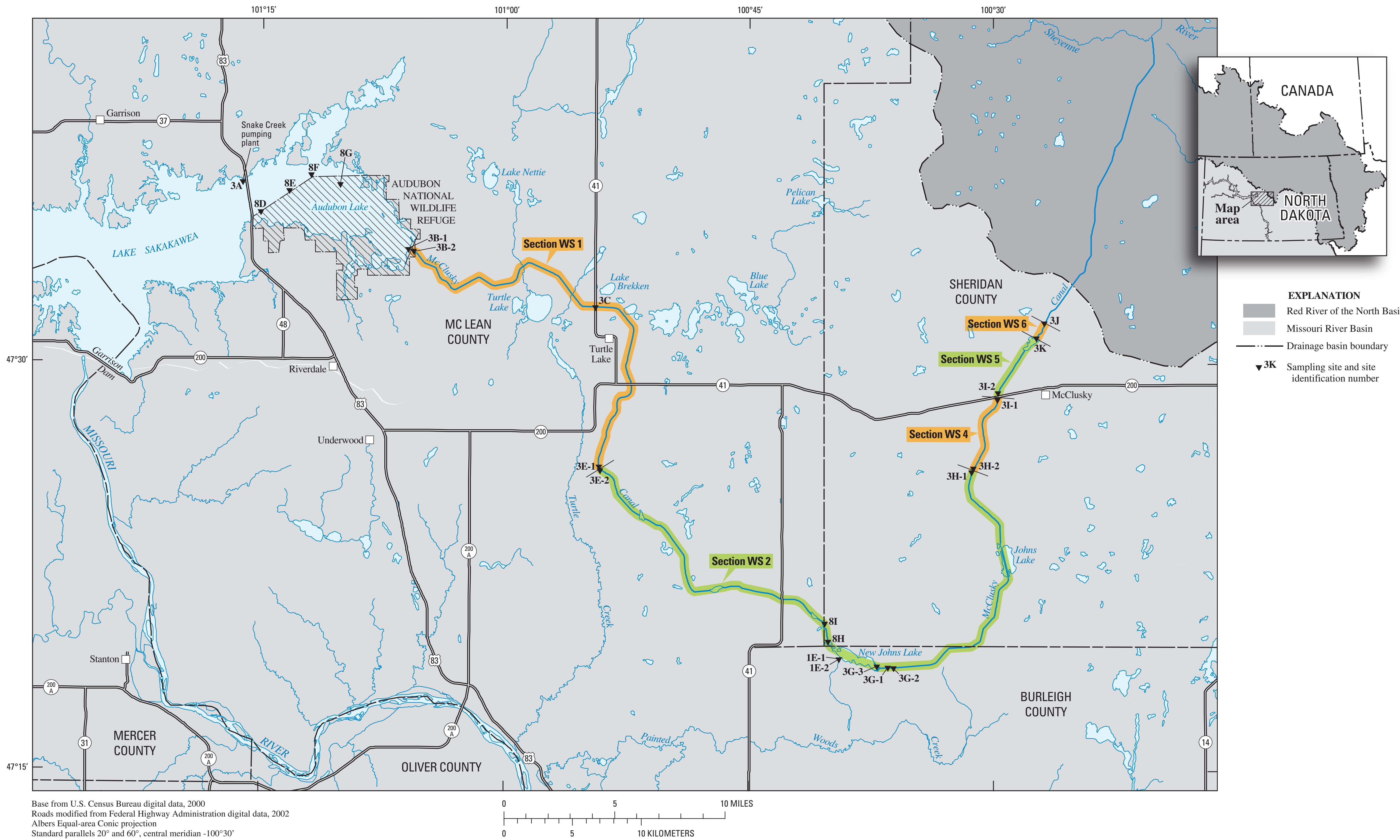

Figure 2. Location of sampling sites in the study area and sections of the McClusky Canal. Section WS 2 is a combination of former WS 2 and former WS 3.

Table 1. Water-quality sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota.

[Sites are listed in downstream order; map numbers are the Bureau of Reclamation site identification numbers; ft, feet]

Map number (fig. 2)	Site description	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Periodic water-quality measurements
3A	Lake Sakakawea at Snake Creek Pumping Plant (off west side of structure)	47°36’41” N	101°16’12” W	05/1990 through 09/2003
8D	Audubon National Wildlife Refuge boundary line no. 2 buoy from U.S. Highway 83	47°35’34” N	101°15’06” W	05/1990 through 08/1996
8E	Audubon National Wildlife Refuge boundary line no. 7 buoy from U.S. Highway 83	47°36’21” N	101°13’21” W	05/1990 through 08/1996
8F	Audubon National Wildlife Refuge boundary line no. 15 buoy from U.S. Highway 83	47°36’57” N	101°12’01” W	05/1990 through 08/1996
8G	Audubon National Wildlife Refuge boundary line 0.5 mile south of no. 17 buoy	47°36’35” N	101°10’13” W	05/1990 through 08/1996
3B-1	McClusky Canal headworks at Lake Audubon (inlet to canal)	47°34’11” N	101°06’00” W	05/1991 through 09/2003
3B-2	McClusky Canal headworks (downstream side of gates)	47°34’07” N	101°05’41” W	05/1990 through 09/2003
3C	McClusky Canal at Lake Brekken turnout (State Highway 41 north of Turtle Lake)	47°32’05” N	100°54’29” W	05/1990 through 08/1996
3E-1	McClusky Canal at radial gate (R1 & R2, upstream)	47°26’13” N	100°54’14” W	08/1990 through 11/1991
3E-2	McClusky Canal bridge south of radial gate (R1 & R2, downstream)	47°26’08” N	100°54’10” W	05/1990 through 08/1996
8I	Hecker’s Lake out from canal	47°20’28” N	100°40’18” W	05/1990 through 09/2003
8H	New Johns Lake west end	47°19’48” N	100°40’08” W	05/1990 through 08/1996
1E-1	Painted Woods Creek outlet channel from New Johns Lake (at structure)	47°19’11” N	100°39’28” W	08/1991 trhough 08/1996
1E-2	Painted Woods Creek outlet channel from New Johns Lake (lakeside)	47°19’11” N	100°39’28” W	05/1990 through 09/2003
3G-3	East end of New Johns Lake (1/4 mile west of canal 400 ft southeast of boat ramp)	47°18’53” N	100°37’07” W	05/1990 through 08/1996
3G-1	McClusky Canal radial gate (west side)	47°18’50” N	100°36’29” W	05/1990 through 05/1995
3G-2	McClusky Canal bridge (downstream of radial gate)	47°18’50” N	100°36’06” W	05/1991 through 08/1996
3H-1	McClusky Canal plug (upstream)	47°26’04” N	100°31’16” W	05/1990 through 08/1996
3H-2	McClusky Canal plug (downstream)	47°26’10” N	100°31’13” W	05/1990 through 08/1996
3I-1	McClusky Canal gate at State Highway 200 (upstream)	47°28’44” N	100°29’44” W	08/1990 through 09/2003
3I-2	McClusky Canal gate at State Highway 200 (downtream)	47°28’56” N	100°29’41” W	05/1990 through 08/1995
3K	McClusky Canal at Hoffer Lake (southeast of mile 58 plug at boat dock)	47°30’58” N	100°27’22” W	02/1992 through 09/2003
3J	McClusky Canal plug (upstream)	47°31’32” N	100°26’51” W	05/1990 through 08/1996

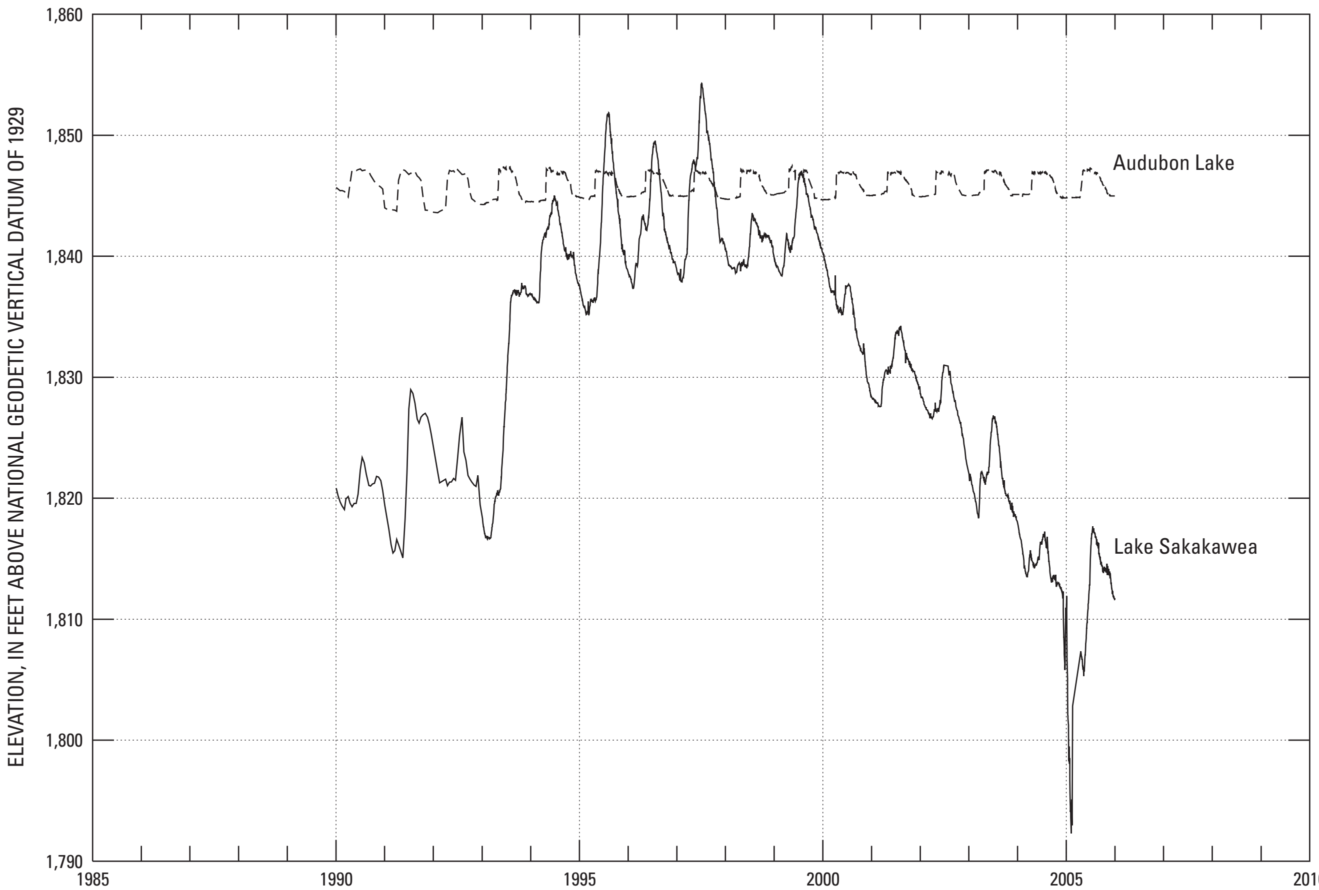

Figure 3. Water-surface elevations of Lake Sakakawea and Audubon Lake at Snake Creek Pumping Plant, 1990-2005.

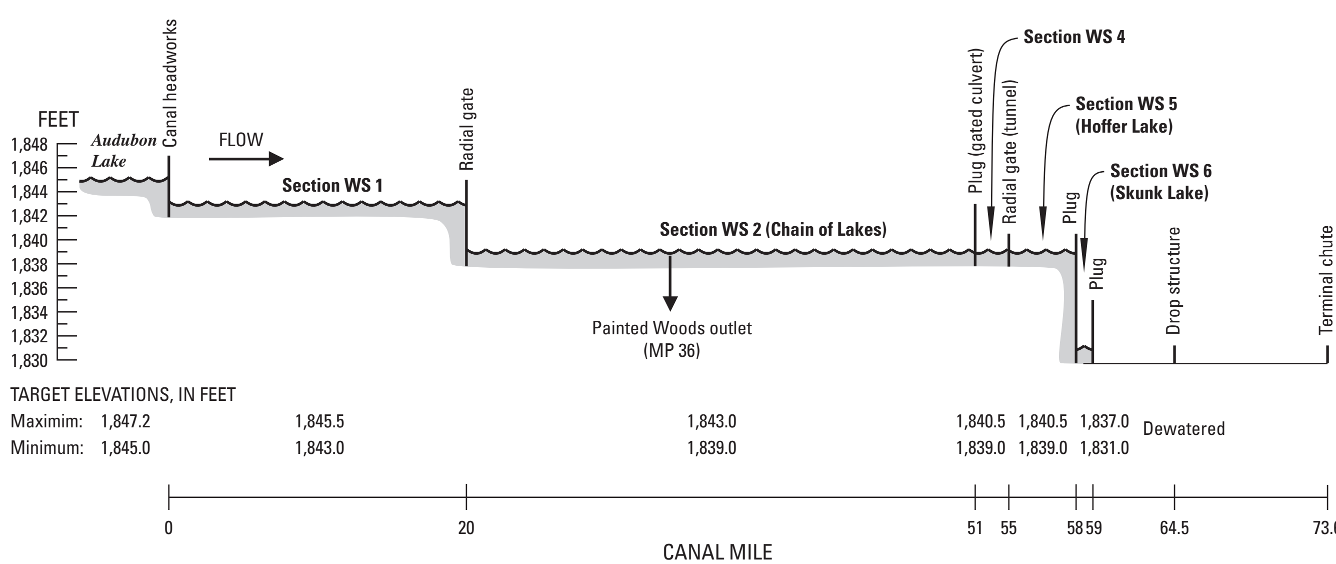

Figure 4. Schematic diagram of McClusky Canal. Section WS 2 is a combination of former WS 2 and former WS 3 (M. Marohl, Bureau of Reclamation, oral commun., 2006).

Downstream from New Johns Lake, there is no outlet and thus essentially no flow in the canal. To maintain target elevations, water is pumped in reverse from sections WS 4, WS 5, and WS 6 to section WS 2 (M. Marohl, Bureau of Reclamation, oral commun., 2006, and unpublished data on file with the Bureau of Reclamation).

Previous Studies

Previous studies of water quality related to the GDU have focused on the potential water-quality impact on the James River (Briel, 1988; Sando and others, 1990) and the Sheyenne/Red River system (Guenthner, 1991, 1993) if streamflows were augmented by water from the GDU. Studies also have examined the effects of GDU irrigation on ground water (Goolsby and others, 1989; Berkas and Komor, 1996) and the James River (Briel, 1989).

Methods Used for Water-Quality Analysis

This section describes how water-quality samples were collected and analyzed and how the data were summarized and interpreted for this study.

Data Collection

The Bureau of Reclamation records the water-surface elevation of Lake Sakakawea and Audubon Lake at the Snake Creek Pumping Plant using float-wells which are accurate to 0.01 ft. Those data are plotted in figure 3. Measurement frequency was generally four to five measurements per week (G. Hiemenz, Bureau of Reclamation, written commun., 2006).

From May 1990 through September 2003, the Bureau of Reclamation collected water-quality samples from 23 sampling sites in the study area (table 1). The lake water-quality samples were depth integrated using a weighted bottle lowered and raised in and out of the lake to obtain a sample representative of the whole water column (D. Hartman, Bureau of Reclamation, oral commun., 2006). Methods for sites on the McClusky Canal varied. If obtained from a bridge or through a hole in the ice, samples were depth integrated using a weighted bottle. Some samples, such as those at plugs, were dip samples (D. Hartman, Bureau of Reclamation, oral commun., 2006). Water-quality physical properties and constituents examined in this study are listed in table 2.

Table 2. Water-quality physical properties and constituents examined in this study, Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

Constituent	Unit of measurement
Physical properties	
Specific conductance, field	Microsiemens per centimeter at 25 degrees Celsius
pH, field	Standard units
Alkalinity	Milligrams per liter as calcium carbonate
Major ions and dissolved solids	
Calcium, dissolved	Milligrams per liter
Magnesium, dissolved	Milligrams per liter
Sodium, dissolved	Milligrams per liter
Potassium, dissolved	Milligrams per liter
Sulfate, dissolved	Milligrams per liter
Chloride, dissolved	Milligrams per liter
Total dissolved solids	Milligrams per liter
Nutrients	
Nitrite, dissolved	Milligrams per liter as nitrogen
Nitrate, dissolved	Milligrams per liter as nitrogen
Ammonia, dissolved	Milligrams per liter as nitrogen
Phosphorus	Milligrams per liter as phosphate

Laboratory Analysis

All water-quality samples were analyzed by the Bureau of Reclamation Dakotas Area Office Water and Soil Laboratory in Bismarck, North Dakota. Laboratory methods used were those of the manufacturer of the analyzing equipment and are based on U.S. Environmental Protection Agency approved methods (D. Hartman, Bureau of Reclamation, oral commun., 2006).

Water-Quality Data Analysis

All water-quality data were reviewed using time-series plots and summary statistics. The total anion charge was 85-110 percent of the total cation charge for all complete water-quality samples. Two samples were identified as potential outliers, a sample from site 3B-2 collected on May 18, 1999, and a sample from site 3H-2 collected on February 19, 1992. A duplicate sample also was collected at site 3B-2 on May 18, 1999, for quality-control purposes. The two site 3B-2 samples had similar values, the charge balance error for both samples was less than 10 percent, and no obvious errors were found. Therefore, the May 18, 1999, sample from site 3B-2 was included in the study. The sample from site 3H-2 appeared to be an outlier in terms of major cations and was missing specific conductance and pH values, both of which were needed for the statistical analysis. Therefore, the February 19, 1992, sample from site 3H-2 was not included in the study. Summary statistics for uncensored water-quality physical properties and constituents at each site are listed in table 3 (at back of report).

Nitrite, nitrate, and phosphorus concentrations were highly censored. Censored values are values that are known to be less than a certain laboratory reporting level, but for which the exact value is not known. Of the samples used in this study, 93 percent of nitrite concentrations were censored at 0.02 mg/L, 80 percent of nitrate concentrations were censored at 0.10 mg/L, 51 percent of phosphorus concentrations were censored at 0.01 mg/L, and 8 percent of ammonia concentrations were censored at 0.02 mg/L.

Summary statistics for the censored constituents are listed in table 4 (at back of report). To calculate the summary statistics for the censored constituents, Helsel's (2005) guidelines were followed. For constituents at sites with more than 80 percent censoring, the maximum concentration was reported, the minimum was reported as less than the censoring level, and the 95^{th} percentile was reported if the data had 95 percent censoring or less. For constituents at sites with 50-80 percent censoring, the maximum concentration was reported, the minimum was reported as less than the censoring level, and the percentiles were estimated using regression on order statistics (ROS). The ROS method used is the "robust form" described in Helsel (2005), which is best when applied to small data sets ($n < 30$), as is the case in this study with most water-quality sampling sites having fewer than 30 samples. For constituents at sites with less than 50 percent censoring, the maximum concentration was reported, the minimum was reported as less than the censoring level, and the percentiles are Kaplan-Meier estimates. The Kaplan-Meier method is described in Helsel (2005) and is a nonparametric method for estimating summary statistics. If a particular site had no censored values for a constituent, the summary statistics reported are actual values, not estimates.

Hierarchical Agglomerative Cluster Analysis

To examine the water-quality data for spatial and temporal differences, hierarchical agglomerative cluster analysis (HACA) was used. Güler and others (2002) described hierarchical cluster analysis as "an efficient means to recognize groups of samples that have similar chemical and physical characteristics." Various types of cluster analysis have been used to view water-chemistry data for both surface water (Alther, 1979; Güler and others, 2002) and ground water (Troiano and others, 1994; Farnham and others, 2000).

For the HACA used in this report, a subset of the water-quality constituents listed in table 2 was used (table 5). Total dissolved solids was not used in the cluster analysis because the amount of dissolved solids present is correlated to total ions present, represented by the major ions in table 5, and specific conductance, and "the use of variables that have specific relationships can cause undesirable redundancies in cluster analysis" (Güler and others, 2002).

Only 8 percent of the ammonia concentrations were censored. Therefore, ammonia was used in the cluster analysis. Substitution methods for the censored ammonia concentrations were examined. A substitute concentration based on the estimated mean of the uncensored data (Sanford and others, 1993) and a Kaplan-Meier estimate of the mean of the entire data set resulted in a substitute concentration of 0.02, equal to the censoring level, so the censored ammonia concentrations were treated as observed values for the cluster analysis. The highly censored constituents, nitrite, nitrate, and phosphorus were not used in the HACA.

Cluster analysis requires that every sample contain values for all of the constituents listed in table 5. Seventeen incomplete samples were not used and are not reflected in the interpretation of results. The data set used for the HACA contained 409 samples.

In performing the HACA, the data were first log transformed. Log transformation results in data that are more constant in variance. The HACA routine also standardized the data. Each constituent was standardized by subtracting the constituent's mean value and dividing by the constituent's mean absolute deviation (Insightful Corporation, 2001). Log transformation followed by standardization results in each constituent value having a range of approximately -3 to +3. This gives each constituent equal weight in the analysis; otherwise, the HACA algorithm would be affected most by constituents with large values.

Table 5. Water-quality physical properties and constituents used in hierarchical agglomerative cluster analysis of water-quality samples from Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

Constituent	Unit
Physical properties	
Specific conductance, field	Microsiemens per centimeter at 25 degrees Celsius
pH, field	Standard units
Alkalinity	Milligrams per liter as calcium carbonate
Major ions	
Calcium, dissolved	Milligrams per liter
Magnesium, dissolved	Milligrams per liter
Sodium, dissolved	Milligrams per liter
Potassium, dissolved	Milligrams per liter
Sulfate, dissolved	Milligrams per liter
Chloride, dissolved	Milligrams per liter
Nutrient	
Ammonia, dissolved	Milligrams per liter as nitrogen

In HACA, each sample forms its own cluster, and then pairs of clusters are successively merged on the basis of similarity of measurement and a linkage method. There are N-1, or 408, (where N is the total sample size, 409) merges in which the closest two clusters are merged into a single cluster, resulting in one less cluster at that merge. In this analysis, the similarity was computed by the Euclidean distance between samples. The Euclidean distance is the straight-line distance between two points in c-dimensional space defined by c variables. Here, c is 10 representing the 10 water-quality properties and constituents listed in table 5. Two points that have very similar values for all 10 constituents would lie close to each other if plotted in 10-dimensional space and, therefore, would have a small Euclidean distance between them and they would cluster together.

The linkage used to merge clusters was Ward's method. Ward's method uses an analysis of variance (ANOVA) approach to evaluate differences between clusters (Güler and others, 2002). The two clusters that are merged are the pair "that leads to the smallest increase in the sum of the within-group sums of squares" (Insightful Corporation, 2001). The within-group sum of squares is the sum of the squared Euclidean distances from each sample to the center of its parent group.

To test statistical significance, the Kruskal-Wallis rank sum test (Higgins, 2004) was used. The Kruskal-Wallis rank sum test is a nonparametric test, meaning it does not assume that the data follow a particular distribution, such as the normal distribution. The differences in sampling periods of record, in the number of samples, and in the operational conditions at different sites in the study do not support the assumption that the samples all follow the same distribution. The Kruskal-Wallis test compares data in more than two groups. When only two groups are compared, the Kruskal-Wallis rank sum test reduces to the Wilcoxson rank sum test (Higgins, 2004).

Results of Hierarchical Agglomerative Cluster Analysis

HACA results in a dendrogram and an agglomerative coefficient. A dendrogram is a "highly interpretable complete description of the hierarchical clustering in a graphical format" and "is one of the main reasons for the popularity of hierarchical clustering methods" (Hastie and others, 2001). The dendrogram resulting from HACA of the water-quality data in this study is shown in figure 5. The individual samples are represented by the vertical lines arranged so that branches of the dendrogram do not cross. The merges of similar clusters are represented by horizontal lines connecting clusters. The y-axis represents the distance between the two clusters being merged. Clusters that do not merge until the upper end of the y-axis represent water-quality samples that are distant from each other in Euclidean distance, that is samples that have widely differing constituent concentrations.

The agglomerative coefficient (AC) is a dimensionless quality index for measuring the clustering structure of the data set and is between 0 and 1. The AC tends to increase with the number of samples; therefore, one should not compare the AC of different data sets that are very different in size (Struyf and others, 1997; Insightful Corporation, 2001). The agglomerative coefficient of the HACA in this study was high, 0.989.

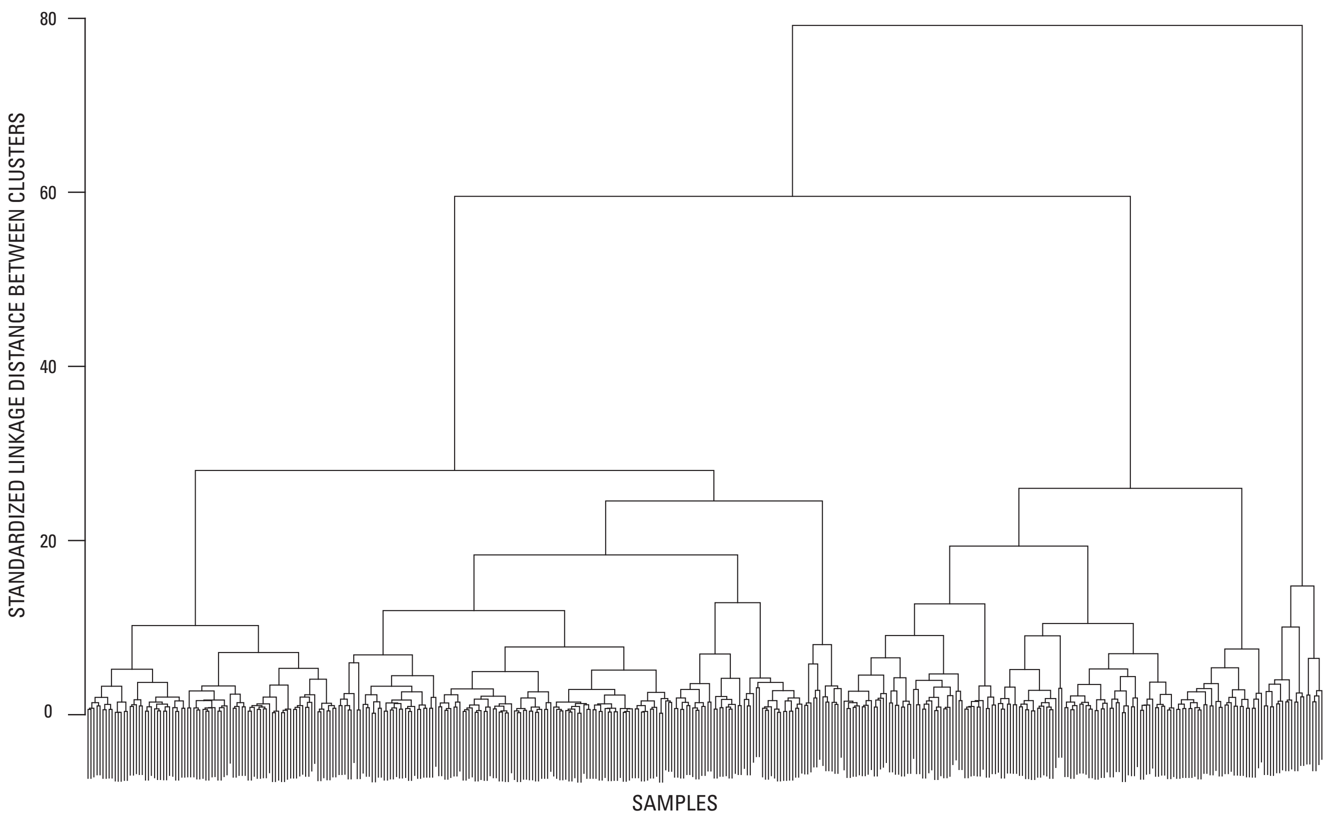

Figure 5. Dendrogram from hierarchical agglomerative cluster analysis of 409 surface-water samples collected from Lake Sakakawea, Audubon Lake, and McClusky Canal, 1990-2003. [Samples arranged so that branches of dendrogram do not cross.]

An AC close to 1 indicates that there is a "very clear clustering structure" in the data; however, the structure needs to be analyzed to determine that it is reasonable (Kaufman and Rousseeuw, 1990).

Cluster Groups

Examination of figure 5 led to the identification of three major branches in the dendrogram. These three branches represent three major cluster groups, labeled as A, B, and C in figure 6. A, B, and C were identified as major cluster groups because the linkage distance at which they combine with each other is relatively large, indicating that there are relatively large Euclidean distances between the samples in groups A, B, and C. The linkage distance at which groups A and B are combined is less than the linkage distance at which group C combines with the rest of the data, indicating that samples in groups A and B are more similar to each other than to the samples in group C. The samples in group C do not merge with the rest of the samples until the final, N-1, step of the algorithm.

Subgroups may be examined within these three main groups. The number of subgroups examined is subjective in that the analyst determines the number of subgroups by balancing interest in interpretable subgroups and avoidance of needless splitting of the data. One determines the number of subgroups examined by drawing a line across the dendrogram and examining the main clusters branching out beneath that line. By means of a dashed horizontal line, figure 6 shows the data divided into six subgroups (1-6). The groups and subgroups can be examined for spatial and temporal differences in sample membership and statistically significant differences in water-quality constituents.

Major Cluster Groups

Initial examination of the sample cluster groups indicated that differences in groups may be attributable to canal operations and the distance from the source water. Therefore, table 6 lists the water-quality sites in order by canal mile. The table also lists the number of samples at each site, and the percentage of samples at each site clustered into each major group.

Group A consists of 250 of the 409 samples and contains all of the samples from sites 3A, 8D, 8E, 8F, 8G, 3B-1, 3B-2, 3C, and 3E-1. Group A contains no samples from sites 3I-1, 3I-2, 3K, and 3J, those farthest from the source of water. Sites 3B-2 to 3E-1 correspond to the section of the canal designated as section WS 1. Water levels in section WS 1 are kept at a higher elevation than the next downstream section of the canal, and the section is part of the canal freshening program (as is section WS 2).

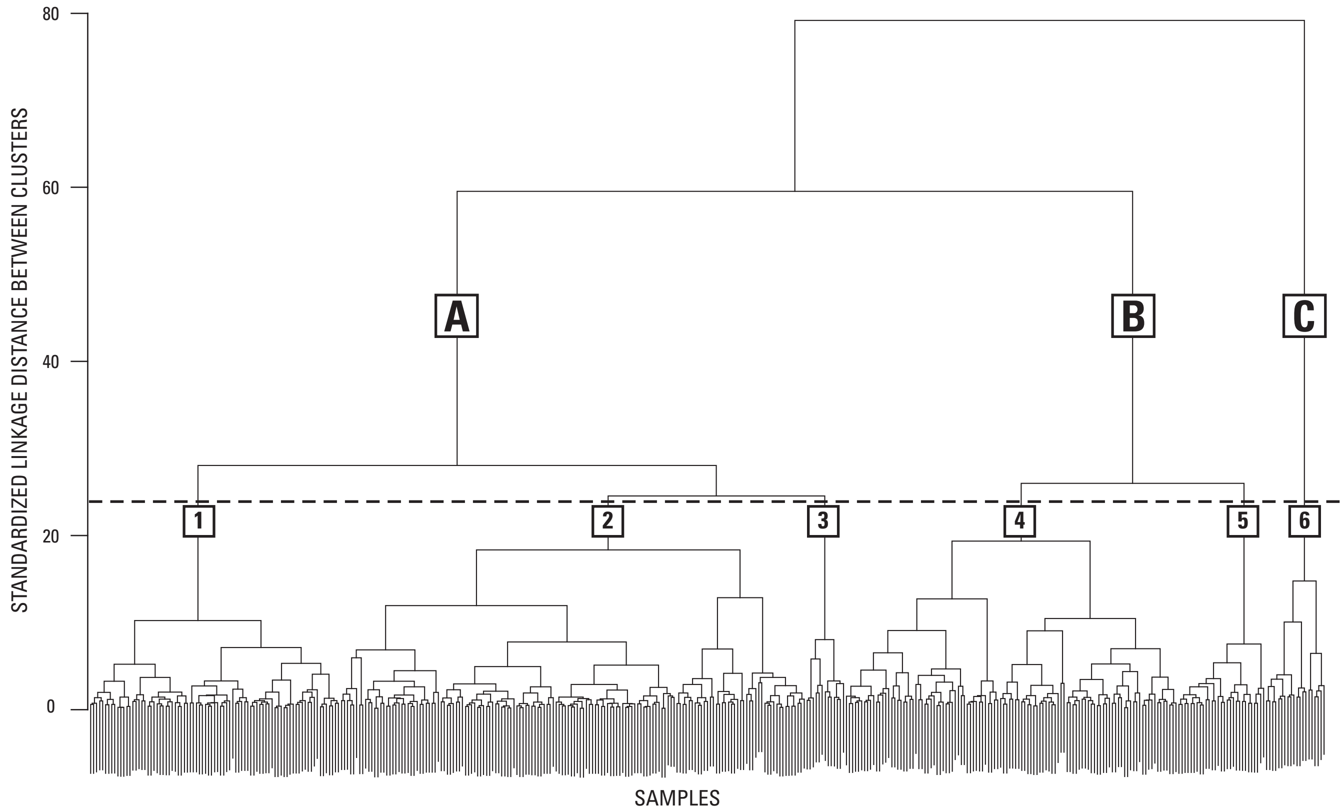

Figure 6. Dendrogram showing groups (A, B, and C) and subgroups (1-6) of surface-water samples examined in this study. The dashed horizontal line identifies the six subgroups and those clusters whose main branches extend below the line. [Samples arranged so that branches of dendrogram do not cross.]

Table 6. Water-quality sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, and percentage of samples that fall into cluster groups A, B, and C.

[Sites are listed in downstream order; map numbers are the Bureau of Reclamation site identification numbers; ft, feet; --, not applicable]

Map number (fig. 2)	Site description	Canal mile	Total number of samples	Percentage of samples in		
				Group A	Group B	Group C
3A	Lake Sakakawea at Snake Creek Pumping Plant (off west side of structure)	--	36	100.0	--	--
8D	Audubon National Wildlife Refuge boundary line no. 2 buoy from U.S. Highway 83.	--	12	100.0	--	--
8E	Audubon National Wildlife Refuge boundary line no. 7 buoy from U.S. Highway 83.	--	11	100.0	--	--
8F	Audubon National Wildlife Refuge boundary line no. 15 buoy from U.S. Highway 83.	--	11	100.0	--	--
8G	Audubon National Wildlife Refuge boundary line 0.5 mile south of no. 17 buoy	--	10	100.0	--	--

Table 6. Water-quality sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, and percentage of samples that fall into cluster groups A, B, and C. —*Continued*

[Sites are listed in downstream order; map numbers are the Bureau of Reclamation site identification numbers; ft, feet; --, not applicable]

Map number (fig. 2)	Site description	Canal mile	Total number of samples	Percentage of samples in		
				Group A	Group B	Group C
3B-1	McClusky Canal headworks at Lake Audubon (inlet to canal)	0	21	100.0	--	--
3B-2	McClusky Canal headworks (downstream side of gates)	0.2	28	100.0	--	--
3C	McClusky Canal at Lake Brekken turnout (State Highway 41 north of Turtle Lake)	11.1	24	100.0	--	--
3E-1	McClusky Canal at radial gate (R1 & R2, upstream)	19.9	4	100.0	--	--
3E-2	McClusky Canal bridge south of radial gate (R1 & R2, downstream)	20.0	16	93.8	6.3	--
8I	Hecker's Lake out from canal	34.2	31	61.3	38.7	--
8H	New Johns Lake west end	35.0	18	77.8	22.2	--
1E-1	Painted Woods Creek outlet channel from New Johns Lake (at structure)	36.0	13	76.9	23.1	--
1E-2	Painted Woods Creek outlet channel from New Johns Lake (lakeside)	36.0	20	25.0	75.0	--
3G-3	East end of New Johns Lake (1/4 mile west of canal 400 ft south-east of boat ramp)	37.8	18	77.8	22.2	--
3G-1	McClusky Canal radial gate (west side)	38.1	12	75.0	25.0	--
3G-2	McClusky Canal bridge (downstream of radial gate)	38.4	9	55.6	44.4	--
3H-1	McClusky Canal plug (upstream)	51.2	19	5.3	94.7	--
3H-2	McClusky Canal plug (downstream)	51.3	17	5.9	94.1	--
3I-1	McClusky Canal gate at State Highway 200 (upstream)	54.9	22	--	100.0	--
3I-2	McClusky Canal gate at State Highway 200 (downstream)	55.0	11	--	100.0	--
3K	McClusky Canal at Hoffer Lake (southeast of canal mile 58 plug at boat dock)	58.0	26	--	96.2	3.8
3J	McClusky Canal plug (upstream)	58.8	20	--	5.0	95.0

Downstream from the radial gate between sites 3E-1 and 3E-2, samples begin to cluster in groups A and B. Group B consists of 139 of the 409 samples. The split between group A and group B appears to be both spatial and temporal. For site 3G-2, samples from 1991 through 1993 clustered in group A, whereas samples from 1994 through 1996 clustered in group B. Water-quality samples from site 3G-3 prior to 1995 clustered in group A, and the remainder of the samples from site 3G-3 clustered in group B. Almost all samples from sites 3H-1 and 3H-2 clustered in group B, with the few clustering in group A being collected during the early 1990s. Canal operations may have contributed to the temporal differences in water quality. From 1993 through 1999, flows through the canal were shut down for about 2 months during July through September and the water-surface elevation in section WS 1 dropped 8 ft. This was done to allow "beachbelting" work, during which rock rip-rap was installed to stabilize the banks of the canal along the waterline of the desired operational water-surface elevation (1,843.0 to 1,845.5 ft for section WS 1). Each fall, during the years in which beachbelting occurred, the water-surface elevation was brought back up before freezeup (M. Marohl, Bureau of Reclamation, oral commun., 2006).

In addition to beachbelting, another change in section WS 2 may help explain the temporal difference in water quality. The North Dakota State Game and Fish Department requested in 1993 that total dissolved-solids (TDS) concentrations in water from section WS 2, the Chain of Lakes, be increased (M. Marohl, Bureau of Reclamation, oral commun., 2006), using TDS concentration as a measure of dissolved ions necessary for the maintenance of aquatic life. TDS concentrations were increased by reducing releases of water from section WS 2 to the Painted Woods Creek outlet channel. In figure 7, TDS concentrations are plotted as points for the sampling sites located in section WS 2 from 1990 through 2003. The line is a Lowess scatterplot smooth (Insightful Corporation, 2002) of the TDS concentrations. TDS concentrations for sites in section WS 2 are listed in table 7 (at back of report). The number of samples and period of record vary at each site; however, TDS concentration in 1993-2003 is generally higher than TDS concentration in 1990-1992 for all sites except 3E-2. Because TDS can be correlated with specific conductance and the ions used in the HACA, a change in TDS concentrations can be related to a change in the variables used in the HACA and may contribute to the clustering of the data. For some of the sampling sites in the Chain of Lakes section, there was

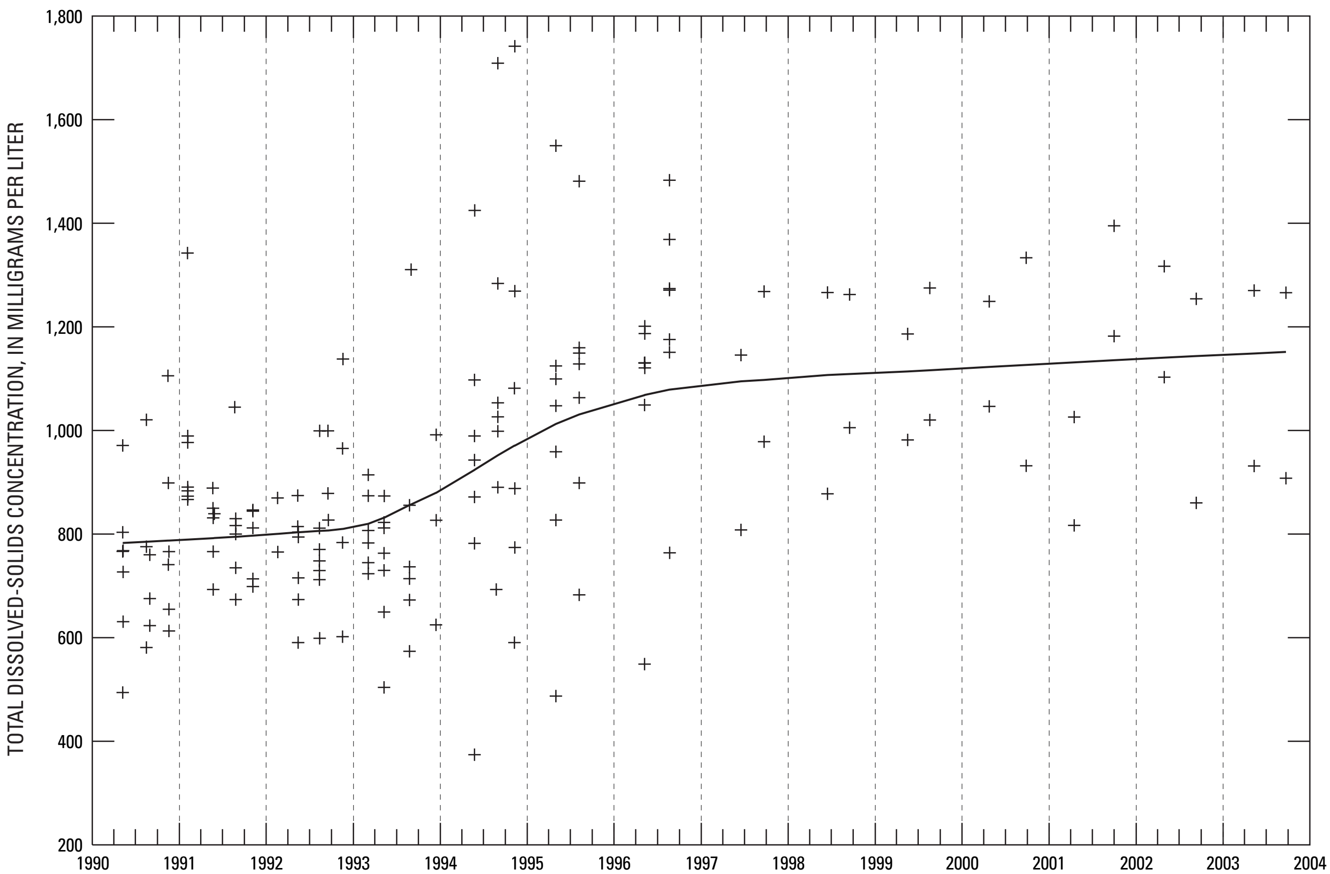

Figure 7. Total dissolved-solids concentrations in samples from water-quality sampling sites located in section WS 2, 1990-2003. The line is a Lowess scatterplot smooth used to exhibit the increase in total dissolved-solids concentrations that began in 1993.

a change in clustering of the data that corresponded to the increase in TDS. For example, for site 1E-2, samples from 1990-91 were grouped in cluster A, and samples from 1994-2003 were grouped in cluster B.

Samples from sites 3I-1 and 3I-2 occurred only in group B, and of the 26 samples from site 3K (table 1), 25 of them clustered in group B. These sampling sites are among those farthest from the source of water and are in the part of the canal that was filled by surface-water runoff and ground-water contributions.

Group C consists of 20 of the 409 samples. Of the 20 samples collected at site 3J, 19 of them occurred in group C. Group C contained only one sample from any other site, the May 26, 1994, sample from site 3K. This indicates that samples from site 3J are similar to each other but dissimilar to samples from other sites. The segment of the canal between sites 3K and 3J, section WS 6, is known as Skunk Lake. Water in this segment is from surface-water runoff and ground-water contribution. There is no mechanical freshening mechanism for this segment, and the stagnant water would explain the high concentrations of water-quality constituents at site 3J.

Cluster Subgroups

The sites in order by canal mile, number of samples from each site used in the HACA, and the percentages of samples that fall into each subgroup are listed in table 8 (at back of report). Some of the water-quality differences are spatial (table 8); however, much of the difference between subgroups also may be temporal.

Subgroup 1 contains 83 of the 409 samples used in this study. For many sampling sites that have samples split between groups A and B, there appears to be a temporal difference in water quality. For example, most of the samples from site 3G-2 that were collected early in the period of record (1991-93) clustered into subgroup 1. The samples collected later in the period of record (1994-96) clustered into subgroup 4. Water quality in samples from site 3G-3 were similar in that most samples collected during 1990-95 clustered in subgroup 1 and samples collected during 1995-96 clustered in subgroup 4. The majority of samples in subgroup 1 were collected during 1990-93. This period corresponds to the part of this study in which water-quality samples were collected before beachbelting began in canal section WS 1 and before the increase in total dissolved-solids concentrations in section WS 2.

Subgroup 2 is the largest subgroup and contains 154 of the 409 samples. Subgroup 2 contains all samples from sites 3B-1 and 3E-1 and the majority of samples from sites 3A, 8D, 8E, 8F, 8G, 3B-2, 3C, and 3E-2. These are the sites closest to the source water. Sample membership in this group generally spans the period of record for each sampling site.

Subgroup 3 contains 13 of the 409 samples. Most of the samples in this group are from sites 3A. Subgroup membership appears to be related to time. Subgroup 2 contains samples collected early in the period of record and late in the period of record for site 3A (1990-92 and 2002-03).

Some of the differences in subgroups 1-3 may be seasonal. However, this is difficult to examine because of the different periods of record at sites and different sampling dates from year to year. For example, it appears that samples collected in February were more likely to cluster into subgroup 1; however, February samples were collected only in 1991 and 1992. Likewise, March samples were collected only in 1993 and 1994.

Subgroup 4 contains 110 of 409 samples. Samples collected at sites 3I-1, 3I-2, and 3K were split between subgroups 4 and 5 (with the exception of the one sample from site 3K in subgroup 6). The differences in water quality among samples in subgroups 4 and 5 appear to be temporal. For example subgroup 4 contains samples collected from site 3K during 1995-2003.

Subgroup 5 contains 29 of 409 samples, none of which were collected during 1996-2001. Samples from site 3K were collected during 1992-95 and 2002-03. These years correspond to the beginning and end of the period of record. For samples from site 3I-1, which occurred only in group B, samples in subgroup 5 were collected early in the period of record (1990-91 and 1994) and late in the period of record (2002-03). Samples from site 3I-2 also clustered only in group B; however, the period of record for site 3I-2 ended in 1995, and samples from the middle part of the period of record (1991-94) occurred in subgroup 5.

At the linkage distance chosen to identify subgroups for analysis (fig. 6), Group C was not subdivided further. Group C and subgroup 6 have the same sample membership and are representative of water quality at site 3J during the study period.

Inter-Subgroup Comparison

Mean concentrations for samples in subgroup clusters 1-6 for all of the uncensored constituents used in the HACA plus total dissolved solids are listed in table 9. Nitrite, nitrate, and phosphorus were highly censored and were not used in the HACA. Ammonia values also were censored, but to a lesser extent, so ammonia concentrations were used in the HACA.

Table 9. Mean concentrations for uncensored constituents in subgroups determined from hierarchical agglomerative cluster analysis, Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

			Uncensored constituent concentrations									
Group	Subgroup	Number of samples	Specific conductance (µS/cm)	pH (standard units)	Alkalinity (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total dissolved solids (mg/L)
A	1	83	1,150.00	8.52	249.00	55.10	55.20	142.00	11.20	388.00	18.60	805.00
	2	154	841.00	8.40	194.00	44.80	32.90	99.00	6.09	246.00	13.90	548.00
	3	13	862.00	7.51	226.00	61.10	26.20	109.00	5.03	254.00	12.60	584.00
B	4	110	1,790.00	8.35	261.00	86.30	99.50	188.00	21.20	733.00	20.20	1,300.00
	5	29	2,720.00	8.47	377.00	78.30	170.00	346.00	41.00	1,240.00	34.90	2,120.00
C	6	20	9,110.00	8.67	637.00	113.00	641.00	1,720.00	115.00	5,640.00	201.00	8,690.00

A summary of the cluster medians for the censored constituents is shown in table 10. For those clusters in which a constituent was more than 80 percent censored, the percentage of censored values is shown. To calculate summary statistics for censored constituents with less than 80 percent of the values censored, Helsel's (2005) methods and guidelines were followed. For subgroups in which less than 50 percent of the values were censored, the median is a Kaplan-Meier estimate of the median. The subgroup median concentrations estimated by Kaplan-Meier are followed by a KM subscript. When 50-80 percent of the values in a subgroup were censored, the median concentration is a ROS estimate of the median. The subgroup median concentrations estimated by ROS are followed by an ROS subscript. For four subgroups in which there were no censored ammonia values, the actual median concentration is shown.

Statistical Testing

Nonparametric rank tests were performed at the 0.01 significance level to test whether all populations (group or subgroups) have the same distribution function or at least one of the populations has a different location (median). Results of the test for statistical significance are summarized in table 11.

The test for statistical significance was first performed on groups A, B, and C, to determine if there was a statistically significant difference in at least one of these groups. The p-values of the test performed for each uncensored constituent appear in table 11. The p-values were all less than 0.01, indicating that there is a significant statistical difference in all uncensored constituent concentrations used in the HACA and in TDS concentrations.

Next, a test of significance was performed for the subgroups in group A and the subgroups in group B. All uncensored constituents and total dissolved solids had statistically significant differences in group A, indicating that at least one of the subgroups, 1, 2, or 3, is different from the others. For Group B, the p-value for calcium was 0.062 (table 11). This means if the data in subgroups 4 and 5 were repeatedly randomly assigned to either subgroup, 6.2 percent of random assignments would result in the calcium values found in this study. The p-value for pH was 0.010. All other constituents in group B had a statistically significant difference with p-values less than 0.01.

Tests of significance were performed on subgroups 1, 2, and 3 of group A to determine which subgroups differed from the others. The p-values for these tests are shown in table 12.

Table 10. Median concentrations for censored constituents in subgroups determined from hierarchical agglomerative cluster analysis, Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

[mg/L, milligrams per liter]

			Censored constituent concentrations, in milligrams per liter (mg/L), or percentage (%) of censored values[1,2,3]			
Group	Cluster	Number of samples	Nitrite (censored at 0.02 mg/L)	Nitrate (censored at 0.10 mg/L)	Ammonia[4] (censored at 0.02 mg/L)	Phosphorus (censored at 0.01 mg/L)
A	1	83	86.6%	95.1%	0.150	0.008_{ROS}
	2	154	97.4%	0.042_{ROS}	0.120_{KM}	0.010_{ROS}
	3	13	92.3%	0.100_{KM}	0.250	0.010_{KM}
B	4	110	97.3%	83.6%	0.100_{KM}	0.006_{ROS}
	5	29	93.1%	82.8%	0.330	0.010_{KM}
C	6	20	0.009_{ROS}	85.0%	0.845	0.050_{KM}

[1]When 80 percent or more of values are censored, the percentage of censored values is displayed.

[2]When censoring occurs, but less than 50 percent of the values are censored, the median is a Kaplan-Meier (KM) estimate of the median.

[3]When 50-80 percent of the values are censored, the median is a regression on order statistics (ROS) estimate of the median.

[4]Actual medians are shown for subgroups 1,2, 5, and 6, which contained no censored values.

Table 11. P-values for Kruskal-Wallis test of significant difference between cluster groups and subgroups for water-quality samples collected from Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

[A p-value of less than 0.01 is a statistically significant difference; <, less than]

	P-values for uncensored constituents									
	Specific conductance	pH	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Total dissolved solids
Test of signficance for groups A, B, and C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Test of significance for subgroups 1, 2, and 3 in group A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Test of significance for subgroups 4 and 5 in group B	<0.001	0.010	<0.001	0.062	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 12. P-values for test of significant difference between cluster subgroups in group A for water-quality samples collected from Lake Sakakawea, Lake Audubon, and McClusky Canal, central North Dakota, 1990-2003.

[To adjust for multiple comparisons in group A, a p-value of less than 0.003 is a statistically significant difference; <, less than]

	P-values for uncensored constituents									
	Specific conductance	pH	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Total dissolved solids
Test of significance for subgroups 1 and 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Test of significance for subgroups 1 and 3	<0.001	<0.001	0.017	0.082	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Test of significance for subgroups 2 and 3	0.981	<0.001	0.006	<0.001	<0.001	0.626	0.015	0.929	0.021	0.262

Doing multiple comparisons within a group results in an increased experiment-wise error rate. To control this error rate, the p-value indicating a statistically significant difference was defined as 0.003. Subgroups 1 and 2 were statistically different for every constituent. Subgroups 1 and 3 were statistically different for all constituents except alkalinity (p-value 0.017, table 12) and calcium (p-value 0.082, table 12).

In examining the subgroup mean concentrations for each constituent, subgroups 2 and 3 appeared to be similar. Above the dashed line in the dendrogram (fig. 6), subgroups 2 and 3 combine at the lowest linkage distance of the cluster merges, indicating that subgroups 2 and 3 are the most similar of the six subgroups identified. Subgroups 2 and 3 were not statistically different for specific conductance, alkalinity, sodium, potassium, sulfate, chloride, and total dissolved solids (p-values > 0.003, table 12). Subgroups 2 and 3 were significantly different for pH, calcium, and magnesium.

Future Water-Quality Sampling

Water-quality samples were collected from four sites on Audubon Lake, sites 8D, 8E, 8F, and 8G. In this analysis, there was not a significant difference in constituent concentrations among these sites. All of the Audubon Lake samples fell into cluster group A, and the majority of samples fell into subgroup 2. The samples from the lake sites also were similar in that none of the samples at any Audubon Lake site fell into subgroup 3. Four samples, one from each Audubon Lake site, fell into subgroup 1. All four samples were collected on February 7, 1991. If water-quality sampling continues in the same manner that the sampling was done for this study, it would not be necessary to sample from the four lake sites because of the lack of variability between sites.

Examination of the clustering of sites in section WS 2 of the McClusky Canal also indicates the possibility of sampling at fewer sites. For example, site 8H, the west end of New Johns Lake, and site 3G-3, the east end of New Johns Lake, had the same sample size, period of record, and the same clustering structure. The clustering structure of the two sites indicates a lack of variability between the two sites. Other sites in section WS 2, 1E-1 and 3G-1, cluster in a similar manner; however, their differing sample sizes and periods of record make direct comparison difficult.

The clustering of the McClusky Canal water-quality samples and past operations of the canal suggest that water quality changes in response to operational changes. Future operational changes, such as the canal being used to transport water for the RRVWSP, may justify additional water-quality sampling to characterize possible water-quality changes.

Summary

As a result of the Dakota Water Resources Act of 2000, the Bureau of Reclamation, U.S. Department of the Interior, identified eight water-supply alternatives (including a no-action alternative) for the Red River Valley Water Supply Project. Of those alternatives, four included the interbasin transfer of water, three of which would use the McClusky Canal to transport the water. Therefore, the water quality of the McClusky Canal and its sources, Lake Sakakawea and Audubon Lake, is of interest to water-quality stakeholders.

This report summarizes water-quality data collected by the Bureau of Reclamation at 23 sites on Lake Sakakawea, Audubon Lake, and the McClusky Canal system. Results of sample analysis were interpreted by the U.S. Geological Survey using hierarchical agglomerative cluster analysis (HACA). HACA clustered the 409 samples into related groups based on physical properties, specific conductance, pH, and alkalinity, and water-quality constituents, calcium, magnesium, sodium, potassium, sulfate, chloride, and ammonia. The HACA indicated that the samples had a strong clustering structure.

The samples clustered into three main groups that had statistically significant differences for all physical properties and constituents used in the HACA. Some of the differences corresponded to different sections of the canal that are under different operational conditions. Differences in operational conditions included sections of the canal, or water surfaces, separated by plugs or gates, that were held at different elevations and differences in source water. Some sections of the canal receive inflow from Audubon Lake and have an outlet to the next water surface (section WS 1) or Painted Woods Creek (section WS 2). Other sections receive water only through surface-water runoff and ground-water contribution and did not have a mechanical freshening mechanism (sections WS 4, 5, and 6).

Operational changes to the canal during specific periods also appeared to affect the clustering of the data. Examples of operational changes included beachbelting work done during 1993-99 that affected the elevation and flow in canal section WS 1 and also affected the flow of water through section WS 2. In addition, beginning in 1993, releases from section WS 2 to the Painted Woods Creek outlet channel were reduced to increase total dissolved-solids concentrations in section WS 2 at the request of the North Dakota Game and Fish Department.

The samples were examined further by looking at six subgroup clusters. These clusters also had statistically significant differences and appeared to correspond with operational changes and the water surfaces of the canal. The strong clustering structure and statistically significant differences in the HACA indicate that future water-quality sampling in response to operational changes in the McClusky Canal system would be justified to characterize possible water-quality changes.

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Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	**Physical property or constituent**	**Sample size**	**Maximum**	**Minimum**	**Mean**	**95**	**75**	**(Median) 50**	**25**	**5**
3A	Specific conductance	36	1,220.00	520.00	716.00	1,080.00	793.00	680.00	600.00	550.00
	pH	36	8.76	7.10	8.06	8.49	8.31	8.21	7.80	7.29
	Alkalinity	36	305.00	144.00	183.00	272.00	198.00	163.00	154.00	148.00
	Total dissolved solids	36	805.00	342.00	470.00	686.00	534.00	417.00	400.00	364.00
	Calcium	36	83.60	44.00	54.20	73.50	56.60	51.80	48.50	45.70
	Magnesium	36	35.40	18.40	22.60	30.30	24.00	21.60	20.10	18.50
	Sodium	36	167.00	45.60	77.80	150.00	89.30	66.00	57.60	50.50
	Potassium	36	7.10	2.40	4.39	6.09	5.12	4.20	3.70	2.98
	Sulfate	36	341.00	128.00	199.00	324.00	231.00	176.00	164.00	143.00
	Chloride	36	15.60	7.43	10.60	13.60	11.30	10.30	9.73	8.22
8D	Specific conductance	12	940.00	600.00	805.00	918.00	845.00	810.00	775.00	672.00
	pH	12	8.61	8.07	8.42	8.59	8.48	8.42	8.39	8.21
	Alkalinity	12	244.00	184.00	198.00	223.00	202.00	192.00	189.00	185.00
	Total dissolved solids	12	687.00	496.00	553.00	655.00	563.00	541.00	508.00	500.00
	Calcium	12	52.00	30.00	45.30	51.20	48.40	47.10	42.50	36.00
	Magnesium	12	40.70	30.00	33.40	38.30	34.00	33.00	31.80	30.30
	Sodium	12	127.00	86.00	101.00	120.00	107.00	99.50	92.40	88.00
	Potassium	12	8.03	5.00	6.68	8.01	7.40	6.87	5.95	5.22
	Sulfate	12	298.00	210.00	251.00	294.00	268.00	243.00	240.00	216.00
	Chloride	12	16.40	12.70	14.50	15.80	14.80	14.30	14.20	13.40
8E	Specific conductance	11	930.00	590.00	819.00	925.00	885.00	830.00	780.00	665.00
	pH	11	8.65	8.18	8.42	8.63	8.52	8.42	8.31	8.23
	Alkalinity	11	242.00	184.00	199.00	226.00	205.00	191.00	189.00	184.00
	Total dissolved solids	11	690.00	499.00	551.00	652.00	547.00	544.00	517.00	501.00
	Calcium	11	52.00	37.00	45.90	50.80	48.40	46.50	43.80	39.50
	Magnesium	11	40.70	30.40	33.40	38.00	34.00	33.00	31.90	30.80
	Sodium	11	130.00	87.00	102.00	123.00	106.00	101.00	94.60	88.80
	Potassium	11	8.03	5.40	6.42	7.87	6.55	6.38	5.97	5.45

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
8E	Sulfate	11	300.00	215.00	249.00	289.00	256.00	242.00	240.00	219.00
	Chloride	11	16.40	12.90	14.40	15.90	14.90	14.30	13.80	13.30
8F	Specific conductance	11	940.00	640.00	836.00	935.00	890.00	840.00	810.00	710.00
	pH	11	8.71	8.25	8.45	8.66	8.52	8.44	8.38	8.26
	Alkalinity	11	236.00	185.00	199.00	221.00	203.00	195.00	191.00	186.00
	Total dissolved solids	11	679.00	503.00	563.00	649.00	582.00	552.00	534.00	506.00
	Calcium	11	52.00	40.00	46.10	50.80	48.30	46.60	44.30	40.50
	Magnesium	11	39.60	30.60	34.10	37.40	34.20	34.00	33.50	31.50
	Sodium	11	125.00	95.30	106.00	120.00	110.00	102.00	101.00	95.80
	Potassium	11	7.48	5.70	6.38	7.39	6.60	6.30	5.88	5.75
	Sulfate	11	299.00	237.00	258.00	293.00	272.00	248.00	244.00	238.00
	Chloride	11	15.70	12.10	14.40	15.50	15.00	14.60	13.90	13.00
8G	Specific conductance	10	940.00	610.00	844.00	936.00	895.00	860.00	830.00	687.00
	pH	10	8.66	8.23	8.46	8.63	8.54	8.46	8.42	8.24
	Alkalinity	10	264.00	186.00	202.00	239.00	198.00	195.00	192.00	188.00
	Total dissolved solids	10	703.00	506.00	558.00	639.00	556.00	554.00	535.00	507.00
	Calcium	10	50.60	37.00	45.00	50.10	47.30	46.30	41.80	38.80
	Magnesium	10	40.70	31.10	34.40	38.70	34.10	34.00	33.50	31.90
	Sodium	10	130.00	93.60	105.00	123.00	109.00	104.00	97.70	94.70
	Potassium	10	7.60	5.70	6.45	7.50	6.68	6.35	6.00	5.77
	Sulfate	10	299.00	237.00	253.00	284.00	252.00	248.00	246.00	239.00
	Chloride	10	16.10	14.00	14.70	15.70	14.90	14.60	14.40	14.10
3B-1	Specific conductance	21	1,090.00	640.00	892.00	1,010.00	930.00	890.00	870.00	770.00
	pH	21	8.74	7.79	8.43	8.73	8.59	8.45	8.38	8.04
	Alkalinity	21	245.00	158.00	203.00	226.00	215.00	201.00	192.00	170.00
	Total dissolved solids	21	690.00	444.00	577.00	634.00	599.00	583.00	557.00	508.00
	Calcium	21	47.00	31.40	41.60	46.00	44.00	42.50	39.00	37.40
	Magnesium	21	39.50	25.30	34.20	39.00	36.50	34.80	32.30	28.60

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
3B-1	Sodium	21	130.00	76.20	104.00	114.00	110.00	107.00	99.80	82.00
	Potassium	21	8.42	1.25	5.63	7.90	6.60	5.50	5.06	3.28
	Sulfate	21	302.00	199.00	255.00	286.00	266.00	256.00	247.00	222.00
	Chloride	21	18.30	11.60	14.80	17.80	15.50	15.30	13.60	11.80
3B-2	Specific conductance	28	1,040.00	610.00	891.00	1,010.00	955.00	885.00	855.00	784.00
	pH	28	8.90	7.82	8.38	8.69	8.54	8.43	8.23	7.98
	Alkalinity	28	290.00	170.00	209.00	251.00	219.00	206.00	198.00	179.00
	Total dissolved solids	28	819.00	526.00	598.00	722.00	611.00	584.00	562.00	531.00
	Calcium	28	73.10	33.00	44.40	59.10	45.80	43.00	40.20	37.10
	Magnesium	28	48.90	31.40	36.30	45.90	36.80	35.10	34.30	31.90
	Sodium	28	151.00	68.90	107.00	129.00	112.00	107.00	102.00	88.60
	Potassium	28	8.47	3.93	6.08	8.12	6.90	6.30	5.01	4.06
	Sulfate	28	392.00	215.00	268.00	344.00	276.00	263.00	247.00	227.00
	Chloride	28	19.10	11.80	14.90	18.50	15.60	15.20	13.90	12.30
3C	Specific conductance	24	1,600.00	660.00	934.00	1,100.00	975.00	920.00	858.00	690.00
	pH	24	8.65	6.87	8.37	8.64	8.51	8.46	8.34	8.07
	Alkalinity	24	293.00	150.00	208.00	262.00	216.00	205.00	189.00	161.00
	Total dissolved solids	24	824.00	424.00	590.00	722.00	616.00	585.00	545.00	480.00
	Calcium	24	59.40	31.00	45.00	58.30	47.40	44.50	41.60	36.10
	Magnesium	24	47.30	28.80	35.60	42.90	37.30	35.10	33.50	29.10
	Sodium	24	153.00	76.00	109.00	131.00	116.00	110.00	102.00	80.10
	Potassium	24	8.90	5.00	6.82	8.59	7.52	6.85	6.07	5.51
	Sulfate	24	360.00	181.00	263.00	312.00	277.00	263.00	247.00	212.00
	Chloride	24	19.30	11.10	15.20	18.70	16.00	15.40	14.10	12.00
3E-1	Specific conductance	5	1,150.00	630.00	910.00	1,110.00	940.00	920.00	910.00	686.00
	pH	5	8.69	8.31	8.47	8.65	8.51	8.49	8.35	8.32
	Alkalinity	5	222.00	194.00	208.00	220.00	212.00	211.00	203.00	196.00
	Total dissolved solids	4	628.00	556.00	585.00	622.00	601.00	577.00	561.00	557.00
	Calcium	4	48.40	37.00	42.60	48.10	46.80	42.60	38.50	37.30

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
3E-1	Magnesium	4	38.50	35.00	36.80	38.50	38.50	36.80	35.00	35.00
	Sodium	4	134.00	109.00	123.00	133.00	128.00	125.00	120.00	111.00
	Potassium	4	8.69	7.20	7.77	8.54	7.95	7.59	7.41	7.24
	Sulfate	5	282.00	254.00	272.00	282.00	279.00	279.00	267.00	257.00
	Chloride	5	16.40	14.80	15.60	16.40	16.20	15.60	15.10	14.80
3E-2	Specific conductance	16	1,160.00	610.00	954.00	1,110.00	1,060.00	950.00	910.00	700.00
	pH	16	8.78	8.29	8.44	8.71	8.47	8.41	8.34	8.30
	Alkalinity	16	308.00	141.00	201.00	273.00	203.00	193.00	184.00	162.00
	Total dissolved solids	16	884.00	374.00	608.00	794.00	685.00	595.00	538.00	459.00
	Calcium	16	68.00	32.00	48.20	65.50	52.40	47.00	41.00	36.00
	Magnesium	16	59.10	23.10	38.00	53.60	44.50	34.50	33.00	27.10
	Sodium	16	171.00	62.30	108.00	145.00	114.00	112.00	92.40	74.80
	Potassium	16	12.50	5.90	7.80	12.10	8.13	7.11	6.65	5.97
	Sulfate	16	392.00	156.00	275.00	386.00	309.00	263.00	248.00	198.00
	Chloride	16	20.50	9.88	14.90	19.20	16.40	14.90	12.60	11.10
8I	Specific conductance	31	1,610.00	750.00	1,250.00	1,590.00	1,420.00	1,270.00	1,070.00	945.00
	pH	31	8.96	8.10	8.50	8.82	8.59	8.50	8.39	8.16
	Alkalinity	33	291.00	183.00	231.00	266.00	238.00	225.00	220.00	216.00
	Total dissolved solids	33	1,180.00	613.00	852.00	1,120.00	978.00	860.00	713.00	628.00
	Calcium	33	93.30	40.00	60.00	80.30	68.70	59.00	49.50	40.40
	Magnesium	33	99.70	43.00	63.30	88.40	74.70	61.10	47.00	44.00
	Sodium	33	158.00	103.00	134.00	151.00	143.00	135.00	128.00	118.00
	Potassium	33	17.60	7.60	12.00	17.10	13.70	11.50	9.10	8.40
	Sulfate	33	669.00	277.00	435.00	635.00	529.00	422.00	323.00	297.00
	Chloride	33	22.40	15.10	17.90	21.60	18.90	17.90	16.70	15.20
8H	Specific conductance	18	1,660.00	780.00	1,200.00	1,610.00	1,270.00	1,150.00	1,080.00	899.00
	pH	18	8.93	8.06	8.49	8.88	8.57	8.48	8.41	8.09
	Alkalinity	19	280.00	202.00	235.00	276.00	244.00	231.00	225.00	216.00
	Total dissolved solids	19	1,180.00	655.00	835.00	1,140.00	923.00	766.00	721.00	671.00

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
8H	Calcium	19	94.00	38.00	58.50	87.30	67.50	53.90	45.80	40.70
	Magnesium	19	87.40	43.60	59.10	85.10	67.30	53.90	50.10	44.00
	Sodium	19	161.00	119.00	140.00	161.00	145.00	141.00	134.00	126.00
	Potassium	19	16.60	6.20	11.40	15.70	12.40	11.00	10.00	8.63
	Sulfate	19	692.00	305.00	421.00	624.00	485.00	363.00	341.00	321.00
	Chloride	19	21.20	15.50	18.00	19.60	18.70	17.90	17.30	16.20
1E-1	Specific conductance	13	1,710.00	870.00	1,220.00	1,640.00	1,200.00	1,150.00	1,110.00	972.00
	pH	13	8.72	7.93	8.44	8.71	8.68	8.46	8.32	7.99
	Alkalinity	13	392.00	216.00	253.00	322.00	252.00	241.00	232.00	221.00
	Total dissolved solids	13	1,270.00	737.00	876.00	1,190.00	943.00	794.00	763.00	739.00
	Calcium	13	103.00	39.00	60.90	94.50	75.00	54.00	48.00	40.70
	Magnesium	13	95.00	49.30	61.00	86.70	66.60	54.00	51.80	49.50
	Sodium	13	163.00	129.00	144.00	161.00	153.00	143.00	136.00	130.00
	Potassium	13	17.60	9.20	12.00	16.90	12.10	11.00	10.70	9.80
	Sulfate	13	645.00	337.00	435.00	643.00	489.00	393.00	363.00	341.00
	Chloride	13	20.10	15.80	18.40	19.60	19.10	18.50	18.00	16.60
1E-2	Specific conductance	21	2,000.00	1,160.00	1,590.00	1,850.00	1,740.00	1,680.00	1,430.00	1,170.00
	pH	21	8.89	7.85	8.42	8.71	8.65	8.48	8.27	8.07
	Alkalinity	22	284.00	197.00	230.00	262.00	243.00	228.00	216.00	200.00
	Total dissolved solids	22	1,400.00	767.00	1,130.00	1,330.00	1,270.00	1,220.00	1,030.00	777.00
	Calcium	22	110.00	40.00	82.20	105.00	96.80	86.40	73.60	50.70
	Magnesium	22	115.00	54.00	86.60	107.00	102.00	91.70	76.00	56.10
	Sodium	22	171.00	133.00	156.00	166.00	164.00	158.00	150.00	142.00
	Potassium	22	21.30	11.50	16.70	21.30	19.60	16.90	14.10	11.60
	Sulfate	22	833.00	393.00	641.00	806.00	748.00	708.00	570.00	407.00
	Chloride	22	24.60	14.70	18.90	22.60	20.00	18.40	17.80	16.40
3G-3	Specific conductance	19	1,730.00	880.00	1,280.00	1,670.00	1,400.00	1,250.00	1,150.00	1,020.00
	pH	19	8.89	7.74	8.44	8.70	8.61	8.46	8.32	7.99
	Alkalinity	19	299.00	220.00	249.00	299.00	256.00	250.00	236.00	221.00

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
3G-3	Total dissolved solids	19	1,270.00	760.00	914.00	1,210.00	1,020.00	831.00	785.00	765.00
	Calcium	20	119.00	41.00	65.00	111.00	77.00	54.90	51.60	41.90
	Magnesium	20	93.10	49.00	64.70	92.40	70.70	59.40	56.20	51.70
	Sodium	20	175.00	124.00	148.00	173.00	154.00	147.00	139.00	130.00
	Potassium	20	17.60	10.10	12.90	17.20	13.70	12.40	11.40	10.50
	Sulfate	20	746.00	362.00	463.00	661.00	537.00	408.00	384.00	370.00
	Chloride	20	23.60	14.30	18.70	21.30	19.40	18.40	18.10	15.80
3G-1	Specific conductance	12	1,480.00	920.00	1,240.00	1,480.00	1,330.00	1,190.00	1,180.00	1,040.00
	pH	12	8.89	7.88	8.41	8.79	8.54	8.43	8.25	8.02
	Alkalinity	12	305.00	221.00	255.00	295.00	269.00	250.00	243.00	224.00
	Total dissolved solids	12	1,120.00	581.00	884.00	1,110.00	971.00	851.00	814.00	703.00
	Calcium	12	139.00	41.00	69.40	114.00	75.00	62.90	53.40	44.90
	Magnesium	12	77.90	42.90	61.60	76.40	68.80	59.00	55.80	48.60
	Sodium	12	178.00	113.00	143.00	168.00	149.00	141.00	136.00	120.00
	Potassium	12	14.40	9.35	12.40	14.20	13.20	12.70	11.70	10.10
	Sulfate	12	602.00	284.00	447.00	595.00	486.00	429.00	403.00	338.00
	Chloride	12	20.90	12.90	18.00	20.80	18.70	17.90	17.40	15.20
3G-2	Specific conductance	9	1,910.00	830.00	1,420.00	1,830.00	1,640.00	1,340.00	1,280.00	966.00
	pH	9	8.62	7.83	8.29	8.56	8.43	8.42	8.10	7.87
	Alkalinity	10	295.00	228.00	254.00	284.00	262.00	253.00	241.00	230.00
	Total dissolved solids	10	1,370.00	830.00	1,070.00	1,330.00	1,240.00	1,060.00	887.00	839.00
	Calcium	10	150.00	42.00	88.00	137.00	115.00	82.30	63.00	45.40
	Magnesium	10	106.00	53.90	76.90	101.00	89.80	76.40	61.50	56.20
	Sodium	10	166.00	136.00	155.00	164.00	161.00	156.00	150.00	142.00
	Potassium	10	20.40	11.90	14.80	18.90	16.70	14.00	12.60	12.00
	Sulfate	10	763.00	400.00	561.00	747.00	700.00	553.00	422.00	405.00
	Chloride	10	23.60	14.90	18.50	22.20	18.70	18.30	17.90	15.20
3H-1	Specific conductance	19	2,120.00	1,170.00	1,600.00	2,090.00	1,900.00	1,490.00	1,380.00	1,200.00
	pH	19	8.45	7.39	8.17	8.38	8.30	8.21	8.11	7.89

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
3H-1	Alkalinity	20	347.00	239.00	275.00	327.00	287.00	274.00	253.00	244.00
	Total dissolved solids	20	1,740.00	870.00	1,200.00	1,710.00	1,440.00	1,120.00	992.00	873.00
	Calcium	20	150.00	58.00	94.10	142.00	108.00	87.90	72.00	64.70
	Magnesium	20	129.00	57.00	87.90	124.00	103.00	85.10	71.40	58.20
	Sodium	20	222.00	134.00	171.00	220.00	189.00	166.00	156.00	135.00
	Potassium	20	29.20	12.60	20.50	28.30	24.60	19.90	17.30	12.70
	Sulfate	20	1,050.00	397.00	653.00	988.00	827.00	597.00	527.00	418.00
	Chloride	20	21.70	14.30	17.80	20.70	18.90	17.30	16.70	15.40
3H-2	Specific conductance	17	2,440.00	1,460.00	1,870.00	2,410.00	2,060.00	1,850.00	1,590.00	1,520.00
	pH	17	8.70	8.08	8.34	8.56	8.48	8.30	8.23	8.18
	Alkalinity	18	342.00	191.00	255.00	320.00	272.00	250.00	235.00	208.00
	Total dissolved solids	18	1,790.00	1,030.00	1,390.00	1,750.00	1,580.00	1,410.00	1,140.00	1,060.00
	Calcium	18	139.00	68.80	85.80	102.00	88.80	81.40	79.40	70.80
	Magnesium	18	140.00	72.30	106.00	140.00	126.00	104.00	90.50	72.50
	Sodium	18	281.00	143.00	212.00	265.00	243.00	212.00	180.00	144.00
	Potassium	18	32.90	16.20	24.40	31.70	28.50	24.20	19.70	17.00
	Sulfate	18	1,050.00	524.00	813.00	1,040.00	977.00	841.00	631.00	576.00
	Chloride	18	26.00	12.00	20.10	24.50	22.40	20.90	18.60	14.10
3I-1	Specific conductance	23	3,220.00	1,400.00	2,330.00	2,900.00	2,540.00	2,330.00	2,070.00	1,760.00
	pH	23	8.78	7.57	8.46	8.71	8.66	8.50	8.36	8.13
	Alkalinity	22	381.00	200.00	304.00	368.00	333.00	314.00	273.00	229.00
	Total dissolved solids	22	2,240.00	977.00	1,700.00	2,110.00	2,000.00	1,770.00	1,400.00	1,210.00
	Calcium	23	106.00	53.00	75.90	89.70	85.40	80.00	65.40	57.40
	Magnesium	23	178.00	73.90	135.00	175.00	155.00	133.00	114.00	96.80
	Sodium	23	363.00	144.00	270.00	359.00	316.00	283.00	225.00	176.00
	Potassium	23	48.50	15.40	30.80	47.40	34.80	28.60	24.60	21.40
	Sulfate	22	1,330.00	548.00	993.00	1,290.00	1,220.00	1,030.00	796.00	655.00
	Chloride	22	40.10	13.20	28.10	39.80	35.20	29.20	21.30	15.60

Table 3. Summary statistics for uncensored water-quality physical properties and constituents at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius; pH in standard units; other constituent concentrations in milligrams per liter]

		Descriptive statistics				Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Maximum	Minimum	Mean	95	75	(Median) 50	25	5
3I-2	Specific conductance	12	3,300.00	2,150.00	2,620.00	3,210.00	2,730.00	2,610.00	2,420.00	2,180.00
	pH	12	8.47	7.93	8.29	8.45	8.42	8.32	8.20	8.03
	Alkalinity	13	482.00	281.00	373.00	474.00	419.00	354.00	332.00	302.00
	Total dissolved solids	12	2,680.00	1,430.00	2,010.00	2,580.00	2,230.00	1,920.00	1,780.00	1,550.00
	Calcium	13	101.00	71.00	81.70	98.60	85.80	80.00	75.00	71.10
	Magnesium	13	214.00	120.00	160.00	206.00	174.00	158.00	135.00	125.00
	Sodium	13	457.00	241.00	331.00	434.00	374.00	328.00	281.00	255.00
	Potassium	13	67.30	28.40	41.30	58.40	47.40	38.40	33.50	29.70
	Sulfate	12	1,530.00	883.00	1,160.00	1,470.00	1,290.00	1,110.00	1,010.00	897.00
	Chloride	13	42.30	22.10	31.50	39.30	35.70	31.30	29.70	22.30
3K	Specific conductance	26	7,190.00	1,820.00	2,660.00	3,320.00	2,670.00	2,560.00	2,250.00	1,890.00
	pH	26	8.78	8.25	8.55	8.72	8.66	8.60	8.44	8.28
	Alkalinity	27	560.00	279.00	357.00	481.00	365.00	341.00	316.00	294.00
	Total dissolved solids	27	6,540.00	1,250.00	2,080.00	2,880.00	2,140.00	1,860.00	1,660.00	1,370.00
	Calcium	27	116.00	68.40	79.60	97.70	82.00	76.00	73.70	69.60
	Magnesium	27	523.00	101.00	165.00	229.00	168.00	149.00	132.00	104.00
	Sodium	27	1,290.00	187.00	342.00	485.00	338.00	297.00	266.00	219.00
	Potassium	27	76.00	22.70	36.50	59.50	39.00	32.70	29.20	23.90
	Sulfate	27	4,110.00	677.00	1,210.00	1,640.00	1,270.00	1,110.00	929.00	745.00
	Chloride	27	146.00	19.40	36.40	46.90	38.00	31.60	26.40	22.30
3J	Specific conductance	20	17,300.00	2,470.00	8,870.00	15,300.00	10,400.00	8,340.00	6,460.00	4,240.00
	pH	20	8.98	8.26	8.66	8.82	8.75	8.72	8.59	8.27
	Alkalinity	21	1,380.00	324.00	622.00	1,050.00	696.00	618.00	406.00	325.00
	Total dissolved solids	21	17,700.00	1,870.00	8,380.00	17,000.00	10,600.00	7,220.00	5,100.00	3,530.00
	Calcium	21	223.00	79.00	111.00	149.00	119.00	106.00	94.00	81.00
	Magnesium	21	1,320.00	158.00	618.00	1,320.00	754.00	589.00	425.00	187.00
	Sodium	21	3,490.00	274.00	1,650.00	3,440.00	1,910.00	1,430.00	1,130.00	688.00
	Potassium	21	248.00	34.00	112.00	222.00	127.00	107.00	76.70	45.40
	Sulfate	21	11,500.00	1,080.00	5,430.00	10,900.00	6,930.00	4,620.00	3,570.00	2,200.00
	Chloride	21	385.00	31.00	194.00	382.00	246.00	170.00	129.00	80.50

Table 4. Summary statistics for censored water-quality constituent concentrations at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003.

[Concentration data in milligrams per liter]

		Descriptive statistics					Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Number of censored values	Maxi-mum	Minimum	Mean	95	75	(Median) 50	25	5
3A	Nitrite	36	34	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	36	21	0.32	<0.10	0.09	0.21	0.11	0.07	0.05	0.03
	Ammonia	36	7	0.33	<0.02	0.12	0.30	0.19	0.10	0.02	0.01
	Phosphorus, as PO_4	36	22	0.14	<0.01	0.01	0.08	0.02	0.00	0.00	0.00
8D	Nitrite	12	11	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	11	7	0.46	<0.10	0.11	0.30	0.13	0.04	0.01	0.00
	Ammonia	12	0	0.26	0.06	0.17	0.26	0.23	0.17	0.12	0.07
	Phosphorus, as PO_4	12	5	0.05	<0.01	0.02	--	0.01	0.01	0.01	0.00
8E	Nitrite	11	10	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	11	7	0.37	<0.10	0.08	0.24	0.11	0.04	0.02	0.00
	Ammonia	11	0	0.28	0.04	0.14	0.24	0.17	0.15	0.09	0.05
	Phosphorus, as PO_4	11	6	0.03	<0.01	0.01	0.02	0.01	0.01	0.00	0.00
8F	Nitrite	11	10	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	11	8	0.31	<0.10	0.07	0.21	0.11	0.03	0.01	0.00
	Ammonia	11	0	0.30	0.05	0.16	0.30	0.24	0.13	0.10	0.06
	Phosphorus, as PO_4	11	6	0.02	<0.01	0.01	0.01	0.01	0.01	0.00	0.00
8G	Nitrite	10	9	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	10	7	0.32	<0.10	0.07	0.32	0.12	0.03	0.01	0.01
	Ammonia	10	0	0.32	0.06	0.16	0.29	0.22	0.13	0.11	0.06
	Phosphorus, as PO_4	10	5	0.02	<0.01	0.01	0.02	0.01	0.01	0.01	0.00
3B-1	Nitrite	21	21	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	21	16	0.26	<0.10	0.07	0.25	0.09	0.04	0.02	0.01
	Ammonia	21	5	0.24	<0.02	0.09	0.22	0.13	0.07	0.02	0.00
	Phosphorus, as PO_4	21	12	0.09	<0.01	0.01	0.09	0.02	0.00	0.00	0.00

Table 4. Summary statistics for censored water-quality constituent concentrations at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Concentration data in milligrams per liter]

		Descriptive statistics					Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Number of censored values	Maxi-mum	Minimum	Mean	95	75	(Median) 50	25	5
3B-2	Nitrite	28	25	0.04	<0.02	--	0.02	--	--	--	--
	Nitrate	27	19	0.62	<0.10	0.07	0.47	0.10	0.03	0.01	0.00
	Ammonia	28	6	0.73	<0.02	0.17	0.49	0.21	0.11	0.02	0.00
	Phosphorus, as PO_4	28	18	0.10	<0.01	0.01	0.08	0.01	0.00	0.00	0.00
3C	Nitrite	24	22	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	24	17	2.80	<0.10	0.17	2.20	0.12	0.01	0.00	0.00
	Ammonia	24	0	0.36	0.03	0.20	0.33	0.27	0.19	0.14	0.06
	Phosphorus, as PO_4	24	12	0.15	<0.01	0.02	0.13	0.02	0.01	0.00	0.00
3E-1	Nitrite	5	5	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	5	2	0.12	<0.10	0.10	--	0.10	0.10	0.06	0.01
	Ammonia	5	0	0.25	0.13	0.19	0.24	0.21	0.21	0.14	0.13
	Phosphorus, as PO_4	5	3	0.01	<0.01	--	0.01	0.01	--	--	--
3E-2	Nitrite	16	15	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	16	11	0.26	<0.10	0.08	0.23	0.12	0.06	0.03	0.01
	Ammonia	16	0	0.40	0.04	0.17	0.36	0.25	0.13	0.10	0.06
	Phosphorus, as PO_4	16	8	0.03	<0.01	0.01	0.03	0.01	0.01	0.00	0.00
8I	Nitrite	33	32	0.02	<0.02	--	--	--	--	--	--
	Nitrate	33	30	0.46	<0.10	--	0.12	--	--	--	--
	Ammonia	33	5	0.44	<0.02	0.15	0.39	0.20	0.12	0.05	0.01
	Phosphorus, as PO_4	33	19	0.11	<0.01	0.01	0.08	0.02	0.00	0.00	0.00
8H	Nitrite	19	18	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	19	18	0.40	<0.10	--	0.13	--	--	--	--
	Ammonia	19	0	0.48	0.02	0.18	0.46	0.21	0.15	0.10	0.06
	Phosphorus, as PO_4	19	8	0.12	<0.01	0.02	--	0.02	0.01	0.01	0.00

Table 4. Summary statistics for censored water-quality constituent concentrations at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Concentration data in milligrams per liter]

		Descriptive statistics					Percentage of samples in which values were less than or equal to those shown				
Site	**Physical property or constituent**	**Sample size**	**Number of censored values**	**Maxi-mum**	**Minimum**	**Mean**	**95**	**75**	**(Median) 50**	**25**	**5**
1E-1	Nitrite	13	13	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	13	12	0.34	<0.10	--	0.20	--	--	--	--
	Ammonia	13	0	0.37	0.02	0.18	0.37	0.23	0.15	0.09	0.03
	Phosphorus, as PO_4	13	8	0.04	<0.01	0.01	0.03	0.03	0.01	0.00	0.00
1E-2	Nitrite	22	20	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	21	19	0.18	<0.10	--	0.13	--	--	--	--
	Ammonia	21	4	0.60	<0.02	0.11	0.23	0.16	0.05	0.02	0.01
	Phosphorus, as PO_4	22	12	0.11	<0.01	0.01	0.10	0.02	0.01	0.00	0.00
3G-3	Nitrite	19	19	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	19	18	0.23	<0.10	--	0.11	--	--	--	--
	Ammonia	20	0	0.68	0.03	0.20	0.60	0.21	0.15	0.10	0.07
	Phosphorus, as PO_4	19	11	0.04	<0.01	0.01	0.04	0.01	0.01	0.00	0.00
3G-1	Nitrite	12	11	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	12	11	0.10	<0.10	--	0.10	--	--	--	--
	Ammonia	12	0	0.32	0.08	0.16	0.27	0.18	0.14	0.12	0.09
	Phosphorus, as PO_4	12	6	0.02	<0.01	0.01	0.02	0.01	0.01	0.01	0.00
3G-2	Nitrite	10	10	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	10	9	0.24	<0.10	--	0.18	--	--	--	--
	Ammonia	10	0	0.61	0.06	0.23	0.47	0.24	0.20	0.15	0.08
	Phosphorus, as PO_4	10	6	0.04	<0.01	0.01	0.03	0.02	0.00	0.00	0.00
3H-1	Nitrite	20	19	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	20	19	0.26	<0.10	--	0.11	--	--	--	--
	Ammonia	20	0	0.97	0.03	0.26	0.48	0.29	0.20	0.16	0.13
	Phosphorus, as PO_4	20	9	0.03	<0.01	0.01	--	0.02	0.01	0.01	0.00

Table 4. Summary statistics for censored water-quality constituent concentrations at sampling sites on Lake Sakakawea, Audubon Lake, and McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Concentration data in milligrams per liter]

		Descriptive statistics					Percentage of samples in which values were less than or equal to those shown				
Site	Physical property or constituent	Sample size	Number of censored values	Maxi-mum	Minimum	Mean	95	75	(Median) 50	25	5
3H-2	Nitrite	18	18	<0.02	<0.02	--	--	--	--	--	--
	Nitrate	18	17	0.39	<0.10	--	0.14	--	--	--	--
	Ammonia	18	0	0.41	0.09	0.20	0.34	0.22	0.20	0.14	0.11
	Phosphorus, as PO_4	18	9	0.03	<0.01	0.01	0.03	0.01	0.01	0.00	0.00
3I-1	Nitrite	23	22	0.03	<0.02	--	--	--	--	--	--
	Nitrate	23	17	0.21	<0.10	0.08	0.20	0.11	0.06	0.04	0.02
	Ammonia	23	3	0.66	<0.02	0.22	0.51	0.33	0.23	0.04	0.01
	Phosphorus, as PO_4	23	9	0.06	<0.01	0.02	--	0.02	0.01	0.01	0.00
3I-2	Nitrite	13	12	0.02	<0.02	--	0.02	--	--	--	--
	Nitrate	13	12	0.17	<0.10	--	0.13	--	--	--	--
	Ammonia	13	0	0.71	0.08	0.42	0.70	0.65	0.43	0.20	0.12
	Phosphorus, as PO_4	13	4	0.07	<0.01	0.03	--	0.03	0.02	0.01	0.00
3K	Nitrite	27	25	0.03	<0.02	--	0.02	--	--	--	--
	Nitrate	27	23	0.21	<0.10	--	0.14	--	--	--	--
	Ammonia	27	5	1.03	<0.02	0.20	0.54	0.29	0.16	0.02	0.01
	Phosphorus, as PO_4	27	17	0.33	<0.01	0.03	0.27	0.02	0.00	0.00	0.00
3J	Nitrite	21	13	0.14	<0.02	0.02	0.14	0.03	0.01	0.00	0.00
	Nitrate	21	18	0.44	<0.10	--	0.18	--	--	--	--
	Ammonia	21	0	4.74	0.12	1.14	2.65	1.69	0.76	0.38	0.21
	Phosphorus, as PO_4	21	1	0.80	<0.01	0.13	0.69	0.10	0.05	0.03	0.01

Table 7. Total dissolved-solids concentrations in samples from water-quality sampling sites located in section WS 2 of McClusky Canal, central North Dakota, 1990-2003.

[Concentration data in milligrams per liter; sites listed in downstream order]

	Sites								
Date	3E-2	8I	8H	1E-1	1E-2	3G-3	3G-1	3G-2	3H-1
5/9/1990	494				767		803		971
5/10/1990		631	727			768			
8/16/1990					776		581		1,020
8/30/1990		623	676			760			
11/15/1990									1,110
11/16/1990				741			899		
11/19/1990		613	655			766			
2/5/1991									1,340
2/6/1991	884	867	873		891	977	989		
5/22/1991									889
5/23/1991								850	
5/24/1991		693	766			831			
5/29/1991					839				
8/22/1991									1,040
8/26/1991		673	735	816		800		830	
11/6/1991		713	699		812	844	847		
2/18/1992									870
2/19/1992						765			
5/13/1992							815		874
5/14/1992	590								
5/15/1992		673	716	794		804			
8/12/1992		712	729	748		770	811		
8/13/1992	599								999
9/17/1992								879	999
9/18/1992						827			
11/17/1992	602			784			965		
11/19/1992									1,140
3/5/1993	723	745	807	783		874		914	
5/10/1993	504	650	730	763		812	823		
5/11/1993									873
8/25/1993	574	714	673	737			856		

Table 7. Total dissolved-solids concentrations in samples from water-quality sampling sites located in section WS 2 of McClusky Canal, central North Dakota, 1990-2003. —*Continued*

[Concentration data in milligrams per liter; sites listed in downstream order]

	Sites								
Date	3E-2	8I	8H	1E-1	1E-2	3G-3	3G-1	3G-2	3H-1
9/1/1993									1,310
12/14/1993	625								
12/15/1993				827				992	
5/25/1994	374		872	943		989	1,097		
5/26/1994									1,420
8/24/1994	693								
11/9/1994	591				1,080				
11/10/1994		774	888					1,270	1,740
5/2/1995	487	827	959	1,050		1,100	1,120		1,550
8/8/1995	683	899	1,060	1,130		1,150		1,160	1,480
5/8/1996	549	1,050							1,130
5/9/1996			1,130			1,200		1,120	
8/21/1996		1,150	1,180	1,270		1,270		1,370	1,480
8/22/1996	764								
6/17/1997		808			1,150				
9/22/1997		978			1,270				
6/15/1998		878			1,270				
9/16/1998		1,010			1,260				
5/18/1999		982			1,190				
8/19/1999		1,020			1,280				
4/25/2000		1,050			1,250				
9/27/2000		932			1,330				
4/16/2001		817			1,030				
10/1/2001		1,180			1,400				
4/30/2002		1,100			1,320				
9/11/2002		860			1,250				
5/12/2003		931			1,270				
9/23/2003		908			1,270				

Table 8. Water-quality sampling sites on Lake Saka kawea, Audubon Lake, and McClusky Canal, central North Dakota, and percentage of samples that fall into cluster subgroups 1-6.

[Sites are listed in downstream order; map numbers are the Bureau of Reclamation site identification numbers; ft, feet; --, not applicable]

				Group A			Group B		Group C
Map number (fig. 2)	Site description	Canal mile	Number of samples	Percentage of samples in subgroup 1	Percentage of samples in subgroup 2	Percentage of samples in subgroup 3	Percentage of samples in subgroup 4	Percentage of samples in subgroup 5	Percentage of samples in subgroup 6
3A	Lake Sakakawea at Snake Creek Pumping Plant (off west side of structure)	--	36	--	66.7	33.3	--	--	--
8D	Audubon National Wildlife Refuge boundary line no. 2 buoy from U.S. Highway 83.	--	12	8.3	91.7	--	--	--	--
8E	Audubon National Wildlife Refuge boundary line no. 7 buoy from U.S. Highway 83.	--	11	9.1	90.9	--	--	--	--
8F	Audubon National Wildlife Refuge boundary line no. 15 buoy from U.S. Highway 83.	--	11	9.1	90.9	--	--	--	--
8G	Audubon National Wildlife Refuge boundary line 0.5 mile south of no. 17 buoy	--	10	10.0	90.0	--	--	--	--
3B-1	McClusky Canal headworks at Lake Audubon (inlet to canal)	0	21	--	100.0	--	--	--	--
3B-2	McClusky Canal headworks (downstream side of gates)	0.2	28	7.1	92.9	--	--	--	--
3C	McClusky Canal at Lake Brekken turnout (State Highway 41 north of Turtle Lake)	11.1	24	8.3	87.5	4.2	--	--	--
3E-1	McClusky Canal at radial gate (R1 & R2, upstream)	19.9	4	--	100.0	--	--	--	--
3E-2	McClusky Canal bridge south of radial gate (R1 & R2, downstream)	20.0	16	18.8	75.0	--	6.3	--	--
8I	Hecker's Lake out from canal	34.2	31	54.8	6.5	--	38.7	--	--
8H	New Johns Lake west end	35.0	18	72.2	5.6	--	22.2	--	--

Table 8. Water-quality sampling sites on Lake Saka kawea, Audubon Lake, and McClusky Canal, central North Dakota, and percentage of samples that fall into cluster subgroups 1-6.—*Continued*

[Sites are listed in downstream order; map numbers are the Bureau of Reclamation site identification numbers; ft, feet; --, not applicable]

Map number (fig. 2)	Site description	Canal mile	Number of samples	Group A			Group B		Group C
				Percentage of samples in subgroup 1	Percentage of samples in subgroup 2	Percentage of samples in subgroup 3	Percentage of samples in subgroup 4	Percentage of samples in subgroup 5	Percentage of samples in subgroup 6
1E-1	Painted Woods Creek outlet channel from New Johns Lake (at structure)	36.0	13	69.2	7.7	--	23.1	--	--
1E-2	Painted Woods Creek outlet channel from New Johns Lake (lakeside)	36.0	20	25.0	--	--	75.0	--	--
3G-3	East end of New Johns Lake (1/4 mile west of canal 400 ft southeast of boat ramp)	37.8	18	72.2	5.6	--	22.2	--	--
3G-1	McClusky Canal radial gate (west side)	38.1	12	75.0	--	--	25.0	--	--
3G-2	McClusky Canal bridge (downstream of radial gate)	38.4	9	44.4	11.1	--	44.4	--	--
3H-1	McClusky Canal plug (upstream)	51.2	19	--	--	--	100.0	--	--
3H-2	McClusky Canal plug (downstream)	51.3	17	5.9	--	--	94.1	--	--
3I-1	McClusky Canal Gate at State Highway 200 (upstream)	54.9	22	--	--	--	59.1	40.9	--
3I-2	McClusky Canal Gate at State Highway 200 (downstream)	55.0	11	--	--	--	27.3	72.7	--
3K	McClusky Canal at Hoffer Lake (southeast of canal mile 58 plug at boat dock)	58.0	26	--	--	--	53.8	42.3	3.8
3J	McClusky Canal plug (upstream)	58.8	20	--	--	--	--	5.0	95.0

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